AD-766 446

AUTOMATED PILOT PERFORMANCE ASSESSMENT IN THE T-37: A FEASIBILITY STUDY

Patricia A. Knoop, et al

Air Force Human Resources Laboratory
Brooks Air Force Base, Texas

April 1973

AFHRL-TR-72-6

AUTOMATED PILOT PERFORMANCE ASSESSMENT IN THE T-37: A FEASIBILITY STUDY

PATRICIA A. KNOOP
WILLIAM L. WELDE

TECHNICAL REPORT AFHRL-TR-72-6

APRIL 1973

AIR FORCE HUMAN RESOURCES LABORATORY
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

ACCESSION for
NTIS White Section ☒
DDC Buff Section ☐
UNANNOUNCED ☐
JUSTIFICATION ____________

BY ____________
DISTRIBUTION/AVAILABILITY CODES

DIST.	AVAIL. and/or SPECIAL	
A		

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D

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

1. ORIGINATING ACTIVITY *(Corporate author)* Air Force Human Resources Laboratory Advanced Systems Division, AFHRL/AS Wright-Patterson AFB, Ohio 45433	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP N/A

3. REPORT TITLE

AUTOMATED PILOT PERFORMANCE ASSESSMENT IN THE T-37: A FEASIBILITY STUDY

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

Final (May 1968 - April 1971)

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

Patricia A. Knoop and William L. Welde

6. REPORT DATE April 1973	7a. TOTAL NO. OF PAGES 463	7b. NO. OF REFS 6

8a. CONTRACT OR GRANT NO. N/A b. PROJECT NO. 6114 12 003 c. 1710 10 001 d.	9a. ORIGINATOR'S REPORT NUMBER(S) AFHRL-TR-72-6 9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES N/A	12. SPONSORING MILITARY ACTIVITY Air Force Human Resources Laboratory Air Force Systems Command Wright-Patterson AFB, Ohio

13. ABSTRACT

Research was conducted to develop a capability for quantification and assessment of in-flight pilot performance for utilization in Undergraduate Pilot Training (UPT). This feasibility effort was directed to overcoming the disadvantages of the traditional subjective rating of a pilot trainee's performance by the instructor pilot. This was accomplished through the development of an automated, objective performance measurement system that possesses the characteristics of reliability, validity, and sensitivity. A T-37B was instrumented to digitally record 24 flight and engine parameters. An extensive computer software system was developed with which to reduce, calibrate, and analyze the recorded data from the lazy 8 and barrel roll maneuvers, and compute performance measures. Criterion values for the two maneuvers were developed by utilizing task analysis data, narrative descriptions, and recorded in-flight maneuver performance of a highly qualified Air Training Command instructor pilot. Utilizing recorded data from 16 students and 4 instructors, experimental performance measures were derived through an iterative analytic approach.

Study results indicated that lazy 8 performance assessment can be accomplished using the flight parameters of roll angle, pitch angle, and airspeed in a single summary error measure. Barrel roll measurement is dependent upon roll and pitch angle, acceleration (g force), and roll rate. A definite relationship between roll and pitch was determined to be critical to measurement. Discussions of measurement validation methods, debriefing plots, a sampling rate study, instrumentation techniques, and problem areas are provided.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Pilot Performance Assessment						
Performance Measurement						
Proficiency Measurement						
T-37B						
In-flight Data Acquisition						
Flight Data Sensors						
Airborne Data Recorders						
Data Calibration/Reduction						
Lazy 8						
Barrel Roll						
Undergrate Pilot Training						

☆U.S.Government Printing Office: 1973 — 759-493/524

AD-766446

POTENTIAL WIDE-INTEREST REPORT

WARNING TO EVALUATORS FROM INPUT

DOCUMENT WILL REPRODUCE POORLY

DECISION BY EVALUATORS:

1. Accepted as wide-interest report ______________________ Signature

2. Accepted as regular report ______________________ Signature

3. Return to source ______________________ Signature

AFHRL-TR-72-6

AUTOMATED PILOT PERFORMANCE ASSESSMENT IN THE T-37: A FEASIBILITY STUDY

PATRICIA A. KNOOP
WILLIAM L. WELDE

Approved for public release; distribution unlimited.

FOREWORD

This report describes an in-house research program conducted between May 1968 and April 1971 in support of the mission of the Advanced Systems Division, Air Force Human Resources Laboratory, Wright-Patterson AFB, Ohio. This research was documented under the following projects: Project 1710 entitled "Training for Advanced Air Force Systems" with Dr. Ross L. Morgan serving as Project Scientist; and Project 6114 entitled "Simulation Techniques for Aerospace Crew Training" with Mr. Carl F. McNulty serving as Project Scientist.

The efforts of several individuals who collectively were instrumental in formulating and obtaining support for this program, establishing initial design concepts, and managing the program during its early phases are recognized. These individuals include Lt Col Melvin S. Majesty, Dr. Donald E. Meyer, and Dr. Herbert J. Clark, all formerly with this Division; and Dr. Theodore E. Cotterman of the Training Technology Branch of this Division.

Special recognition is extended to Mr. Fred E. Kirk of the Test Instrumentation Branch, 4950th Test Wing for his invaluable efforts in the instrumentation and maintenance of the data acquisition system. Also, Mr. Eugene H. Guthrie of the Computing and Information Systems Branch, 4950th Test Wing deserves special recognition for his contribution in the development of computer techniques for the calibration and analysis of the recorded data.

Other individuals deserving commendation are Major Alan E. Walker and Captain Richard C. Oliver of the Flying Training Division, Air Force Human Resources Laboratory, for their dedication in conducting the student data collection flights. The contribution of Major W. Neely Johnson from the Air Training Command Pilot Instructor Training School for his inflight demonstrations of the training maneuvers is gratefully acknowledged.

AFHRL-TR-72-6

The authors appreciate the support and cooperation of the pilots from the Fighter Operations Branch of the 4950th Test Wing. The efforts of Jean F. Hixson, Lt Col, USAFR, in preparing Appendix V of this report are gratefully acknowledged. In addition, the valuable contributions of the Data Reduction Branch, 4950th Test Wing in reformatting flight data for compatibility with data processing equipment are appreciated. Finally, the authors extend thanks to Headquarters, Air Training Command, Randolph AFB, Texas, for the preparation of maneuver analyses and helping to define the requirements and scope of this effort.

This report has been reviewed and is approved.

Gordon A. Eckstrand
GORDON A. ECKSTRAND
Director, Advanced Systems Division
Air Force Human Resources Laboratory

ABSTRACT

Research was conducted to develop a capability for quantification and assessment of in-flight pilot performance for utilization in Undergraduate Pilot Training (UPT). This feasibility effort was directed to overcoming the disadvantages of the traditional subjective rating of a pilot trainee's performance by the instructor pilot. This was accomplished through the development of an automated, objective performance measurement system that possesses the characteristics of reliability, validity, and sensitivity. A T-37B was instrumented to digitally record 24 flight and engine parameters. An extensive computer software system was developed with which to reduce, calibrate, and analyze the recorded data from the lazy 8 and barrel roll maneuvers, and compute performance measures. Criterion values for the two maneuvers were developed by utilizing task analysis data, narrative descriptions, and recorded in-flight maneuver performance of a highly qualified Air Training Command instructor pilot. Utilizing recorded data from 16 students and 4 instructors, experimental performance measures were derived through an iterative analytic approach.

Study results indicated that lazy 8 performance assessment can be accomplished using the flight parameters of roll angle, pitch angle, and airspeed in a single summary error measure. Barrel roll measurement is dependent upon roll and pitch angle, acceleration (g force), and roll rate. A definite relationship between roll and pitch was determined to be critical to measurement. Discussions of measurement validation methods, debriefing plots, a sampling rate study, instrumentation techniques, and problem areas are provided.

SUMMARY AND CONCLUSIONS

PROBLEM

Traditionally, pilot performance has been assessed by an instructor pilot applying a subjective rating scale which places the student in one of several skill categories. Subjective rating is largely a matter of judgment and is subject to many sources of unreliability and invalidity. In addition, it places an unnecessary burden on the instructor who must apply it in-flight, and provides no way of assessing solo performance of students or of pilots transitioning to single seat aircraft. The purpose of this study was to develop improved methods of pilot proficiency assessment which would produce more valid, reliable, and sensitive measures of proficiency; and which would free the instructor from responsibilities associated with in-flight subjective rating, that detract from his attention to instruction and safety. The particular problem to which the study was addressed was T-37 pilot performance measurement in the Undergraduate Pilot Training (UPT) program.

APPROACH

The approach was to develop and implement instrumentation for recording T-37 flight data; and to develop technology and computer software for automatically measuring pilot performance using the recorded flight data. Twenty-four flight variables were recorded at rates of 10 and 100 samples per second using appropriate sensors and a data acquisition system which encoded the data in digital form on magnetic tape. Software was developed for calibration of the data and for producing an initial condensed print-out for purposes of maintaining a continual check on the instrumentation. Automated measurement studies, addressing two representative maneuvers, were conducted using the calibrated flight data recorded for a number of students and instructor pilots. The approach used was to compute measures that were initially selected on the basis of Air Training Command maneuver analyses and which possessed content validity; then test and, as necessary, revise the measures based on experience with the data. Correlation between the derived measures and instructor pilot ratings was also investigated to address inter- and intra-rater reliability and to identify measures which consistently failed to reinforce the ordering of performances achieved by the rating system.

RESULTS

A summary error measure for the lazy 8, based on the flight parameters of roll, pitch, and airspeed, was developed. Criteria were based on data from skilled pilots, and the measure accounted for 67% of the variance in subjective ratings for the data used to formulate criteria. In contrast, no significant correlations existed between the measure and subjective ratings for student data. Upon investigation, this was found to be primarily due to inconsistency between instructor pilots' rating techniques and standards. Using validation techniques which do not depend on subjective ratings, face-validity of the error measure as applied to student data was demonstrated. Good validation was not possible due to lack of sufficient data per individual student.

For the barrel roll, the parameters of roll, pitch, normal acceleration, and roll-rate were used as a data base for measurement. It was found that the roll/pitch relationship and not roll or pitch as single variables, is critical to measurement. The constancy of rol rate and maximum excursions of normal acceleration are also critical. Considerable difficulty was encountered in developing criteria for this maneuver due to variance in performance technique.

Debriefing charts were developed for use in pictorially describing the performance of each maneuver and conveying measures and diagnostic comments to instructor and student. Central charts for both the lazy 8 and barrel roll consisted of plots of pitch versus roll.

During the effort, data were collected on the lazy 8, and barrel roll (about 160 performances of each), and seven other UPT maneuvers. With the major exception of ground-reference data, the variables recorded appear to form a sufficient data base for measurement within UPT. Techniques were developed for determining required sampling rates. For pitch angle, a rate of one per second was found to be adequate for both the lazy 8 and barrel roll.

CONCLUSIONS

This study achieved its original goals of establishing feasibility and developing prototype techniques for automated measurement. One disappointing aspect of the effort was inability to adequately validate results (beyond the content validity inherent in the measures) due to lack of sufficient data per student. Future efforts should rely heavily on within-subject sampling for validation of measures; however, concurrent validation using subjective ratings is also worthwhile investigating so long as it is applied as a necessary (not sufficient) test and results are interpreted with the cautions identified in the report.

The most surprising aspect of the study, and one which essentially caused it to require twice the time and effort originally estimated, was the level of effort needed to acquire and prepare for use good in-flight data. In part this was due to the prototype nature of the effort, and many of the problems encountered can be prevented in future studies. However, there are a number of types of problems characteristic of in-flight data collection for which details cannot be anticipated. Sufficient time and manpower must be programmed to take care of such problems on an as-required basis.

Automated proficiency assessment must be blended properly with subjective evaluation of certain primary skills that do not lend themselves to automated measurement. Such a system can provide more valid and reliable measurement techniques than ever before employed. This can greatly enhance pilot selection and training and will also lay the groundwork for important research in such areas as simulator-to-aircraft transfer of training. Future efforts are required to expand the technology to other maneuvers in the UPT curriculum and to develop similar techniques for other aircraft.

TABLE OF CONTENTS

TABLE OF CONTENTS (Contd)

TABLE OF CONTENTS (Contd)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS - Cont'd

LIST OF ILLUSTRATIONS - Cont'd

LIST OF ILLUSTRATIONS - Cont'd

LIST OF ILLUSTRATIONS - Cont'd

LIST OF TABLES

SECTION I

INTRODUCTION

This report documents a three-year exploratory development effort in the area of quantitative assessment and automated measurement of pilot performance. The effort involved the instrumentation of a T-37B aircraft, collection and calibration of student and instructor performance data, and the development of objective measurement techniques for selected training maneuvers.

The development of performance measurement techniques with all of the appropriate characteristics (objectivity, reliability, etc.) is one of those problems which has truly withstood the test of time. Witness the following extract from a 1952 technical report (Smith, Flexman, and Houston, 1952):

> "An examination of the training program and a survey of previous research on pilot training indicate that, for the most part, objective standards did not exist and that measures of pilot proficiency were not sufficiently reliable or discriminating for use as effective criterion measures for training research."

The prevailing truth and existence of statements such as above attest not only to the difficulty and complexity of (pilot) performance measurement as a research problem, but also to its recognized importance over the years.

The importance of measurement as a research problem is due to the fact that measurement is a fundamental requirement which pervades all of training, education, and any associated research. It is not possible to perform good research in training innovations, for instance, unless a valid method exists for measuring the results of training. Neither is it possible to optimize training and achieve good quality-control in pilot "production" if it is necessary to rely on rudimentary subjective judgments of performance which place a student in one of a few rating categories. Much training oriented research of the future can benefit considerably from the development of valid performance measurement techniques; and some very beneficial research is strictly dependent on such developments.

The above remarks hopefully help to place measurement, as a critical problem, in its proper perspective. Despite its criticality, however, measurement is largely a means to many ends and not necessarily an end in itself. For this reason it is too often treated as a "nice to have" but nonessential ingredient in a training or research system, and attention is turned to more popular endeavors with more immediate and visible dividends. The authors contend that this is why the measurement problem has persisted over the years — not because it is unsolvable, and not because of its difficulty in the context of complex tasks such as flying.

Traditionally, in an introductory section such as this, one would address in detail three major topics: (1) the problem, why it is difficult to solve, and what characteristics should exist in a good performance measurement system; (2) why the problem is important and what the many applications of its solution are; and (3) what, if anything, is different about the approach used in this study from all of the previously tried approaches. The first topic has been discussed at length in literally every measurement report published, beginning in the 1940's. (In fact, in many reports, discussion of the problem is the essence of the text!) It will be treated only in summary fashion in this report.

The second topic, if addressed completely, could result in another technical report. The authors choose to categorize the applications of measurement into two general classes and will present just a few representative examples of each class.

The third topic, the approach, covers both the method of acquiring data and the methods of treating it. It is the latter of these which is most controversial. The approach documented in this report is only one of those being pursued by the authors. Therefore, in addition to summarizing the approach in this Introduction, it is evaluated in Section VIII and compared with another, more highly automated approach.

1. PROBLEM

From a historical perspective, interest in the measurement of the proficiency of aircrew personnel can be traced to the World War I period, and the work on the selection of military pilots. Even after these many years of endeavor, the measurement and assessment of in-flight pilot performance is a long way from being successfully achieved, and less than complete information is provided by present measures and methods. The measurement of pilot performance is sufficiently difficult due to the inherent nature of the human and the environment in which he operates that unfortunately, in many instances, the practive has been to obtain what is measurable rather than what is desired or required.

There are two general methods or approaches in which performance measurement can be categorized. The most common is the evaluation of performance qualitatively — the subjective method. The second approach represents a goal that is the subject of this report, and that is the assessment of performance quantitatively — the objective method. These two methods are not strictly a dichotomous classification, but rather represent a continuum of performance measurement. On the one side there exists the strictly personal judgment and rating of performance, and on the other end of the continuum is a completely automated performance measurement and assessment system. The middle area of this performance measurement dimension consists of various techniques whereby the human observer may record performance and then compare this data with pre-established standards to provide an evaluation of the quality of performance. The desired goal of an effective performance measurement system is to capitalize on the advantages of an automated, objective system and yet retain some of the unique capabilities afforded by the human evaluator so a comprehensive assessment of performance can be achieved.

a. Requirements of Objective Performance Measurement Systems

The significant problem in developing an objective pilot performance measurement system consists of acquiring data and developing analytic and software techniques which derive, from that data, measures that are reliable, valid, and sensitive. Also, the practical aspect of pilot acceptability must be addressed for such a system to be successful. Each of these factors will be discussed in turn.

(1) Reliability

Basically reliability refers to consistency or stability in the recorded data and computed measures upon repetition. Reliability is essential in both the acquisition or recording of performance data and in the measurement of performance using that data. When the performance of the same individual is scored on different occasions, reliability is the opposite of variability.

Several sources of variability inherent in customary measurement situations, which hinder reliable measurement of pilot performance, include the following (Reference 1):

1. A major source of variability is a function of variations in the environment in which performance is being measured. Variability may be introduced in the in-flight environment by differences in traffic, weather, amount of turbulence, wind direction and velocity, visibility, etc., producing "between-flying conditions" unreliability. In addition, situational factors such as unexpected noise, extreme temperatures, g forces, and other distractions may further affect performance scores.

2. A second source of unreliability is a function of fluctuation associated with the operation of the system in which an individual's performance is being measured. Variation in scores due to system instability may reflect random fluctuations either in the mechanical components or in other human components in the system.

3. Response-evaluating instruments used and personnel participating during proficiency assessment are a third possible source of unreliability The equipment used during measurement must be carefully calibrated prior to testing.

4. The fourth source of unreliability is a function of the particular sample of items (parameters) selected for inclusion in the test instrument.

5. The complexity of the behavior being evaluated is a fifth type of influence on the reliability of a proficiency measure. Since it is possible that an individual's proficiency level may fluctuate considerably from one dimension to the next and across time, each component element in a sense represents a somewhat different test.

6. A sixth source of unreliability is attributable to the change in the physiological condition of the pilot himself. This includes emotional state, motivation, susceptibility to fatigue and stress, variation in the individual rate of adaptation, and many others.

To minimize unreliability in the data itself, the hardware and software components of the performance measurement system require a high degree of reliability or repeatability. Calibration of equipment must be conducted on a continuing basis to be able to determine inaccuracies in the data or complete component failure. This includes checking the reliability of the power supply output, parameter sensor operation regarding resolution, range of values, response rate, and environmental effects, recording device operation, and any interface equipment. The software processes involved in data reduction, conversion, analysis, and plotting should be closely monitored to avoid data loss. Accurate records of flight conditions and mission requirements should be maintained to facilitate the interpretation of the assessed pilot performance data based upon the actual conditions under which the performance was flown and recorded.

The technique of performance measurement, which develops the final measures, must (1) eliminate any remaining data unreliability and (2) produce reliable measures. There is no standard technique for eliminating data unreliability because each case must be treated individually depending on the source of unreliability. One example is in the recording of normal acceleration (g force) using an accelerometer. The data are not reliable indicants of sustained acceleration, which would expectedly be the focus of interest. Even with filtering, the recording would pick up some instantaneous effects of gust loading. Therefore it would not be acceptable to sample this data at discrete points. Instead some method of smoothing should be applied to the data through the development of appropriate software.

Of primary importance, ultimately, the measures that are developed must be reliable indicies of performance. One example of when reliability would not be assured is if unrealistic criteria were applied. A derived measure may be considered reliable in that it consistently reflects a comparison with the criteria; but it could be an unreliable (and invalid) index of performance due to the inappropriateness of the criteria. Without proper precautions, it is entirely possible to induce unreliability in the measures themselves through improper treatment of, what is otherwise reliable, performance data.

(2) Validity

This refers to the degree to which the measuring or testing process correctly measures the variable intended to be measured. Validity can be categorized into various kinds, but the one that is most appropriate to the problem of in-flight pilot performance measurement is empirical validity. Essentially, this is based upon the relation between performance scores and a criterion, the latter being a direct indication of performance goals. Criterion-referenced proficiency measures permit assessment of performance and provide information on the degree of competence considered independently of the performance of others. Such measures permit one to determine whether an individual has reached a given performance standard, hence, the term absolute scoring is sometimes applied. Performance is measured against a definitive task specification that has previously been determined either by analysis, subjective judgments by a panel of experts, or numerous successful performances, sampled from large population.

In addition to a criterion-referenced measure or performance standard, proficiency measures can also be distinguished as norm-referenced measures. A norm-referenced proficiency measure evaluates an individual's proficiency in terms of a comparison between his performance and the performance of other members of the group. Norm-referenced measures can be considered a relative scoring method since they are related to level of performance at a selected moment in time during the process of learning a specified task. Such measures are of limited value in measurements intended for quality control, because they are not referenced to fixed performance standards. However, by employing an objective measurement system, norm-referenced measures may be of significant training value for improving the student's performance through more feedback via class competition. Also, the average class performance can be readily determined with a norm-referenced measurement system.

An automated performance measurement system inherently permits the assessment of pilot performance to be highly valid, since performance can be recorded on-line for numerous system variables. In most in-flight evaluations, performance data is seldom recorded until the flight has been completed, which introduces inaccuracy simply due to the inability of the individual to remember features of performance relevant to success. Furthermore, greater detail regarding the performance is afforded with an automated system since more flight parameters can be recorded and more data accrued per unit of time than is possible with human observation. Because of multi-dimensional role of the instructor in the in-flight training environment, a serious difficulty can frequently occur whereby the instructor's ability to detect and assess subtle differences in performance when they, in fact, exist is jeopardized.

(3) Sensitivity

The reliability with which and method by which a measure changes whenever the pilot's performance changes is known as measurement sensitivity. This fundamental requirement for an objective pilot performance measurement system pertains to the fact that performance should be discriminated into as many categories of proficiency as possible (Whenever feasible, continuous measures of performance should be obtained), and the rate of change of the measures with respect to skill acquisition must be known. Thus, the sensitivity of the measurement system relates to (1) the resolution capability of the sensors to discriminate each parameter into values that meaningfully reflect pilot performance and (2) the development of measures to an acceptable measurement scale; i.e., interval scale.

(4) Acceptability

Pilot acceptability becomes a rather important factor when the time arrives for making the decision to implement an automated pilot performance measurement system that has been proved to possess reliability, validity, and sensitivity. Too often, concern is expressed that the instructor pilot will be replaced in the training environment by an automated device. However, whatever the level of sophistication of automated performance measurement, the human observer must always be an integral part of the total measurement system. In the complexity of flight environment, there are specific behavioral skills which do not lend themselves to quantification or objective scoring. It is in these areas where the human observer can make more subtle judgments and more apppropriate evaluations than is possible with any electromechanical device.

At least the following behavioral factors should and will continue to be evaluated by the instructor:

1. decision making capability
2. ability to plan effectively

3. coordination and smoothness of control

4. maturity — willingness to accept responsibility, ability to accomplish objectives, judgment, and reactions to stress, unexpected conditions, and aircraft emergencies.

5. confidence — proportionate with the individual's level of competency

6. motivation (attitude) — the manner in which it affects performance

7. ability to time share attention and efforts appropriately in an environment of simultaneous activities

8 coordination with other crew members

9. knowledge and systematic performance of tasks

10. fear of flying

11. motion sickness

12. air discipline — adherence to command authority and assigned tasks.

The presence of an instructor is required and recommended for in-flight training and evaluation. The judgment of the instructor regarding the student's total flying capability, however, can be supported by the objective assessment of psychomotor skills with an in-flight pilot performance measurement system.

b. Applications

The applications possible for an automated, objective pilot performance measurement system can be categorized in two classes: (1) applications which enhance flying training in its operational context; and (2) applications which make research possible.

(1) Operational Flying Training

Five examples of how operational flying training can be enhanced with an automated measurement system are discussed:

(a) Inflight Evaluation Enhanced

The aircraft is a prime example of a complex system where the large number of interacting elements lessens the chances of deriving reliable and easily interpretable performance measurement data. The dynamics of the in-flight environment and complexity of flying, involving a large number of procedural, judgmental, and perceptual-motor activities, imposes a tremendous burden upon the instructor to assimilate and synthesize the student's performance and provide a reliable and valid evaluation. Any attempt at manual recording procedures is fruitless since the instructor is unable to effectively time-share the activities of observing and recording multiple parameters at an adequate sampling rate and accuracy to provide the necessary pilot performance measurement data. There are many subtle aspects of flying which do not lend themselves to recording, and automated performance measurement systems normally permit assessment of only those actions by the pilot which result in some effect on the aircraft. This permits the instructor to concentrate on the evaluation of those qualitative behaviors reflecting on the student's ability to effectively and safely cope with the flight environment.

(b) Objectivity Achieved

In subjective evaluations, considerable variation occurs in the performance ratings of the instructors as a function of: (1) judgments made without reference to a definitive standard since the same maneuver may be flown satisfactorily in a number of different ways, (2) different standards of performance which are employed due to differences in the instructor's knowledge and proficiency, (3) operational flight experience and training affecting the perspective and judgment of instructor ratings, (4) performance ratings relating to what the instructor deems are the critical aspects of the job, (5) possibility of bias and halo effects existing from the instructor-student relationship, (6) different conception of the specific grading system regarding the flight parameters incorporated, weighting assigned, and the range of the qualitative categories, and (7) difficulty of comparing actual performance with what the average proficiency level should be at any moment in time. Subjective measures generally lack the accuracy and reliability needed for effective performance measurement because of their dependence upon the judgment and veracity of the individual observer. The antithesis of this is an objective measure that is founded on data that is free from personal and emotional bias. The greatest objectivity is attained when a permanent record of behavior is obtained at the time of performance by an automated data acquisition system.

(c) Training Facilitated

An automated performance measurement system relieves the instructor of the burden of in-flight evaluation, and permits him to concentrate on the job for which he is most professionally qualified, teaching flying. The instructor can devote complete attention to developing the procedural, judgmental, and perceptual-motor skills in the student during the flight, which maximizes the effectiveness of the training sortie. Additionally, the aspect of flight safety is enhanced by reducing the in-flight tasks of the instructor and possibly eliminating the requirement for the "head-in-the-cockpit" situation.

(d) Playback Capability Provided

Automated performance measurement also provides the means for playback of critical mission phases for demonstration and instructional purposes. This playback capability can be performed in the simulator and even correlated with earlier simulator or aircraft missions. Furthermore, it is an excellent method for quantifying the rate of learning and affording the opportunity to diagnose consistent weaknesses in performance.

(e) Solo Performance Assessed

It is also possible to record pilot performance during solo flights, which provides the instructor a method whereby he can maintain continuity and assess the stability of performance across dual and solo flights. Without an automated measurement system of the type developed in this study, it is not possible to assess solo performance, even though it is an important criterion. This would include performance in single-seat aircraft (e.g., A-7D) as well as regular student solo performance in training aircraft. In-flight recording and subsequent automated measurement of solo performance will enhance both basic pilot training and transition training by providing the first and only means of measuring performance of this type.

(2) Research

Following are selected examples of capabilities and/or new knowledge, the research and pursuit of which will be greatly enhanced when sensitive, objective measurement systems are developed:

1. Replacement of highly sophisticated and expensive simulators with lower fidelity and less costly simulators and trainers by having the capability to definitively assess the transfer-of-training effects (simulator to aircraft) with regard to the factor of simulator fidelity. For example, it would be possible to determine if six degrees-of-freedom motion systems and full color and/or field-of-view visual systems contribute sufficiently to transfer-of-training to be cost effective.

2. Replace more aircraft time with simulator time, and know the resulting effects on training.

3. Develop adaptive training methods (impossible without performance measurement).

4. Develop completely automated simulator instruction for use in proficiency training.

5. Accurately predict operational and combat performance of pilots based upon their in-training performance.

6. Improve pilot trainee selection and reduce the wash-out rate.

c. Immediate Application and Program Genesis

The need for objective performance measurement has been recognized and continually advocated by the Air Force, one of the largest agencies involved in pilot training. The recognition of this requirement culminated in a research request (RTR-68-25-A) directed to the Advanced Systems Division of the Air Force Human Resources Laboratory (AFHRL) at Wright-Patterson AFB, Ohio, by the Air Training Command. A research project was initiated in 1968 entitled Pilot Performance Measurement System to develop an in-flight data recording system and a ground-based automated performance assessment capability for utilization in UPT.

2. APPROACH

The objective of this research effort was to develop prototype methods for quantitative assessment and automated measurement of pilot performance. The approach to achieving this objective was to (1) develop methods of acquiring reliable and accurate in-flight performance data; (2) develop methods of measuring pilot performance using the acquired data; and (3) perform preliminary tests of the derived methods. In scope, the acquisition of in-flight data was designed to be applicable to all in-flight performance, but investigation of methods for measuring performance using the data was limited to two representative maneuvers: the lazy 8 and the barrel roll.

Before describing the approach in more detail, it is appropriate and necessary to define and clarify the term "performance measure" as used within the framework of this study:

A performance measure, as the term is used in this report, is a number that is selected from or computed from recorded performance data, and which, in itself, effects a comparison or directly contributes to the drawing of a comparison between (1) actual performance and a standard or criterion; or (2) actual performance and the normative performance of a selected population.

Recorded in-flight data do not necessarily constitute performance measures. Similarly, the act of recording in-flight data does not constitute the measurement (assessment) of performance.

With these introductory remarks, we will next describe in outline form the approach that was pursued in this study. The approach consisted of accomplishing the following tasks:

1. Developing hardware and software required for acquiring and calibrating in-flight pilot performance data.

2. Developing performance measurement techniques and implementing them in software.

3. Collecting extensive data on the lazy 8 and barrel roll and some representative data on other maneuvers.

4. Testing the measurement techniques.

Each of these tasks will be discussed in turn.

Acquisition and Calibration of In-Flight Performance Data. This required the development of hardware and software subsystems. From a hardware standpoint, a T-37 aircraft was instrumented to record a number of flight and engine variables, such as roll angle, pitch angle, stick position, RPM, airspeed, altitude, and heading. This required the installation and calibration of a digital flight recorder system and parameter sensors such as gyros, tranducers, accelerometers, and potentiometers. In addition to initial installation of the instrumentation package, numerous modifications were completed during the first several months of use as problem areas were revealed regarding flight safety, electrical power distribution, resolution of recorded variables, and recording reliability.

From a software standpoint, computer programs were written to (1) convert the aircraft magnetic tape to a tape physically compatible with data processing equipment; (2) calibrate the data, or convert it to engineering units; (3) produce a magnetic tape record of the calibrated data for use in the measurement research; and (4) produce a condensed print-out of the data for use in testing the accuracy and reliability of the in-flight recording system.

Development of Performance Measurement Techniques. This required the identification of performance measures and the development, testing, and print-out of the measures using the recorded data. The approach to accomplishing this was to (1) analyze each of the maneuvers to be measured, with particular attention to the ATC published criteria for performance; (2) develop a set of theoretical measures based solely upon the information in the maneuver analyses; (3) compute the theoretical measures for initial representative performances; (4) using the initial data, develop a refined set of measures, called experimental measures herein, for application to a broad spectrum of student and instructor performances; and (5) test the validity of the experimental measures and, from them, select final measures for future applications.

This approach is called (by the authors) an "analytic" approach because it is based strongly on detailed analyses of the maneuvers to be measured. During the period of the program, an alternative approach that is more highly automated was pursued under contract using some of the same data collected in this investigation. For this reason, the data collection effort, to be described next, was responsive to contractual requirements in support of the alternative approach as well as to the central requirements of the study as reported in this document.

Data Collection. The data collection was pursued in three phases. Phase 1 consisted of collecting data to establish and verify the accuracy and reliability of the in-flight data acquisition and ground-based data calibration systems. For this phase, specific performance requirements were outlined based on the parameters to be tested during each flight. Flight test pilots then flew sorties in accordance with the outlined requirements.

Phase 2 was devoted to collection of data which supported related contractual requirements as well as the requirement for representative instructor pilot (IP) data for this study. For this, a highly qualified IP from the ATC Pilot Instructor Training (PIT) school flew a number of lazy 8's and barrel rolls and provided subjective ratings for each performance. As per request, he attempted to fly a variety of performances to illustrate perfect performance as well as typical student errors encountered during this maneuver.

Phase 3 was to collect data on students and instructor pilots at Williams AFB, Arizona. This data was required primarily to test and validate measures, as described below.

Testing the Measurement Techniques. Content validity was built in to the measures initially selected for investigation as a result of the selection-method employed (i.e., Air Training Command training and evaluation criteria and maneuver analyses served as the bases for selection). While content validity is a useful and necessary consideration, it is not an apriority that it is sufficient in itself. Therefore, a number of supplemental validation techniques that are more empirical in nature were also considered.

One technique that constituted part of the original study design was to employ within-subject sampling and examine "measure-progress" across training. This would provide an additional necessary (but not sufficient) validation test in that candidate measures consistently exhibiting zero or negative "slope" when plotted against trial-number, for example, would be highly subject to question. Conversely, those exhibiting opposite characteristics would still be considered likely candidates. Due to problems discussed elsewhere in this report, sufficient data per student were not collected to permit pursuit of this test.

An alternative supplemental method that was applied in this study is that of investigating concurrent validity, which means comparing the experimentally derived measures with some other direct and independent measure of proficiency. Again, within the context of the subject at hand, this validation method must be considered as another necessary (with qualifications) but not sufficient test. The reason for this is that although an independent measure of proficiency in UPT is readily available, it is not as discriminating (sensitive) as the measures to be developed; and, since it is based on human judgment, its reliability must be considered subject to question.

The independent measure most readily available for use is the instructor pilot's rating of performance, generated on a four-point scale (excellent, good, fair, unable). Because of the properties of these ratings, as outlined in the preceding paragraph, their utility within the context of concurrent validation is limited to distinguishing between new experimental measures which (a) tend to reinforce the ordering dictated by the ratings, and therefore should definitely be considered further, and (b) consistently do not reinforce the ordering, and therefore should be considered highly subject to question.

In this report, concurrent validation, in the context described above, is explored by analyzing correlations between potential quantitative measures and instructor pilot ratings. Summarily, this analysis serves several useful functions: (1) it provides a preliminary foundation for investigating inter- and intra-rater reliability; (2) it provides data which contributes to validity considerations by flagging measures which should be considered highly questionable; and (3) it provides a basis for demonstrating where/when derived measures do and do not reinforce the ordering achieved by the existing ATC rating system. (In this last regard, where derived measures do not reinforce the ratings, other supplemental validation methods that are applied should ultimately be used to prove the derived measures are "correct" -- if only for instructor and Command acceptance of the new system.)

3. REPORT OUTLINE

In this report, the four tasks briefly described above, are presented in the order listed. Sections II and III present the hardware and software subsystems developed for data acquisition and calibration, and the initial tests performed on the system. Section IV presents a sampling-rate study done to establish methodology for empirically determining required recording rates. Section V describes the development of performance measures and measurement techniques to be applied and tested. Section VI describes the scope of and methods employed in data collection. Section VII describes the analyses and tests performed on the measurement techniques and presents the results derived. The last, Section VIII, summarizes the findings.

For the casual reader interested in a good overview of the research effort at the expense of all details, it is recommended that attention be focused on Sections II, III, VII, and VIII.

SECTION II

AIRBORNE DATA ACQUISITION SYSTEM

1. T-37B AIRCRAFT

A T-37B aircraft with a USAF tail number of 58-1948 (hereafter referred to as 948) was bailed to the Air Force Systems Command (AFSC) by the Air Training Command (ATC) to support the research requirements of the AFHRL Pilot Performance Measurement System Program.

a. Aircraft Description

The T-37B is a low-wing, twin-engine jet trainer with side-by-side seating (student pilot flys from the left seat). Manufactured by Cessna, the aircraft has a gross weight of 6600 pounds and an internal fuel load for a normal training mission duration time of 1 hour 15 minutes. The aircraft includes full instrumentation for IFR flight. Figure 1 represents the cockpit arrangement of 948. The dual-control flight control system is manually operated with an electrical trim tab system for the ailerons, elevator, and rudder. The aircraft has full aerobatic and spin capability with a g-load limitation of +6.67 and -2.67 g's. (A +4g limitation was imposed during a large percentage of the research program flights due to structural problems in the T-37 fleet.) Airspeeds for the aircraft are: takeoff at 90 knots; a maximum of 382 knots; a final approach speed of 100 knots; and a touchdown speed of 75-80 knots. Some of the noteworthy operational features the T-37 affords are excellent out-of-the-cockpit visibility, good handling characteristics, and high reliability.

b. Role of T-37 in UPT

The T-37 has proved to be a valuable training vehicle in Undergraduate Pilot Training (UPT). Introduced into the Air Force primary flying training program in 1957, UPT students fly the T-37 for approximately 90 hours. The performance and handling characteristics of the T-37 provide an excellent medium through which UPT students can progress from a low-performance and a simple-mission aircraft (T-41) to

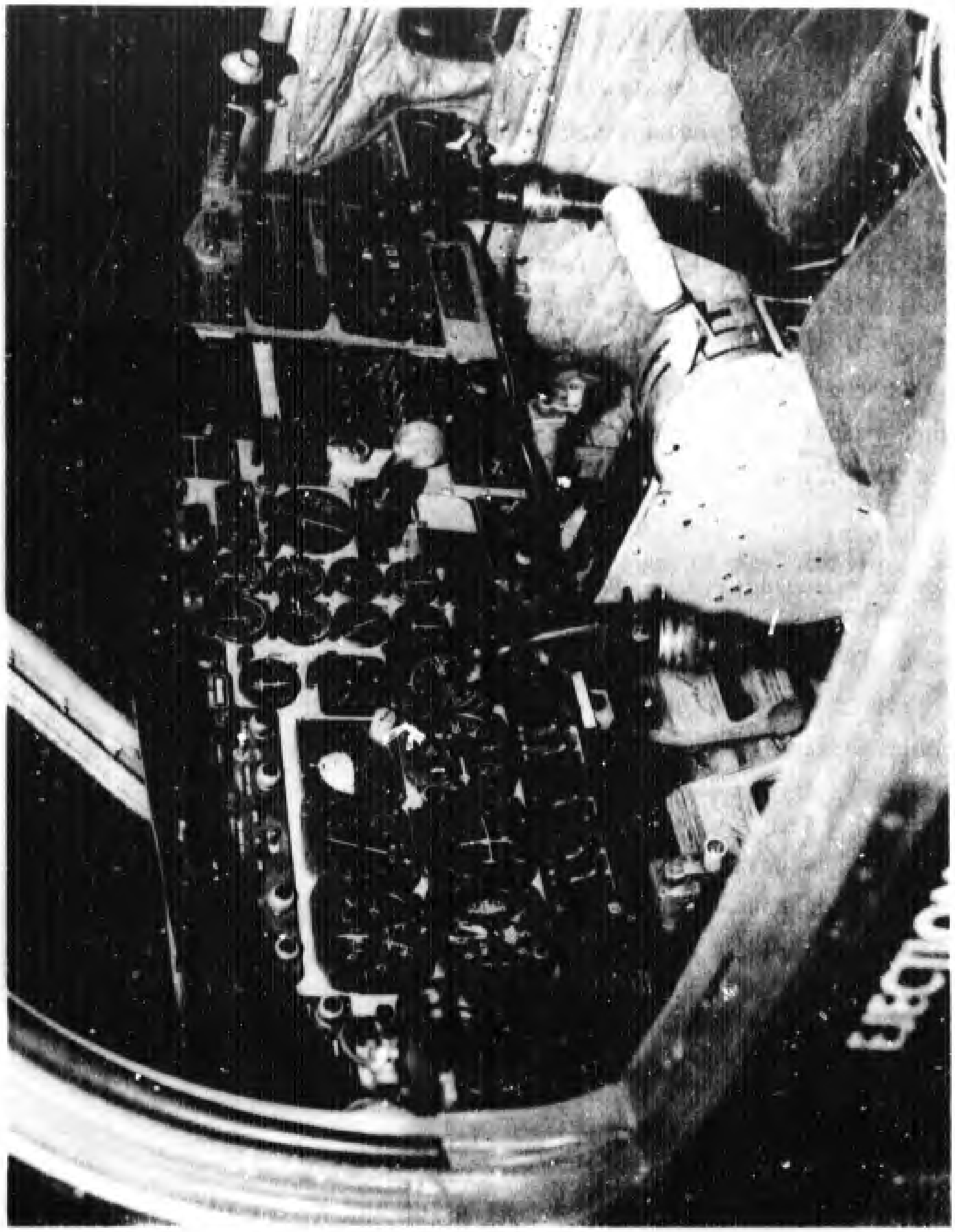


Figure 1. T-37 Cockpit

a high-performance and more operationally oriented mission aircraft (T-38A).

Utilized principally for contact (VFR) flying training, basic instrument training, and some navigation and formation flying, the T-37 flying training curriculum outlines a total of 68 sorties (55 dual, 13 solo). The contact phase of the T-37, with which this research program was solely concerned, specifies that 42 sorties (29 dual, 13 solo) will be flown in 54.7 hours. The instructional units contained in the contact phase include: aircraft familiarization, fundamental maneuvers (stalls, spins, traffic pattern), supervised solo flights, area checkout, advanced (arobatic) maneuvers, night flying, and check flights.

The role of the T-37 in UPT is presently undergoing minor revision through a reduction in emphasis and the number of flying hours in specific areas of the UPT curriculum.

c. Flight Test Support

In May 1968, the T-37 (948) was transferred to Wright-Patterson AFB, Ohio, and placed under the operational control of the Directorate of Flight Test of the Aeronautical Systems Division (currently designated the 4950th Test Wing). Flight Test responsibilities for supporting the aircraft and the research program included:

1. Assigning a Test Director to coordinate all Flight Test support agencies and AFHRL research requirements with regard to the instrumented aircraft.

2. Engineering design, installation, calibration, and maintenance of the data acquisition system.

3. Maintenance for the T-37 aircraft.

4. Providing a qualified test pilot and a scheduling service for the equipment calibration and data collection flights.

5. Computer data reduction support by processing the one inch aircraft magnetic tape and producing a one-half inch IBM compatible tape.

6. Photographic documentation of the project.

7. Radar flight following during the missions.

2. AIRCRAFT INSTRUMENTATION

The T-37 948 was instrumented with a data acquisition system by Flight Test at Wright-Patterson AFB. This equipment installation was considered to be a Class II modification, which is a temporary change to the standard configuration of an aerospace vehicle that is essential to the successful accomplishment of research, development, test, and evaluation (RDT&E) program in compliance with AFR 80-14 and AFSCR 80-23. However, the Class II modification did not place any restrictions upon the operational capability of the aircraft with regard to IFR flight, aerobatic maneuvers, or other UPT training maneuvers. All engineering design, installation, maintenance, flight safety, and quality control functions were accomplished in the same manner as if the data acquisition system were a permanent installation in 948.

a. Recorded Parameters

Upon activation by the instructor pilot, the data acquisition system recorded pilot performance on 17 continuous and 7 discrete flight and engine parameters. An additional 8 parameters were obtained via computational techniques from the 24 recorded parameters. Table I provides (1) a listing of each of the 32 recorded and computed parameters, (2) the aircraft component or system from which the recorded values originated, (3) the sersor that converted the various forms of flight or engine data into the correlated changes in electrical output to the magnetic tape recorder, (4) the range of values for each recorded parameter, (5) sampling rate that the data was recorded, and (6) the resolution or sensitivity achieved.

TABLE I

PERFORMANCE PARAMETERS RECORDED BY THE DATA ACQUISITION SYSTEM

	Parameter	Component	Sensor	Range	Record Rate	Resolution
1.	Heading	J-4 Compass	Synchro-Follower	0-360°	10 per sec	± 1°
2.	Altitude	Pitot-Static	Transducer	0-30,000 ft	10 per sec	± 166 ft
3.	Airspeed	Pitot-Static	Transducer	0-350 kts	100 per sec	± 2 kts
4.	Pitch Angle	MD-1 Gyro	Synchro-Follower	± 0-82°	100 per sec	± 1.5°
5.	Roll Angle	MD-1 Gyro	Synchro-Follower	0-360°	100 per sec	± 1.5°
6.	Acceleration (g force)		Accelerometer	-1 to +5 g	10 per sec	± 0.3 g
7.	Pitch Rate		Rate Gyro	90° per sec	10 per sec	
8.	Roll Rate		Rate Gyro	180° per sec	10 per sec	
9.	Yaw Rate		Rate Gyro	70° per sec	10 per sec	
10.	Longitudinal Stick Position	Elevator Cable	Potentiometer	-15 to +25°	100 per sec	
11.	Lateral Stick Position	Left Aileron Cable	Potentiometer	± 16°	100 per sec	
12.	Rudder Position	Rudder Cable	Potentiometer	± 24°	100 per sec	
13.	Left RPM	Tach Generator	Frequency Converter	0-100%	10 per sec	-1% RPM
14.	Right RPM	Tach Generator	Frequency Converter	0-100%	10 per sec	-1% RPM
15.	Left Throttle Position	Throttle	Potentiometer	0-64°	10 per sec	
16.	Right Throttle Position	Throttle	Potentiometer	0-64°	10 per sec	
17.	Flaps		Potentiometer	0-100%	10 per sec	1%
18.	Landing Gear		Switch	Up or Down	10 per sec	
19.	Speed Brakes		Switch	In or Out	10 per sec	
20.	Thrust Attentuator		Switch	In or Out	10 per sec	
21.	Elevator Trim Tab-Up	Trim Tab Switch	Switch	On or Off	10 per sec	
22.	Elevator Trim Tab-Down	Trim Tab Switch	Switch	On or Off	10 per sec	
23.	Time		Clock	0-24 hrs	10 per sec	1 sec
24.	Record Number		Counter	0-999	10 per sec	1
25.	Vertical Velocity		Computed			
26.	Pitch Rate		Computed			
27.	Roll Rate		Computed			
28.	Yaw Rate		Computed			
29.	Turn Rate		Computed			
30.	Longitudinal Stick Rate		Computed			
31.	Lateral Stick Rate		Computed			
32.	Rudder Rate		Computed			

Since the research program represented a study in feasibility throughout, the parameters selected for recording do not necessarily represent an optimum set to reflect in-flight pilot performance. Rather, the instrumented parameters signify an initial attempt, based on experience and intuitive judgment, at evolving a meaningful set of variables from which performance measures could be developed to assess actual pilot performance. To be precise, the parameters listed in Table I have previously undergone several iterations of analysis and modification. The effectiveness of these parameters with regard to the characteristics of reliability, validity, and sensitivity in recording in-flight pilot performance is contained in a later discussion that concludes Section II.

b. Sensor Systems

The selection of sensors for each of the recorded parameters was based on the estimated resolution requirements for conducting pilot performance measurement research. With the exception of the altitude, g, pitch rate, and roll rate parameters, those flight and engine measures have either equalled or exceeded the predetermined resolution requirements. It is necessary to point out at this time that some of the recorded parameters were discarded by the authors early in the development of performance measurement techniques as not being applicable to the maneuvers being investigated. Thus, the determination of the resolution achieved from these unessential parameters was not pursued.

The sensors and recording equipment were strictly off-the-shelf components that had proved to be reliable in previous Flight Test projects. Table II presents a description of the dimensions, weight, power requirements, and cost of the equipment installed in 948 that comprised the data acquisition system. The approximate physical location of the equipment installed in 948 is indicated in Figure 2.

TABLE II

DESCRIPTION OF EQUIPMENT INSTALLED IN THE T-37 (948)

NOMENCLATURE	DIMENSIONS			WEIGHT	ELECTRICAL POWER REQUIREMENTS						COST
	L	W	H	(LBS)	DC VOLTS	AMPS	AC VOLTS	FREQ	VA	PH	
Pulse Code Modulator	12.6	9.2	9.5	32	28	3	115	400	230	1	$ 76,000
Tape Recorder	20	10	9	44	28	8					28,000
Signal Conditioning Unit	10	10	6	18	28	.5					1,000
Digital Recorder Control	6	5.5	5	1.5							750
Recorder Remote Control	6	5.5	5	1.5							500
Power Supply - Inverter	.5	4	5.5	3			115	400	100	1	200
Synchro Converter	4.5	3	5.5	3.5			115	400	115	1	200
Altitude Transducer	3.5	2.5	2.5	1							390
Airspeed Transducer	3.5	2.5	2.5	1							390
Vertical Gyro	11	6	6.5	10	28	4.5	115	400	330	1	900
Accelerometer	5	5	2	1	28	2					100
Frequency Converter (2)	12	6	10	2			115	400	100	1	800
Rate Gyro Unit	8	8	10	10			115	400		3	800
Phase Adapter	10	5	3	1			115	400		1	100
TOTALS				129.5							$110,130

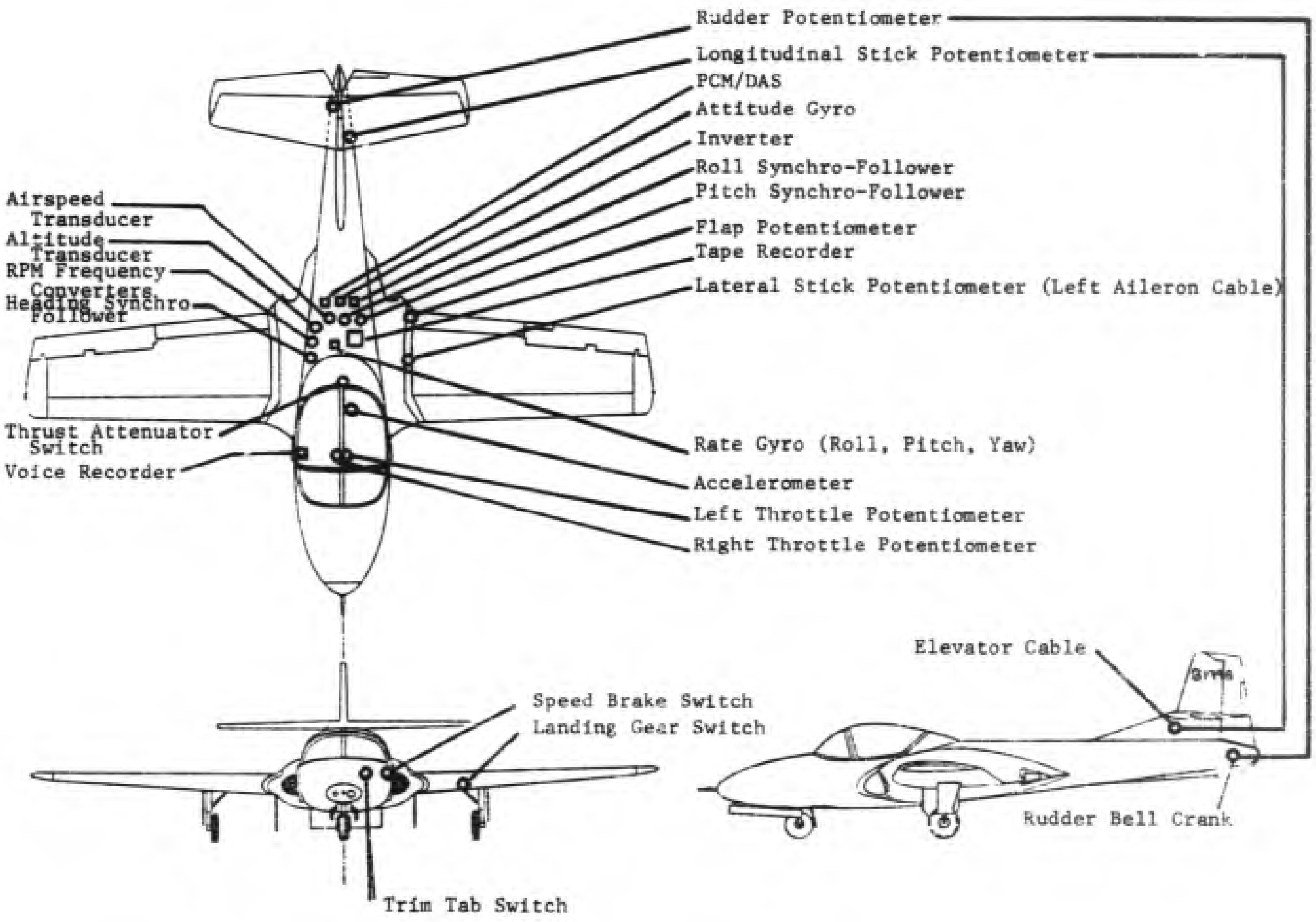


Figure 2. T-37 Instrumentation Diagram

The following is a cursory description of the recorded parameters including the components employed in the sensor systems and the displays provided to the pilot in the cockpit:

(1) Heading

The T-37B aircraft normally contains a J-2 slaved directional gyro system. However, due to excessive precession errors and a basic lack of responsiveness encountered during calibration flight tests when performing high pitch and bank angle maneuvers (e.g., lazy 8 and barrel roll), a J-4 compass system was substituted in 948. The J-4 system added the capability for (1) latitude correction, (2) a synchronizer switch to provide a normal means of orienting the gyro to the signals from the remote compass transmitter, and, most importantly, (3) a 15-second fast slave cycle that could be induced whenever the function selector switch was moved from the MAG (magnetic) to the DG (directional gyro) position and returned to MAG by the instructor pilot. A synchro-follower provided the signal output from the compass to the Pulse Code Modulation/Data Acquisition System (PCM/DAS). The heading system was excited by +5 volts DC over a range of 0-360° with approximately 0.0128 volts representing 1°. The effective resolution achieved was ±1° from the cockpit instrument, which consisted of a standard T-37 heading indicator with a fixed card and rotating needle. A heading set knob permitted the compass card to be rotated by the pilot.

(2) Altitude

A Model 7000 altitude transducer manufactured by Computer Instruments Corporation provided a signal output to the PCM/DAS for aircraft pressure altitude. The altitude transducer was linked directly with the normal aircraft pitot-static system. With a voltage output of +5 DC over a range of 0-30,000 ft, each 100 ft was represented by approximately 0.0150 volts. The effective resolution achieved with the parameter of altitude varied between 139 and 189 ft error on the data collection flights with a mean resolution of ±166 ft. A standard three-pointer altimeter was located on the left side of the cockpit with which the transducer was correlated.

(3) Airspeed

The airspeed signal to the PCM/DAS was transmitted by a Model 7100 Computer Instruments Corporation airspeed transducer. Connected to the pitot-static system of the aircraft, the +5 volt DC transducer output covered 0 to 350 knots IAS with approximately 0.0118 volts representing 1 knot. The resolution achieved was a fairly constant error of +2 knots from the standard airspeed indicator on the left side of the cockpit.

(4) Pitch and Roll Angles

The T-37 has an attitude-indicating system consisting of a MD-1 vertical gyro and a MM-3 attitude indicator located on the left instrument panel. Due to the possibility of affecting the safe operation of this system by attaching a synchro-follower, a second MD-1 gyro was installed in 948 that provided a +5 volts DC output from the synchro-follower directly to the PCM/DAS. Within the pitch limitation of the gyro of ±82°, an effective resolution of ±1.5° of the pitch angle as indicated on the MM-3 attitude indicator was achieved. Approximately 0.0144 volts represented 1° of pitch attitude. The roll angle parameter had a full 360° capability from the gyro and a resolution error of ±1.5° from the indicated bank angle. A voltage output of 0.0143 represented 1° roll angle.

(5) Acceleration (g Force)

Acceleration along the Z axis of the aircraft was sensed by a separate accelerometer that was installed in 948 and correlated in-flight with the standard g meter located in the center of the instrument panel. With a ±5 volts DC output from the accelerometer to the PCM/DAS, approximately 0.140 volts represented 0.1g. An effective resolution of ±0.3g was obtained with the parameter system.

(6) Pitch, Roll, and Yaw Rates

A single unit containing rate gyros for the pitch, roll, and yaw axes was installed and powered by 115 volt, 400 cycle, single phase AC. The outputs from the gyros were transmitted through a Signal Conditioning Unit to the PCM/DAS. Pitch rate was represented by approximately 0.0553 volts DC for 1° per second over a range of 0-90° per second. Roll rate was represented by approximately 0.0259 volts DC for 1° per second over a range of 0-180° per second. Yaw rate was represented by approximately 0.0680 volts DC for 1° per second over a range of 0-70° per second. The resolution achieved on these three parameters was not empirically ascertained because of the lack of a cockpit indication with which to compare the accuracy of the rate gyros in-flight.

(7) Longitudinal and Lateral Stick Position, Rudder Position

The pilot's movement of the aircraft control stick and rudder pedals was recorded by linking "pots" (potentiometers) to the elevator cable, left aileron cable, and rudder cable that produced a +5 volt DC signal to the PCM/DAS. The longitudinal stick position had a range of -15° for forward stick (elevator down) to +25° for aft stick (elevator up) with approximately 0.1238 volts representing 1° of elevator travel. The lateral stick position had a range of ±16° in which 0.1526 volts represented 1° of aileron travel. Rudder pedal input had a range of ±24° so that 0.1027 volts represented 1° of rudder travel.

(8) Engine RPM

The RPM of the left and right engines was recorded by linking frequency converters to the tach generators. Approximately 0.0500 volts represented 1% RPM for the left engine and 0.0400 volts for the right engine over a range of 0-100%. A somewhat constant resolution error of -1% RPM was achieved when compared with the two tachometers on the center instrument panel in the cockpit.

(9) Throttle Position

The left and right throttle positions were recorded by a +5 volt DC output from pots linked to the throttle. With a range of 0-64° from the CUTOFF position to 100% engine RPM, approximately 0.0689 volts represented 1° movement for the left throttle and 0.0659 for the right throttle.

(10) Flaps

The position of the wing flaps was recorded by a pot output of +5 volts DC that was linked to the flap indicator signal to the cockpit instrument. With a range of 0-100% (0-40°), 1% of flap movement was represented by approximately 0.0475 volts within 1% resolution.

(11) Landing Gear, Speed Brakes, Thrust Attenuator, Elevator Trim Tab Up and Down

The operations of these systems were recorded as discrete events by linking the switch signal directly to the PCM/DAS.

A complete listing of the calibration data for the recorded flight and engine parameters may be found in Appendix I.

c. Recording System

The actual recording of the parameter data transmitted by the various sensor systems was accomplished by two components, an analog-to-digital converter and a digital tape recorder.

(1) Analog-to-Digital Converter

A Pulse Code Modulation/Data Acquisition System (Model 101) manufactured by Brown Engineering Co. (Reference 2) converted the analog signals from the sensors to a digital format and transmitted the output to the magnetic tape recorder. The PCM/DAS possesses the functional capability of (1) accepting up to 30 analog signals varying between ±5 volts, (2) sampling 6 of these analog signals at 100 times per second and the remaining 24 at 10 times per second, (3) converting these analog signals to a 10-bit digital representation plus a sign bit, (4) providing an output format containing 98 data words and 2 sync words per master frame (major cycle), and (5) generating a binary coded decimal (BCD) representation of the elapsed time in hours, minutes, and seconds from a stable time reference.

(2) Digital Tape Recorder

A 16-channel Leach tape recorder (Model MTR-3200) recorded the PCM/DAS digital signals on a 1-inch magnetic tape. Powered by +28 volts DC, the tape recorder was operated at a speed of 7-1/2 inches per second. The tape capacity of 3/4 mil and 2,400 feet loaded on an 8-inch reel provided 60 minutes of recording time. The recorder unit was located in a lower fuselage bay area with a remote control unit in the cockpit.

(3) Cockpit Recorder Control Panel

The acquisition of in-flight pilot performance data was controlled by the instructor pilot (in the right seat) through the operation of the magnetic tape recorder with the Recorder Control Panel. This control unit shown in Figure 3 was located between the ejection seats in an area formerly occupied by a map and data case. A description of the Recorder Control Panel switch functions (left to right and top to bottom) follows:

(1) MASTER SW (ON-OFF) - controls power to the entire data recording system.

(2) INVERTER

(a) red FAIL light - illuminates to signal inverter failure.

(b) ON-OFF switch - 115-volt, 400-cycle, single-phase AC power supply which provided 5 volts DC excitation for all the pots.

(3) COUNTER - three-digit counter that continuously codes record number on the tape.

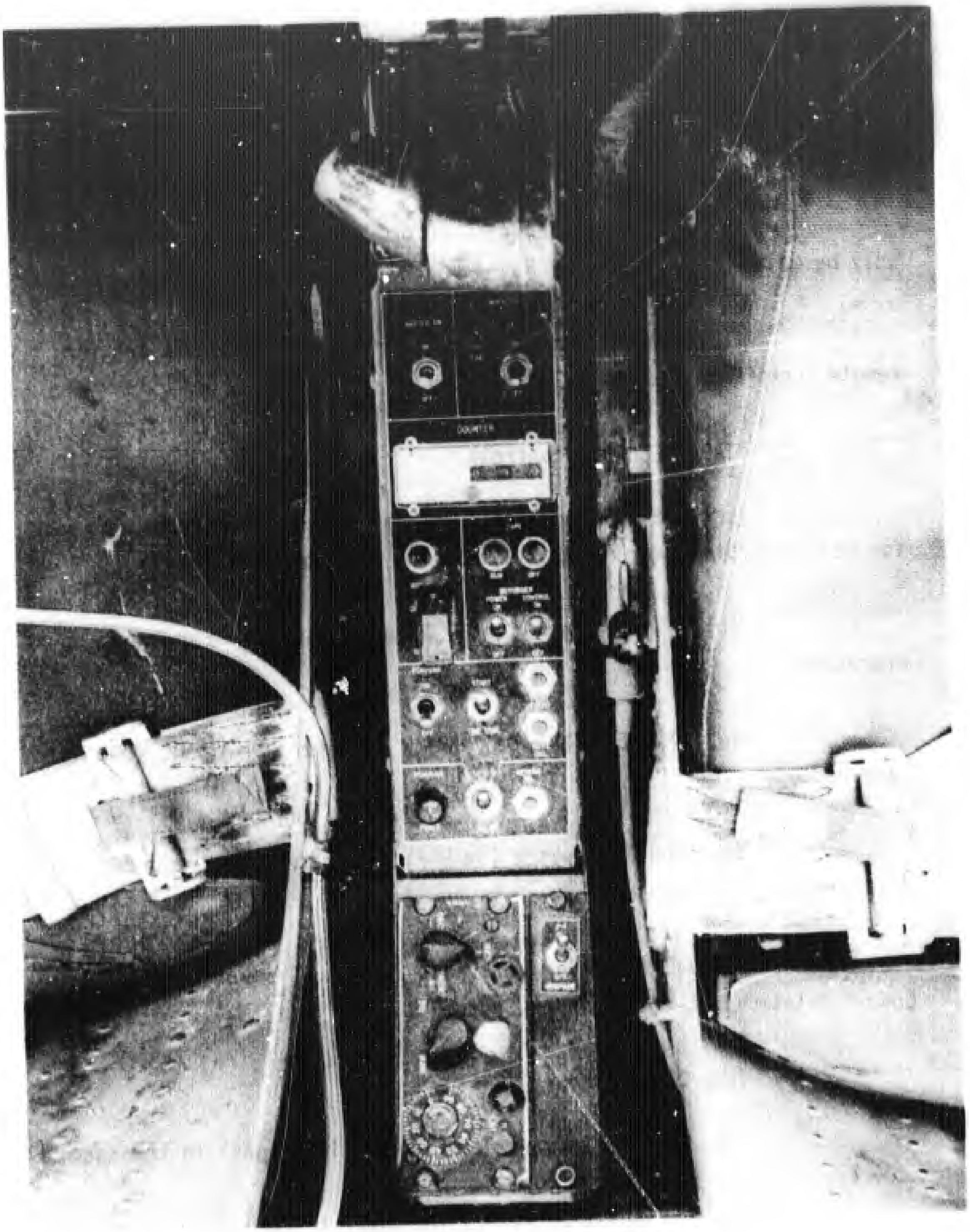


Figure 3. Recorder Control Panel

(4) GROUND-TO-FLIGHT guarded switch.

(a) OFF (guard up) - permits local manual operation of recorder on the ground for purposes of checkout, tape loading, and maintenance.

(b) ON (guard down) - recorder in remote mode controlled only by adjacent RECORDER POWER and CONTROL switches.

(c) green light - illuminates when recorder is set for remote cockpit operation.

(5) TAPE RECORDER controls

(a) left amber light - illuminates when recorder is ready for data recording and extinguishes during tape operation.

(b) right amber light - illuminates when recorder is operating.

(c) POWER switch (ON-OFF) - provides 28-volt DC power to tape recorder.

(d) CONTROL switch (ON-OFF) - operates tape recorder for data acquisition purposes.

(6) PCM/DAS (ON-OFF) - provides 28-volt DC power to the Pulse Code Modulation/Data Acquisition System.

(7) TIME CODE switch

(a) START - inputs a continuous time signal to the tape.

(b) OFF position resets the clock to zero.

(8) PILOT EVENT button - permits momentary coding on tape of a significant event when depressed.

(9) AUTO. CAL. button - initiates an automatic 300-millisecond internal calibration program sequentially on each scoring parameter.

(10) PCM/DAS POWER fuse - a 1-1/2 amp fuse protecting the system.

(11) RECORD NO. - advances counter one number when depressed.

Just aft of the Recorder Control Panel is located the J-4 Compass System Control Panel which contains the following switch functions:

(1) DEC/SET/INC Synchronizer Switch - permits manual slaving of the gyro to the signal from the remote compass transmitter by using the MAG annunciator window as a slaving reference.

(2) DG/MAG Function Selector Switch

(a) operates in a non-slaved mode by selecting the DG position.

(b) operates as a slaved heading system in the MAG position by using the signals from the remote compass transmitter located in the left wing tip.

(c) a 15-second fast slaving cycle is induced when the function selector switch is moved from the MAG to DG position and returned to MAG.

(3) Latitude Correction Knob (LAT) - reduces the apparent precession caused by the higher latitudes when operating in a non-slaved mode.

A J-4 POWER switch was installed adjacent to the J-4 Control Panel to provide system power.

(4) Audio Tape Recorder

A Norelco portable audio tape recorder (Model 150) was utilized to record all interphone and UHF radio communications in the aircraft. The transistorized recorder operated on five 1.5 volt (C cell) batteries at a tape speed of 1-7/8 inches per second that provided 30 minutes' recording time on each side of the C-60 cartridge. A holder was installed on the right sidewall of 948 (see Figure 1) in which the recorder was placed during the flight. A "Y" cord was locally fabricated that would interface between the normal aircraft interphone jack and the tape recorder.

(5) System Effectiveness

The effectiveness of the data acquisition system must ultimately be evaluated in terms of the capability it provided in the development of measurement methods and the quantitative assessment of in-flight pilot performance. This system effectiveness is directly related to the three fundamental requirements of an objective pilot performance measurement system - reliability, validity, and sensitivity.

The data acquisition system overall provided a degree of reliability that was considerably better than was originally expected. Many of the problems encountered early in the program during the calibration flights were corrected by modifications and improvements to the sensor systems and power supply. The subsequent data collection flights conducted at Williams AFB, Arizona, with students and instructors were virtually unhampered by equipment failure in the instrumentation package. The Leach magnetic tape recorder did cause some difficulty occasionally that was usually corrected by cleaning the tape head. At one point in the student data collection phase, the tape recorder had to be returned to the manufacturer's facility for overhaul.

A rather serious problem was experienced throughout the entire Pilot Performance Measurement Program with the heading parameter. As stated earlier, a J-4 compass system was substituted for the normal J-2 system in the T-37 due to excessive precession errors with the original system. This change was quite valuable since the J-4 system proved to be more stable and any precession encountered during the flight could be quickly eliminated by manually inducing the fast slave cycle between recorded maneuvers. However, inherent limitations of the heading sensor system with the synchro-follower permitted the accurate recording of heading (±1°) only in the southeast, southwest, and northwest quadrants, or specifically between 090 and 360°. Anytime the aircraft turned to the northeast (360-090°), the recorded data was erroneous. This heading restriction could be compensated for somewhat by performing the maneuvers on southern and westerly headings. Unfortunately this was not always possible due to the constraints imposed upon the aircraft operations by the ATC airspace requirements. Although the parameter of aircraft heading was the primary reference variable in the lazy 8 maneuver, the lack of full 360° recording capability inhibited the development of performance measures and forced the authors to eliminate it as a measurement variable.

The sensitivity achieved from altitude was somewhat less than the predetermined requirement of 50 ft, but the actual altitude error of ±166 ft was still sufficiently accurate to permit meaningful measurement research on the lazy 8 and barrell roll maneuvers. However, for other types of maneuvers, such as the 360° overhead traffic pattern, the altitude error would have to be reduced considerably before appropriate performance measures could be developed. The altitude error encountered appeared to vary to some extent from one day to the next, perhaps as a function of temperature or humidity. Generally the altitude recorded from the surface of 5500 ft was less than the actual mean sea level altitude of the aircraft. At approximately 5500 ft, a crossover occurred such that the recorded altitude became greater than the actual altitude of the aircraft (positive error), and the error increased slowly but progressively as a function of increasing altitude. The altitudes between 2500 and 8500 ft resulted in the most accurate data on aircraft altitude.

Initially, it appeared the gyro limitation of ±82° would pose a problem for the accurate recording of pitch angle; but, subsequent student data collection flights revealed the maximum pitch angle for the two primary maneuvers of interest did not exceed 70°. Thus, the attitude gyro was quite satisfactory regarding the range of values sensed as well as the ±1.5° resolution from the indicated pitch and roll angle. In the over-the-top maneuver such as loop, clover-leaf, Immelmann, etc., the vertical limitation of 82° affected the capability to accurately reconstruct the actual maneuver. Of course, the 360° roll capability of the MD-1 gyro and a resolution of ±1.5° bank angle provided accurate performance data on that parameter irrespective of the maneuver performed. It was possible to experience some degradation in the accuracy of pitch and roll data whenever insufficient time was allocated between maneuvers with large pitch and roll excursions. An attitude fast erection system switch on the instrument panel could be activated within certain operational limitations by the pilot whenever the attitude indicator was precessed excessively.

The parameters of acceleration (g force), pitch rate, roll rate, and yaw rate were quite adversely affected by turbulance and gust loads. Large spikes in the data indicated the sensor systems of these four parameters were too sensitive for accurate recording of in-flight data.

With respect to the validity of the in-flight pilot performance data, the basic philosophy adopted was that the recorded values should correlate as closely as possible with the values displayed on the respective cockpit flight or engine instrument from which the pilot derived his information. Thus, there was less concern regarding a minimal error existing between the actual parameter value and instrument reading than any error encountered between the instrument reading and recorded value. However, the cockpit instruments of the more significant parameters (e.g., heading, altitude, and airspeed) were calibrated by bench checks, tower fly-bys, and pacer aircraft flights to ascertain their real-world accuracy and the extent of inherent errors existing that affect the instrument indications such as mechanical error, scale error, installation/position error, reversal error, and hysteresis error.

SECTION III

GROUND-BASED DATA CALIBRATION SYSTEM

1. OVERVIEW

Considerable data processing and logistics effort was required to convert the recorded flight data into a form suitable for research and analysis. The physical characteristics of the flight recorder tape made it incompatible with the data processing equipment available for extensive data analysis. This necessitated an initial conversion of the data to IBM-compatible tape. The operating system characteristics of the data processing installation supporting the study made necessary a reformatting of data prior to calibration. Also, the quantity of data involved necessitated the development and rigid adherence to an extensive data-cataloging system.

While these requirements are not necessarily unique to this particular study, they were complicated by the fact that different sources had to be used for various portions of the data processing effort. The initial conversion of the data to IBM-compatible tape was accomplished by the ASD Flight Test Data Reduction Branch, whereas all subsequent data processing work was done by the ASD Computing and Information Systems Branch using different equipment. Among other things, this amplified problems inherent in reading and writing magnetic tape. In addition, data analysis requirements, as anticipated, varied as the research progressed, and several different programmers were subsequently involved. This resulted in more data-passes than desired and, to enhance reliability and simplify data handling, necessitated the transfer of individual flight maneuvers data to cards. Figure 4 illustrates the general flow of data and the order in which various processing and research tasks were accomplished.

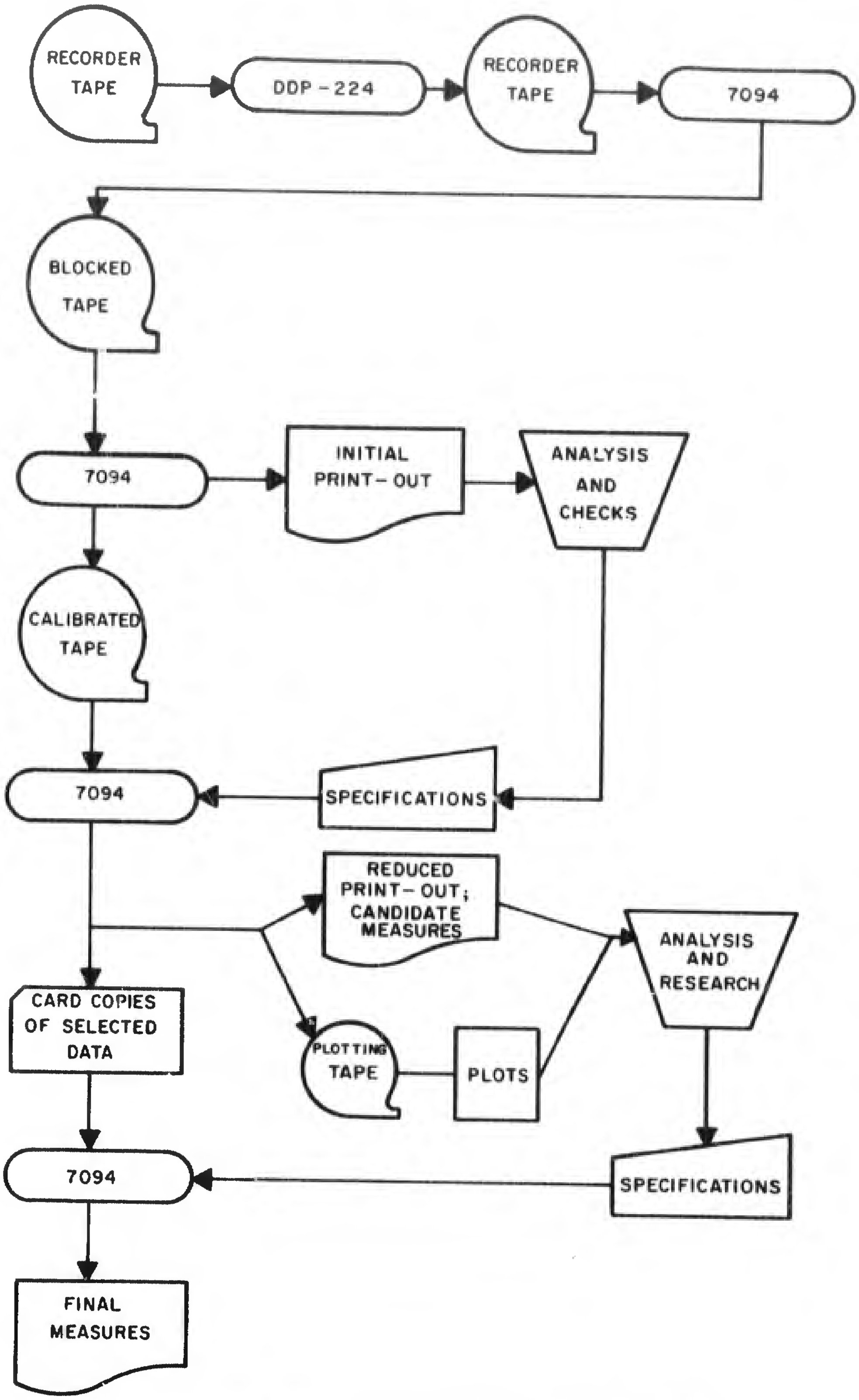


Figure 4. Flight Data Processing Flow

2. TAPE FORMAT CONVERSION

a. Recorder Tape

The flight data, as it appears on the recorder tape, consists of successive frames of 100 words each. The 1st and 100th words of each frame are sync words, the 2nd through 97th words are data words, and the 98th and 99th are time words.

The tape is 1 inch wide and has 16 tracks (14 recorded). Figure 5 illustrates the information format and the order of the recorded variables stored repeatedly in each 100-word frame. Each frame represents 0.1 seconds of data. Since the recording speed of the tape is 7.5 inches per second, the data density on the tape is 133 bits per inch (BPI) per track.

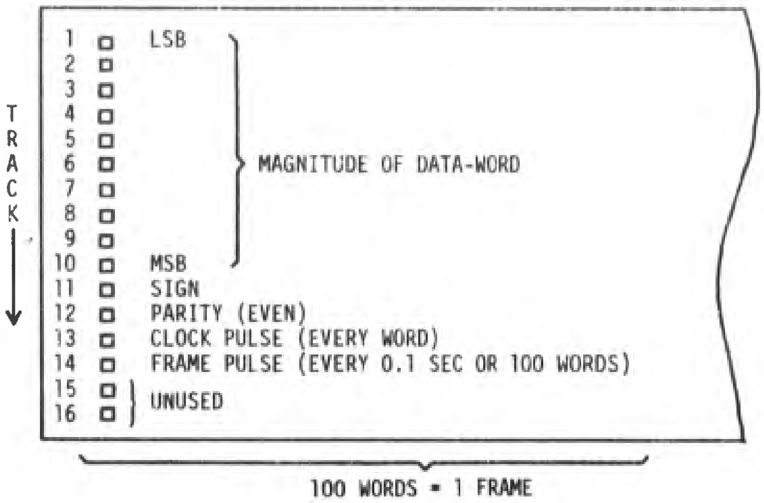
The recorder tape is read on an Ampex FR-1200 recorder-reproducer, processed through a DDP-24 system, and written on 1/2 inch processor tape.

b. Processor Tape

As it appears on the processor-tape, the flight data are formatted in 1230-word records, each word of which has a parity bit (bit 1), sign bit (bit 2), and ten magnitude bits (bits 3-12). There are 12 frames of 100 words apiece, each preceded by 2 frame-delineation words (7777_8, 7777_8). The first two words of each record are the record number, and the last four words contain all zeros. The record length of 1230 12-bit words makes it possible to convert each record into 410 36-bit words for compatibility with the IBM 7094. The processor tape density is 556 bits per inch (BPI).

c. Blocked Tape

All operations on the data subsequent to the conversion from recorder to processor tape were accomplished using a 7094/7044 Direct Coupled Computing System (DCS). In the DCS, the IBM 7044 computer processes all input/output, and the system requires that magnetic tape



WORD	VARIABLE
1	Sync
2-7	100/Sec Words: Pitch, Roll, Long. Stick Position, Lat. Stick Position, Rudder Position, Airspeed
8	Thrust Attenuator
9-11	None
12-17	100/Sec Words
18	Roll Rate
19-21	None
22-27	100/Sec Words
28	None
29	Trim Tab Up
30	Trim Tab Down
31	None
32-37	100/Sec Words
38	Altitude
39	Heading
40	Yaw Rate
41	Acceleration (g Force)
42-47	100/Sec Words
48	Flap Position
49	Speed Brake
50	Landing Gear
51	LH Throttle Position
52-57	100/Sec Words
58	RH Throttle Position
59	LH RPM
60	RH RPM
61	Pitch Rate
62-67	100 Sec Words
68	Event Number
69-71	None
72-77	100 Sec Words
78-81	None
82-87	100/Sec Words
88-91	None
92-97	100/Sec Words
98-99	Time (BCD)
100	Sync

Figure 5. Flight Recorder Tape

input be blocked into successive 460-word records. Therefore, a blocked tape had to be prepared from each processor tape prior to beginning calibration and other computations.

To generate the blocked tape, the 12-bit words on the processor tape were picked up three at a time to form 36-bit 7094-compatible words. These words were written onto the blocked tape in binary records of 460 36-bit words at a density of 800 BPI.

3. CALIBRATION

a. Calibration Data and Procedures

Calibration of the flight data required a conversion of each recorded digital number to volts, then a conversion from volts to parameter values. For the conversion to volts, the following formula was applied:

$$\text{Volts} = 0.0051281\ (\text{recorded number}) - 0.1256$$

This formula was derived from data published in a Brown Engineering manual (Reference 2).

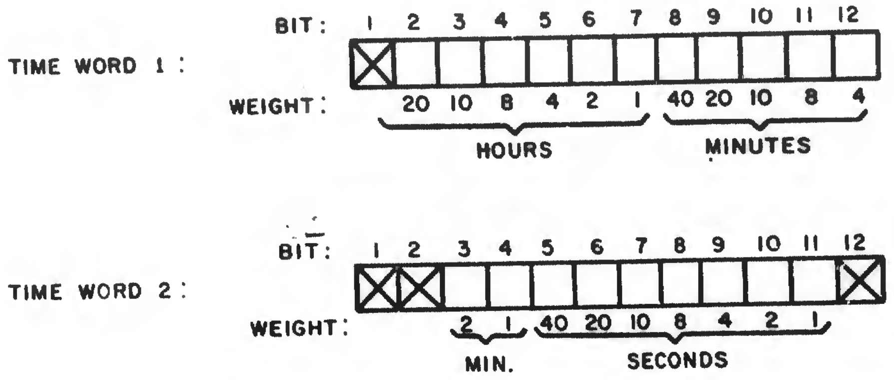
For conversion from volts to parameter values, calibration data derived by instrumentation personnel were used. An attempt was made to curve-fit the calibration data using (1) a single linear fit for each set of calibration data as well as (2) a quadratic fit. The fits were evaluated by a comparison with data obtained through linear interpolation. Considering the magnitude of the errors obtained with either type of curve fit (see Table III) and considering the likely (and eventually all too true) requirement of frequent alterations to the calibration data, it was decided that linear interpolation must be used.

TABLE III

ERRORS OBSERVED IN TRIAL ATTEMPT TO CURVE-FIT CALIBRATION DATA

Word	Maximum Error		Units
	Quadratic fit	Linear fit	
Pitch	1.47	1.69	Deg
Roll	.61	.58	Deg
Stick Pos. (Long.)	.48	1.54	Deg
Stick Pos. (Lat.)	.82	.87	Deg
Rudder Pos.	1.25	1.61	Deg
Airspeed	6.47	11.02	Knots
Roll Rate	2.04	23.80	Deg/Sec
Altitude	31.48	1972.07	Ft
Yaw Rate	15.45	15.45	Deg/Sec
Acceleration	.62	.64	g's
Flap Pos.	2.58	4.95	Percent
Throttle (LH)	1.12	.99	Deg
Throttle (RH)	1.93	2.27	Deg
RPM (LH)	.14	.34	Percent
RPM (RH)	.53	.52	Percent
Pitch Rate	6.73	6.89	Deg/Sec

Appendix I shows the calibration data and calibration block diagram for all recorded variables except (1) discrete variables, (2) event number, and (3) time. The calibration data were stored on cards to simplify updating and were read into the 7094 and interpolated linearly to effect the calibration. Discrete variables were converted to 1 if volts were greater than or equal to 2.5, and to 0 otherwise. No calibration was required for the event number. Time is recorded on the flight tape as a type of BCD quantity and required special treatment for conversion to hours, minutes, and seconds. As recorded, time consumes two 12-bit words, with individual bits therein weighted BCD as follows:



During the calibration run, time was converted to seconds by appropriately adding products of weights and bits as indicated above, multiplying the result by 60, in the case of minutes, and 3600, in the case of hours, and summing.

b. Computed Variables

Some additional variables were computed from the recorded flight data at the time of data calibration. The computed variables are summarized in Table IV. The first five variables in the table were computed because they were believed to be potentially useful in measurement. Pitch, roll, and yaw angles were computed solely as a check on the recorded pitch and roll values and the recorded body-axis rates. Time was computed as a check on the recorded time and the sampling frequency.

TABLE IV

COMPUTED FLIGHT VARIABLES

	Variable	Computed From	Using
1.	Vertical Velocity	Altitude	Numerical Differentiation
2.	Longitudinal Stick Rate	Longitudinal Stick Position	
3.	Turn Rate	Heading	
4.	Lateral Stick Rate	Lateral Stick Position	
5.	Rudder Rate	Rudder Position	
6.	Pitch	Pitch Rate	Euler Angles & Numerical Integration
7.	Roll	Roll Rate	
8.	Yaw	Yaw Rate	
9.	Time	Recording Frequency	Cumulative Summation

Unfortunately, little use could be made of any of the computed variables with the exception of time. The primary reason was because spurious "glitches" in the data destroyed computational continuity. In addition, numerical differentiation amplified all noise and thereby rendered the variables computed useless. Some experiments with other methods of computation were attempted. However, the importance and urgency of other problems to be contended with and the main research to be conducted quickly forced abandonment of the computation of additional variables during calibration. It was decided that such computations, if required, should be attempted only after smoothing of the data.

c. Calibrated Tape Format

As recorded on the calibrated tape, each data word is an IBM 7094 36-bit floating point binary word, with a sign bit (bit zero), 8-bit exponent field (bits 1-8), and 27-bit mantissa (bits 9-35). The data are recorded on 1/2 inch, 7-channel magnetic tape at a density of 800 BPI. Record length is 460 words, with words 1, 2, and 460 used as control words meaningful only in connection with the 7094/7044 DCS.

The data are placed on the tape in successive groups, each group representing all data for 1.2 seconds of real time. The order of the data as it appears on the tape is illustrated in Table V. All data recorded at a sampling rate of 100 per second appear first, e.g., the first 1.2 seconds of pitch data, or 120 samples of pitch, appear first, followed by each of the remaining 100 per second sampled variables. Data recorded at 10 per second follows. The tape format is illustrated in Figure 6.

d. Tape Capacity

Each binary data word consumes 36 bits or 6 frames on the tape. At a recording density of 800 BPI, this is equivalent to 6/800 inches of tape per word. There are 9 words recorded at 100 per second and 25 words at 10 per second, for a total of 1150 words per second, or 1380 words in 1.2 seconds. At 460 words per record, there are about

TABLE V

ORDER OF T-37 AIRCRAFT VARIABLES ON CALIBRATED TAPE

Variable	Units	No. of Consecutive Samples in 1.2 Seconds
1. Pitch	Deg	120
2. Roll	Deg	
3. Long. Stick Pos.	Deg	
4. Lat. Stick Pos.	Deg	
5. Rudder Position	Deg	
6. Airspeed	Knots	
7. Long. Stick Rate	Deg/Sec	
8. Lat. Stick Rate	Deg/Sec	↓
9. Rudder Rate	Deg/Sec	120
10. Thrust Attenuator	Discrete	12
11. Roll Rate	Deg/Sec	
12. Trim Tab Up	Discrete	
13. Trim Tab Down	Discrete	
14. Altitude	Ft	
15. Heading	Deg	
16. Yaw Rate	Deg/Sec	
17. Acceleration	g's	
18. Flap Position	Percent	
19. Speed Brakes	Discrete	
20. Landing Gear	Discrete	
21. Throttle Pos. (L)	Deg	
22. Throttle Pos. (R)	Deg	
23. RPM (L)	Percent	
24. RPM (R)	Percent	
25. Pitch Rate	Deg/Sec	
26. Event Number	------	
27. Time	Sec	
28. Roll-Computed	Deg	
29. Vertical Velocity	Ft/Sec	
30. Rate of Turn	Deg/Sec	
31. Yaw	Deg	
32. Pitch-Computed	Deg	↓
33. Time-Computed	Sec	12

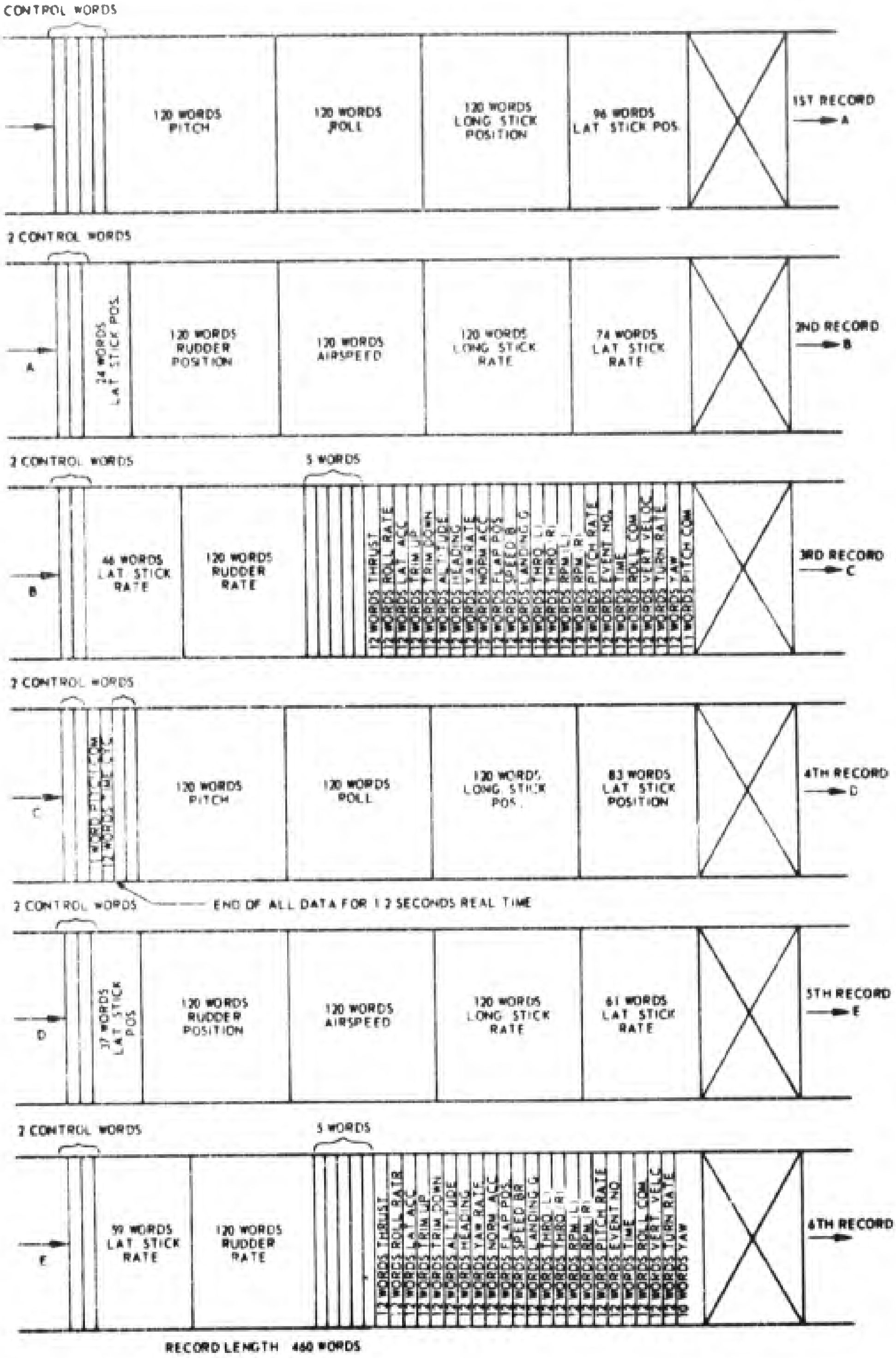


Figure 6. Magnetic Tape Format

3 records per 1.2 seconds of data. Therefore, for each 1.2 seconds (3 records) of data, we require

$$\frac{6}{800}(1380) + 3(\text{IRG}) = 10.35 + 2.25 = 12.6 \text{ inches of tape,}$$

where IRG = 3/4 inches = length of inter-record gap. With 2350 feet of tape (standard reel, allowing for leader and trailer), it is possible to score

$$\frac{12(2350)}{12.6}(1.2) = 2686 \text{ seconds}$$

worth of data, or about 45 minutes. Normally, this resulted in two calibrated tapes per flight.

e. Print-Out Format

During the calibration run, an initial print-out of the data at one sample per second is produced. This print-out is used for quick checks of the system (i.e., verification of revised calibration data, guarantee that total recording system is operating accurately, etc.) and preliminary measurement research. The data are printed in columns using three pages to represent 50 seconds of data.

An illustration of the print-out format is provided in Appendix II. Recorded time is printed in the left-most column of all pages. Page 1 (of every 3 pages) is used to present all variables normally associated with movement about the lateral axis of the aircraft. Page 2 presents variables associated with movement about the longitudinal or vertical axes. Page 3 presents engine and discrete variables, the event number, computed time, and a record number.

f. Calibration Software

The calibration programs are listed in Appendix III. A main program and seven subroutines were developed to (a) calibrate the data; (b) write the calibrated data on magnetic tape; and (c) print the calibrated data at one sample per second. The program's approximate number of statements (including comments and data), and main function of each are as follows:

PROGRAM	LANGUAGE	STATEMENTS	FUNCTION
Main	Fortran	108	Control program
Cyclex	Fortran	60	Extract, calibrate, and store data in 100-word blocks
Calbrt	Fortran	41	
Aitken	Fortran	114	
Stores	Fortran	19	Array-storage
Selecx	Fortran	54	Arrays data for printout and calls print when page is full
Prints	Fortran	40	Prints data, 1/sec
Xtratc	Map	87	Tape handling Routines
IOCS	Map	171	
Units	Map	17	
	TOTAL:	711	

SECTION IV

SAMPLING RATE STUDY

1. INTRODUCTION

At the onset of this study, a decision had to be made regarding the in-flight sampling rate which would be adequate for purposes of performance measurement. Error in one direction would result in redundant data, contributing to the already difficult problem of data handling. Error in the opposite direction would result in a lack of sufficient data to accomplish the research.

The popular existing approach to determining required sampling rates is to base the decision on sampling theory, which relates the worst case natural frequency of the aircraft to the sampling rate that effectively allows the entire "waveform" to be reproduced. This approach has been employed for years in the area of flight simulation. However, it is conceivable that such an approach would only guarantee the sufficiency, not the necessity, of the amount of data to be recorded. This is particularly true in light of the present intended use of the data, i.e., performance measurement of selected flight maneuvers.

For lack of better guidelines, the sufficiency of 10 and 100 times-per-second sampling rates was intuitively assumed for launching the present study. An investigation of the necessity for such rates for those flight variables relevant to measurement on each flight maneuver is required, however, before specification of an optimal recording system can be made. In support of this, an initial sampling rate study was conducted, the primary purpose being to establish a methodology for such investigations.

2. APPROACH

a. Discussion

The recorded data were sampled at a number of different sampling intervals (e.g., every 0.05 seconds, every 0.01 seconds, etc.). For each test run, or each sampling interval used, tests were made to determine the errors that would result from generating the between-sampling-interval data from the sample-points using linear interpolation. In other words, the question addressed was, "If the only data available were those values sampled at an interval of n seconds, and intermediate data were then generated using those sampled values, what errors could be expected in the generated data?" Figure 7 illustrates this concept.

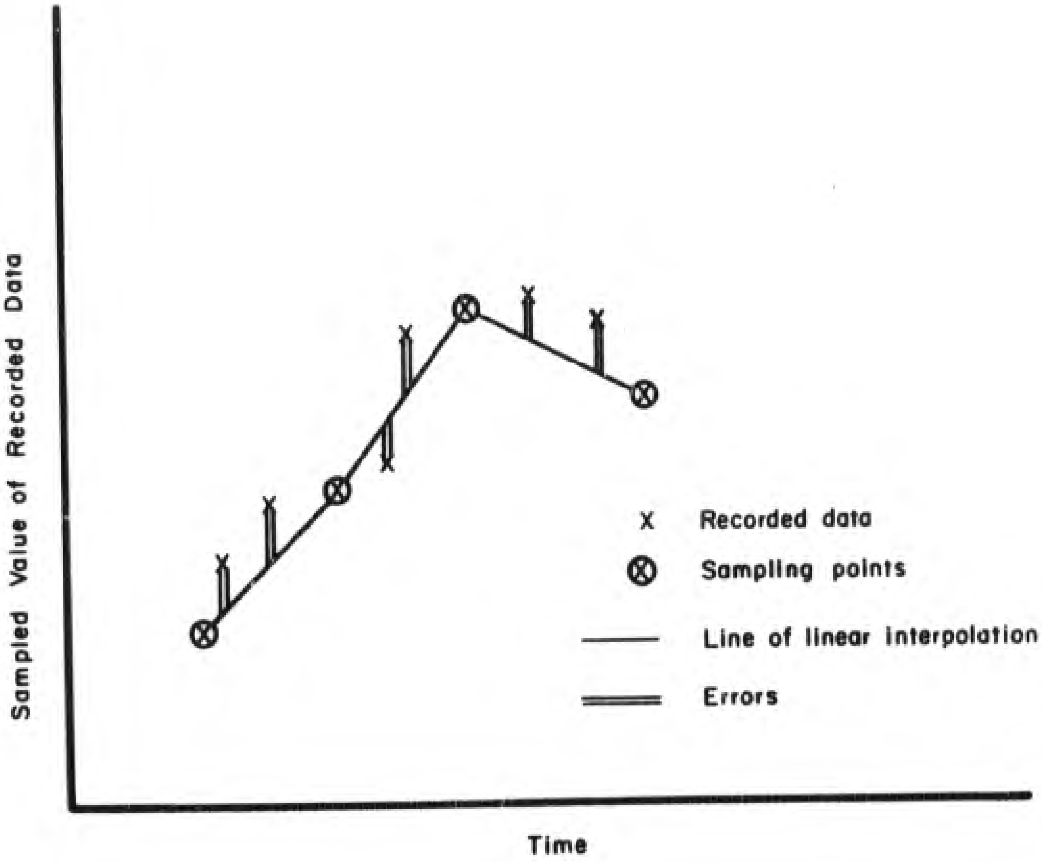


Figure 7. Nature of Error Computation for Sampling Rate Study

As a test case for the study, pitch angle was examined during the performance of (a) 46 lazy 8 maneuvers and (b) 44 barrel roll maneuvers. Pitch was recorded in-flight at a sampling interval 0.01 seconds. Sampling intervals of 0.05, 0.10, 0.50, 1, 2, 3, 4, and 10 seconds were tested. An error distribution (histogram) for each maneuver and each sampling interval was then constructed.

b. Software

Appendix IV presents the FORTRAN program listings of routines used in the experiment. Portions of a typical print-out are presented in Figure 8. In Figure 8a, the first seven columns present (1) the event number (ENVO) of the maneuver; (2) sampling rate tested; (3) the total number of points comprising the maneuver as recorded on tape; (4) the "resolution" error (RES) tested, which was the tolerance within which an error was not counted and beyond which it was counted (RES set to zero for this application); (5) the number of times a tested point produced an error which exceeded RES; (6) the worst error (one with largest magnitude) encountered; and (7) the time into the maneuver (seconds) at which the worst error occurred. The remaining twelve columns present the number of errors whose absolute value lay in the range indicated at the top of the respective column.

Figure 8b summarizes the data in terms of fractional parts. The 3rd column presents the part of all samples tested in which any error was detected. Subsequent columns present the part of all samples-in-error in which error magnitudes fell in the indicated range.

Since the two types of maneuvers to be examined were intermixed on several different tapes, it was most expedient to compute the summary of all data by hand, following the several necessary computer runs. Each computer run produced results as shown in Figure 8 for all lazy 8's and barrel rolls on one tape, plus additional computations which aided the hand-summarization (by maneuver) of all data.

```
        SAMPLING ANALYSIS FOR FLIGHT CF  12-17-69

VAR IS PITCH

       SAMP   NO.         TIMES WORST
EVNO RATE SAMP RES.  EXCED.   ERR      TIME   0-.5 .5-1. 1-1.5 1.5-2. 2-2.5 2.5-3 3-3.5 3.5-4   4-5  5-10 10-20  GR-20

19.   0.05 4690   0.   3024.   1.099 31.55 1958.    63.     3.     0.     0.     0.     0.     0.     0.     0.     0.     0.
19.   0.10 4680   0.   3010.   1.216 30.59 2537.    70.     3.     0.     0.     0.     0.     0.     0.     0.     0.     0.
19.   0.50 4690   0.   4160.   1.425 30.59 3929.   217.    14.     0.     0.     0.     0.     0.     0.     0.     0.     0.
19.   1.00 4680   0.   4477.   1.436 30.59 4058.   359.    20.     0.     0.     0.     0.     0.     0.     0.     0.     0.
19.   2.00 4680   0.   4397.   2.364 32.90 2970.   782.   462.   148.    35.     0.     0.     0.     0.     0.     0.     0.
19.   3.00 4680   0.   4293.   4.960 34.03 2420.   828.   423.   181.   142.   113.    37.    41.   108.     0.     0.     0.
19.   4.00 4680   0.   4378.   6.809 23.77 1706.  1099.   479.   199.   257.   102.    49.    60.   184.   243.     0.     0.
19.  10.00 4680   0.   3992.  33.889 34.03  339.   300.   313.   260.    91.    58.    59.    42.   179.   871.   574.   897.

20.   0.05 9600   0.   3843.   3.103 35.99 3763.    75.     3.     1.     0.     0.     1.     0.     0.     0.     0.     0.
20.   0.10 9600   0.   5922.   3.746 35.99 5830.    84.     2.     1.     1.     1.     2.     1.     0.     0.     0.     0.
20.   0.50 9600   0.   8468.   2.523 35.00 8209.   227.    17.     9.     5.     1.     0.     0.     0.     0.     0.     0.
20.   1.00 9600   0.   9116.   2.540 35.00 8747.   308.    26.    23.    11.     1.     0.     0.     0.     0.     0.     0.
20.   2.00 9600   0.   9504.   4.046 35.05 7389.  1691.   294.    32.    29.    23.    23.    22.     1.     0.     0.     0.
20.   3.00 9600   0.   9365.   4.605 36.20 5777.  1709.   819.   445.   363.    92.    54.    57.    49.     0.     0.     0.
20.   4.00 9600   0.   9363.   4.948 22.19 4028.  1821.  1296.   710.   497.   340.   142.   206.   323.     0.     0.     0.
20.  10.00 9600   0.   8982.  13.054 55.21 1453.  1142.  1185.   807.   665.  *380.   193.   188.   493.  1354.  1122.     0.

21.   0.05 9000   0.   3579.   1.026 25.99 3504.    74.     1.     0.     0.     0.     0.     0.     0.     0.     0.     0.
21.   0.10 9000   0.   5758.   1.216 26.99 5682.    74.     2.     0.     0.     0.     0.     0.     0.     0.     0.     0.
21.   0.50 9000   0.   8406.   1.093 25.79 8049.   353.     6.     0.     0.     0.     0.     0.     0.     0.     0.     0.
21.   1.00 9000   0.   8699.   1.196 26.90 8162.   522.    15.     0.     0.     0.     0.     0.     0.     0.     0.     0.
21.   2.00 9000   0.   8910.   1.675 59.15 7020.  1774.   107.     9.     0.     0.     0.     0.     0.     0.     0.     0.
21.   3.00 9000   0.   8940.   2.563 19.31 5113.  2002.  1125.   506.   193.     1.     0.     0.     0.     0.     0.     0.
21.   4.00 9000   0.   8756.   3.872 18.05 4050.  1579.   955.   921.   725.   304.   180.    42.     0.     0.     0.     0.
21.  10.00 9000   0.   8982.  17.984 55.85 1770.  1007.   682.   467.   582.   259.   268.   275.   580.  2007.  1085.     0.

 EVNO     DEL     GT :    LE .5   LE 1.  LE 1.5   LE 2.  LE 2.5   LE 3.  LE 3.5   LE 4.   LE 5.  LE 10   LE 20  LE INF

 19.      0.05     0.4    0.967   0.999   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000
 19.      0.10     0.6    0.976   0.999   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000
 19.      0.50     0.9    0.944   0.997   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000
 19.      1.00     1.0    0.915   0.996   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000
 19.      2.00     0.9    0.675   0.853   0.958   0.992   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000
 19.      3.00     0.9    0.564   0.757   0.855   0.897   0.930   0.957   0.965   0.975   1.000   1.000   1.000   1.000
 19.      4.00     0.9    0.390   0.641   0.750   0.796   0.854   0.878   0.889   0.902   0.944   1.000   1.000   1.000
 19.     10.00     0.9    0.085   0.169   0.238   0.303   0.326   0.343   0.358   0.368   0.413   0.632   0.775   1.000

 20.      0.05     0.4    0.979   0.999   0.999   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000
 20.      0.10     0.6    0.984   0.999   0.995   0.999   0.999   0.999   1.000   1.000   1.000   1.000   1.000   1.000
 20.      0.50     0.9    0.969   0.996   0.998   0.999   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000
 20.      1.00     0.9    0.960   0.993   0.996   0.999   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000
 20.      2.00     1.0    0.777   0.955   0.986   0.990   0.993   0.995   0.998   1.000   1.000   1.000   1.000   1.000
 20.      3.00     1.0    0.617   0.759   0.887   0.934   0.973   0.983   0.989   0.995   1.000   1.000   1.000   1.000
 20.      4.00     1.0    0.430   0.625   0.763   0.839   0.892   0.928   0.944   0.966   1.000   1.000   1.000   1.000
 20.     10.00     0.9    0.162   0.289   0.421   0.511   0.585   0.627   0.649   0.669   0.724   0.875   1.000   1.000

 21.      0.05     0.4    0.979   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000
 21.      0.10     0.6    0.987   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000
 21.      0.50     0.9    0.957   0.999   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000
 21.      1.00     1.0    0.938   0.998   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000
 21.      2.00     1.0    0.788   0.967   0.999   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000   1.000
```

Figure 8. Sample Print-Out for Sampling Rate Study

3. RESULTS

Table VI summarizes the results obtained for the lazy 8 and barrel roll pitch-angle sampling rate study. The heavy line indicates the boundary which delineates the point in the error distribution where an asymptote is apparently reached. (The results must be interpreted in terms of this asymptote rather than solely in terms of the number of errors within certain bounds because of the existence of data spurs, or glitches.

Table VI suggests that for the lazy 8, little would be gained using a sampling interval smaller than 1.0 seconds. Increasing the interval from 1.0 to 2.0 would effectively double the worst-case error. For the barrel roll, an interval smaller than 0.10 seconds would apparently be unnecessary. A slight increase in worst-case error would be experienced in a sampling-interval increase from 0.1 to 0.5 or 1.0. The real breakpoint occurs with intervals at 2 seconds or larger.

It would appear, then, that, for pitch-angle, a sampling rate of 1 per second for both maneuvers would be optimal, with slightly improved accuracy possible in the barrel roll by going to 10 per second. (Of course this investigation considered only a discrete set of test intervals, and a more thorough study may show a 5 or 7 per second rate optimal for the barrel roll.) If the pitch accuracy tolerance were $\pm 2°$ for both maneuvers, then a rate of 2 per second on the lazy 8 and 1 per second on the barrel roll would probably be required.

This type of information is of some benefit both for specifying recording systems and for performing measurement analyses. Figures 9 and 10 show how the data can be presented graphically to provide immediate indication of the adequacy of any proposed sampling rate for various error tolerances. Using Figure 9, for example, it is easy to discern the sampling intervals which would provide comparable results for, say, an error tolerance of $\pm 2°$.

TABLE VI

FRACTIONAL PART OF PITCH ERRORS ≤ x FOR VARIOUS X[1] VALUES

Error Magnitude (x) Lazy 8 (N = 46)

SAMPLING INTERVAL (SEC) Δ \ ≤	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	5.0	10.0
.05	.960	.988	.991	.991	.991	.991	.992	.992	.992	.993
.10	.968	.988	.990	.991	.991	.991	.991	.991	.992	.993
.50	.942	.987	.990	.991	.991	.991	.991	.992	.992	.993
1.0	.913	.984	.990	.991	.991	.991	.992	.992	.992	.993
2.0	.711	.917	.971	.986	.989	.990	.991	.991	.991	.992
3.0	.506	.731	.850	.920	.956	.972	.980	.984	.989	.990
4.0	.376	.580	.697	.778	.844	.895	.930	.949	.967	.987
10.	.121	.204	.274	.334	.387	.432	.471	.503	.552	.753

Error Magnitude (x) Barrel Roll (N = 44)

SAMPLING INTERVAL (SEC) Δ \ ≤	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	5.0	10.0
.05	.960	.985	.988	.989	.990	.990	.991	.991	.991	.993
.10	.961	.983	.986	.987	.988	.988	.988	.989	.989	.991
.50	.923	.974	.982	.985	.985	.986	.986	.986	.987	.988
1.0	.861	.962	.980	.984	.985	.986	.986	.987	.987	.989
2.0	.639	.813	.887	.926	.949	.963	.974	.979	.983	.988
3.0	.477	.674	.768	.820	.855	.881	.905	.924	.948	.984
4.0	.361	.538	.637	.703	.750	.784	.811	.832	.871	.967
10.	.098	.173	.239	.299	.353	.392	.428	.460	.506	.649

---

[1] x represents the error magnitude. The table shows the fractional part (how many) of the total errors that were ≤ x at each sampling interval tested. For example, at Δ = 1.0 (lazy 8), 98.4% of the errors incurred were ≤ 1.0 in magnitude.

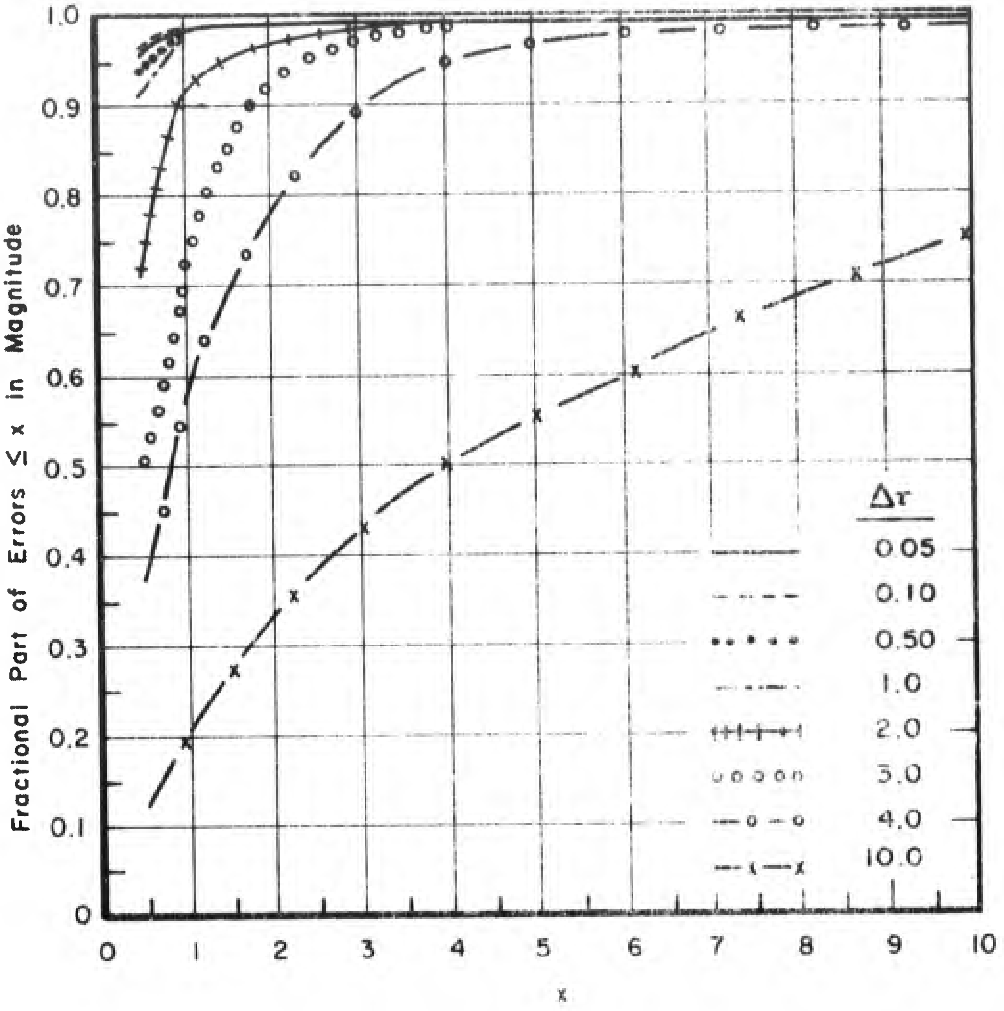


Figure 9. Sampling Interval Plot for Pitch (Lazy 8, N = 46)

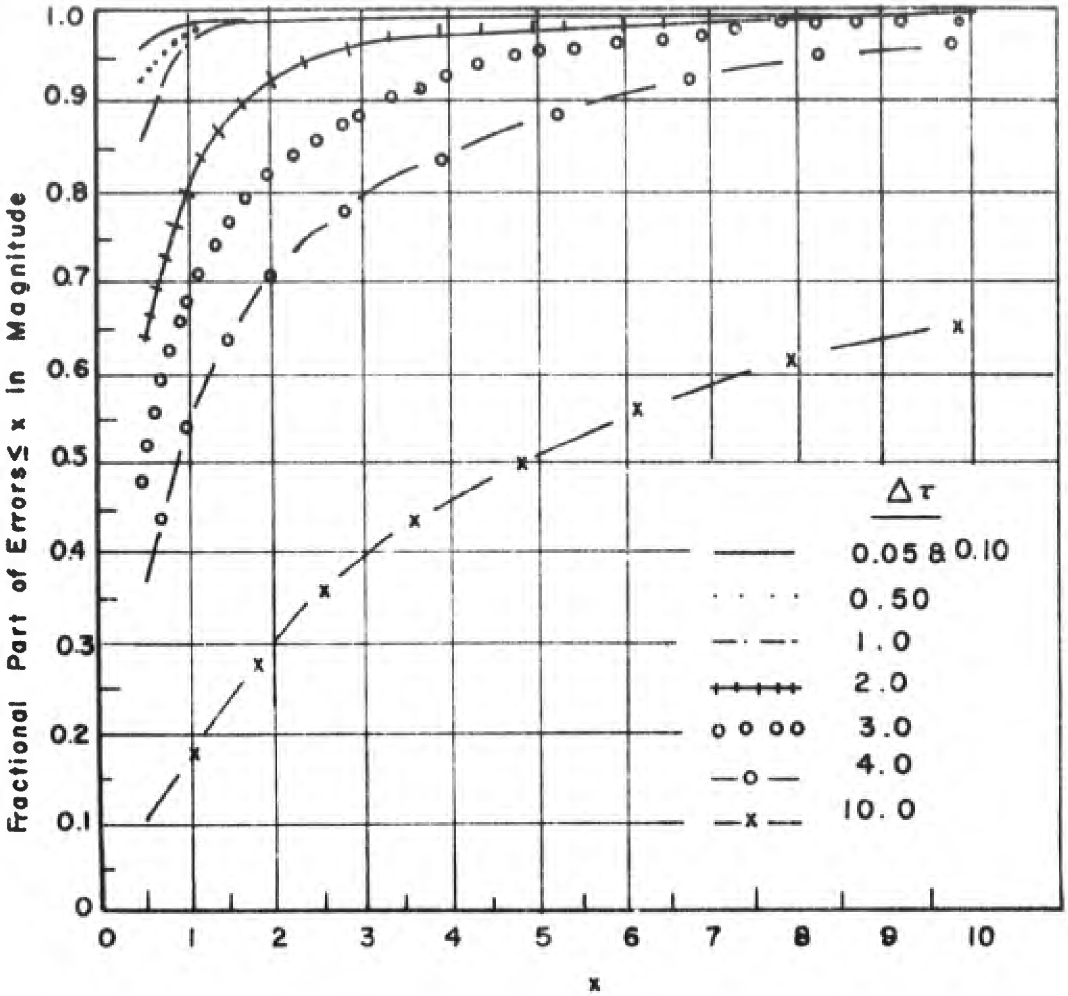


Figure 10. Sampling Interval Plot for Pitch (Barrel Roll, N= 44)

In addition to developing the type of data presented here, the sampling rate analysis could include a matching of the error distribution to the portion of the maneuver being flown. For this purpose, maneuver-sections could be delineated using a Boolean Time Function approach, wherein necessary and sufficient conditions for each state or group of states of the aircraft, relating in turn to sections of the maneuver, are identified using logical operators (Reference 3). This could lead to an identification of the portions of the maneuver which, from a sampling-rate standpoint, load the requirements most heavily. These portions may or may not be critical in performance measurement and, hence, the sampling rate may be adjustable for a reduction of requirements.

SECTION V

BASIC PERFORMANCE MEASUREMENT SYSTEM

1. GENERAL APPROACH

The approach consisted of several distinct but interrelated tasks. Summarily, these tasks were:

1. Perform analysis of the maneuvers to be studied in detail.
2. Develop theoretical measures based strictly on the results of the analyses.
3. Compute the theoretical measures for representative performances to determine which measures have face-validity.
4. Develop experimental measures consisting of (a) those theoretical measures which appear valid and (b) other measures derived through examination of the data.
5. Compute the experimental measures for a broad sample of student and instructor data and perform analyses to validate the measures.

The maneuver analyses were performed by Air Training Command. The analyses included (1) a maneuver description, (2) an itemization of maneuver elements, or separate portions of the maneuver, and (3) for each maneuver-element, the primary pilot tasks, the knowledge and skill required, and suggested error tolerances on critical parameters. Supplementing the information provided in the Primary Flying Manual (Reference 4), the task analyses provided a fair "picture" of each maneuver in addition to an indication of Air Training Command standards of performance, insofar as it was possible at that time to quantify these standards.

Theoretical measures were then developed based on the maneuver-analyses. This was accomplished during the instrumentation/test flight phases of the study, so that quite early in the preliminary data-collection phase, measurement programs were available to enable data analysis and research to be initiated.

These preliminary measurement programs were applied to early performances of the Flight Test pilots. The resulting data were analyzed to determine expected ranges of the critical flight parameters and evaluate the face validity of the various theoretical measures. Also, those portions of the maneuvers and/or those pilot skills which seemed the most feasible candidates for automated measurement were identified.

Final measurement programs were then developed for analysis of each student and instructor/pilot performance. These programs computed a variety of experimental measures believed to be relevant to performance evaluation. In addition, they produced automated plots of certain combinations of variables to produce a "picture" of the most relevant features of each performance.

The remainder of this Section is devoted to a description of how each of the above tasks was accomplished and, where applicable, how measurement programs were implemented.

2. ATC MANEUVER ANALYSES

a. Lazy 8

(1) General Description

The lazy 8 is a maneuver requiring simultaneous turning and climbing or descending so that a horizontal figure eight is described about a selected reference point located on the horizon.

This analysis assumes that the aircraft is in the local flying area in level flight between maneuvers.

Also assumed is that the student is in a post-solo phase of the T-37, is able to control the aircraft in turns of specified bank angles, and to maintain straight and level flight.

For analysis purposes, the heading indicated on the compass should be used as a primary reference although the student will perform the maneuver using outside references.

(2) Maneuver Elements

Figure 11 illustrates the nine maneuver elements of the lazy 8. The element numbers coincide with the circled task analysis numbers (Table VII).

(3) Maneuver Analysis

Table VII presents the analysis of the lazy 8 as developed by Air Training Command.

b. Barrel Roll

(1) General Description

The barrel roll consists of an aerobatic roll maneuver of 360° bank about a selected reference point located ahead of the aircraft.

The student must maintain a constant angle off a selected reference point through the 360° of bank with constantly changing pitch attitudes and airspeeds.

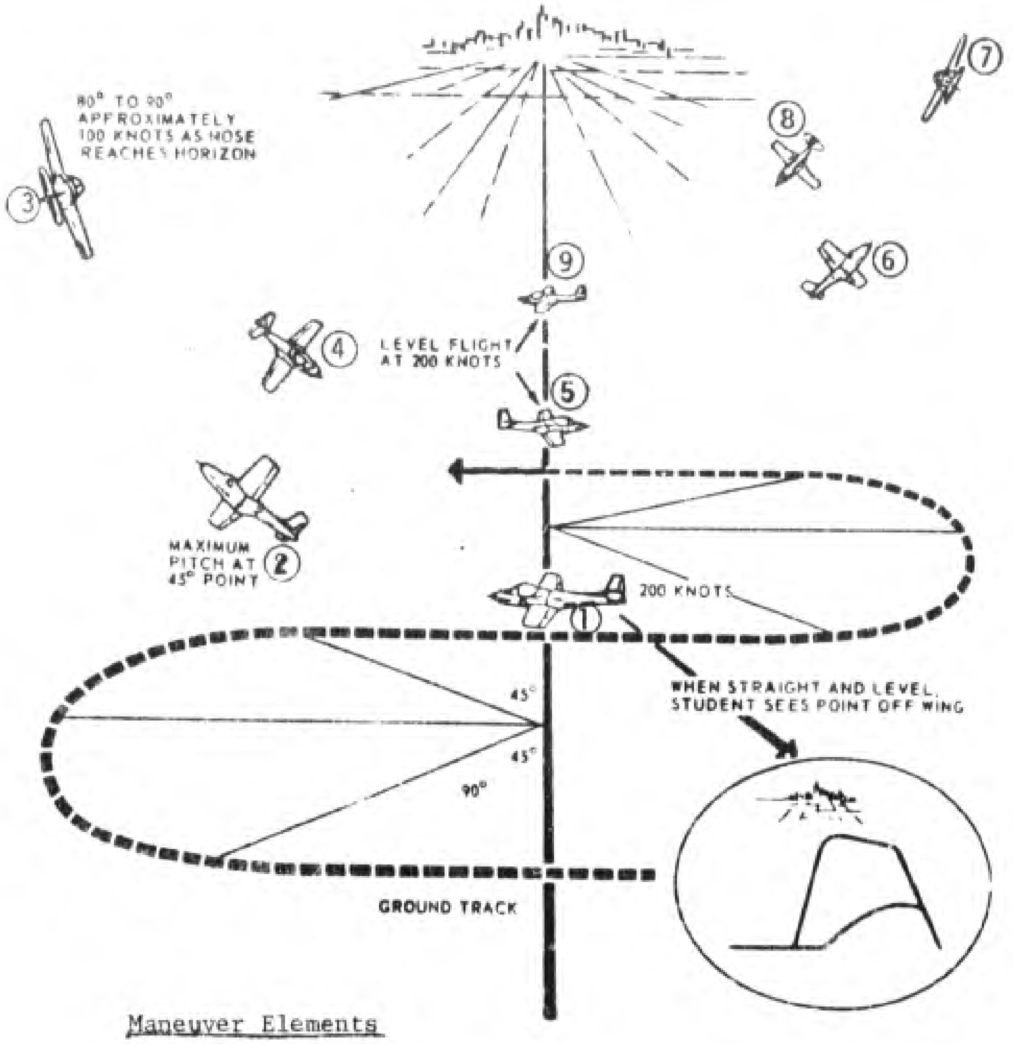
Positive seat pressures must be maintained and roll rate must be constant.

The student must coordinate rudder, elevator, and aileron deflection from normal.

(2) Maneuver Elements

The maneuver is divided into five segments (Figures 12a through 12e):

1. Entry, which is not considered an integral part of the maneuver, but is important for identifying the reference point and establishing maneuver orientation.



Maneuver Elements

1 Maneuver entry
2 45° turn point
3 90° turn point
4 135° turn point
5 180° turn point (midpoint of maneuver)
6 135° turn point (direction opposite from 0.1-0.5)
7 90° turn point
8 45° turn point
9 Maneuver termination (straight and level flight)

Figure 11. Lazy 8 Maneuver Profile

TABLE VII

LAZY 8 MANEUVER ANALYSIS

Maneuver Element Element Sub-Part	Purpose: What does the crewman do? Why is it done?	Knowledge and Skill Required	Tolerance (Task critieria) How well -
1.0 Maneuver Entry 1.1 Clear area	Visually ensures no other aircraft will conflict with maneuver.		No omissions or incompletes
1.2 Set airspeed 1.3 Set power 1.4 Select reference point	Set up aircraft condition and orientation for reference point (on wing tip). Straight and level flight.	Procedural knowledge in ATCM 51-4 200 kts 90% power level flight 5000 Ft A.G.L. +	±3 kts ±1% ±0 ft/min climb or descent above 5000' A.G.L.
1.5 Begin maneuver	Start climbing turn in direction of reference point	Direction to turn. Proper back pressure application for bank rate change.	1-2 g's
2.0 45° Turn point 2.1 15° turn point	Continue climbing turn in direction of reference point. As airspeed decreases, elevator and aileron deflection is increased to continue bank and pitch change. As 45° turn point is reached, the pitch attitude change (vertical velocity) is reversed in order for nose to reach horizon at 90° turn point.	Flying skill to reach: -13-15° of bank 15° of turn 1/3 of highest pitch Attitude (45° point)	±4° ±4° ±10%
2.2 30° Turn point		-27 - 30° of bank 30° of turn 2/3 of highest pitch attitude	±4° ±4° ±10%
2.3 45° Turn point		-40-45° of bank 45° of turn Highest pitch attitude in maneuver	±4° ±4° ±10%
3.0 90° Turn point 3.1 60° Turn Point	Continue climbing turn (although pitch attitude is decreasing) in direction of reference point. Bank angle continues to increase and some back pressure is released to allow nose to fall to horizon at 90° point.	Normal skill to reach: -53-60° of bank -60° of turn -2/3 of highest pitch attitude	±4° +4° +10°
3.2 75° Turn point		-67-75° of bank 75° of turn -1/3 of highest pitch attitude	±4° ±4° ±10°

TABLE VII

LAZY 8 MANEUVER ANALYSIS

Maneuver Element Element Sub-Part	Purpose: What does the crewman do? Why is it done?	Knowledge and Skill Required	Tolerance (Task criteria) How well-
3.3 90° Turn point	Maximum bank angle is reached	-80-90° of bank -90° of turn -Level flight (vertical velocity = zero) attitude -A/S -100 kts IAS	±4° ±4° ±5° ±5 kts
4.0 135° Turn point	The turn is continued in the same direction.	Normal skill to reach:	
4.1 105° Turn point	The pitch attitude is now less than zero and bank angle is constantly being changed toward zero degrees. Reference point is now on opposite side of longitudinal axis.	- bank angle = to 3.2 - 105° of turn - negative pitch attitude =1/3 of highest pitch attitude at 45° turn point	±4° ±4° ±10°
4.2 120° Turn point		-bank angle = to 3.1 - 120° of turn - negative pitch attitude =2/3 of highest pitch attitude at 45°turn point	±4° ±4° ±10°
4.3 135° Turn point	Negative vertical velocity is maximum	- bank angle = 2.3 - 135° of turn - negative pitch attitude = pitch at 45° turn point	±4° ±4° ±10%

TABLE VII (Concluded)

LAZY 8 MANEUVER ANALYSIS

Maneuver Element Element Sub-Part	Purpose: What does the crewman do? Why is it done?	Knowledge and Skill Required	Tolerance (Task criteria) How well -
5.0 180° Turn point	Continue descending turn in same direction. At 130° point descent rate should have started to decrease. This will require some back pressure to arrest movement about lateral axis; and g forces should increase. Student should be aware of bank angle vs amount of turn left to accomplish. Also to be taken into account is that aircraft should not come to level flight (zero vertical velocity) until turn is completed and bank angle is zero.	Sufficient motor skill to reach the following:	
5.1 150° Turn point		-Angle bank = 2.2 -150° Turn -negative pitch attitude = 2.2	±4° bank error ±4° turn error ±10% pitch error
5.2 165° Turn point		-Angle of bank = 2.1 -165° Turn -negative pitch attitude = 2.1	±4° bank error ±4° turn error ±10% pitch error
5.3 180° Turn point		-0° Bank -Heading = to 180° from maneuver start -Airspeed = 200 kts -Pitch attitude	±4° bank error ±4° turn error ±5 kts A/S error ±3° pitch error
5.4 Maneuver Continuance	Start the climbing turn in direction of reference point (Bank will be opposite to first 180° of maneuver).	Direction to turn. Proper back pressure application for bank rate change.	1-2 g's
6.0 135° Turn point	Same as 2	Same as 2	Same as 2
7.0 90° Turn point	Same as 3	Same as 3	Same as 3
8.0 45° Turn point	Same as 4	Same as 4	Same as 4
9.0 Maneuver termination	Same as 5	Same as 5	Same as 5

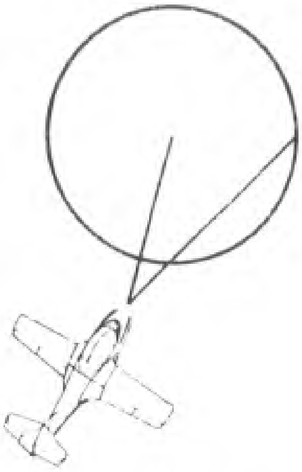


Figure 12a. Maneuver Start

Figure 12b. 90° Roll Point

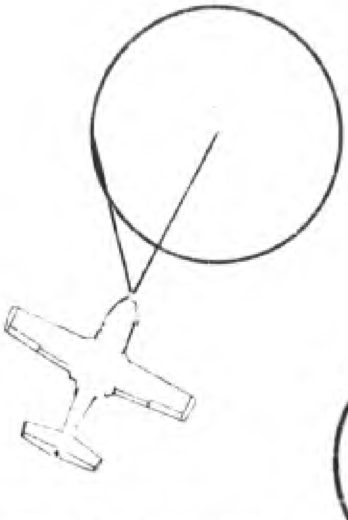


Figure 12c. 180° Roll Point

Figure 12d. 270° Roll Point

Figure 12e. Maneuver End

Figure 12. Barrel Roll Positions

2. First quarter roll (0 - 90° roll)
3. Second quarter roll (90 - 180° roll)
4. Third quarter roll (180 - 270° roll)
5. Fourth quarter roll (270 - 360° roll)

(3) Maneuver Analysis

Clearing the Area. This ensures visually that no other aircraft flight path would be in a position to conflict with maneuver area. It can be accomplished by a 180° turn or two medium (40°) to steep (60°) banked turns in opposite directions of sufficient duration to visually clear the maneuver area.

Selection of Reference Point. The reference point is usually an isolated cloud formation of small size or a section line stretching to horizon. The selected point must be easily identifiable and should contrast enough with surroundings so the student has no difficulty in keeping an eye on it.

Entry to Barrel Roll. After selection of the reference point, the throttles are adjusted to 90%. The nose of the aircraft is then lowered below the reference point to attain an airspeed of 200 to 230 knots. The aircraft is then rolled right or left with the aircraft continuing the descent until 20-30° to one side of the reference point. The wings are then rolled level to simultaneously allow the aircraft nose to come to level flight attitude.

First Quarter of Roll. The student notes his angle off the reference point. This angle alpha (a) is between a line parallel to the longitudinal axis of the aircraft projected forward from the pilot and a line projected to the reference point. This reference point should remain in the same position on the windscreen throughout the maneuver regardless of aircraft attitude. A climbing turn is executed toward the reference point to simultaneously reach 90° of bank when the nose is alpha (a) degrees above the horizon. At this point, the longitudinal axis of the aircraft should be in the vertical plane which passes through the reference point. Constancy of roll rate is the major difficulty in this task segment. Control deflection must be increased to compensate for decreasing airspeed.

Second Quarter of Roll. The aircraft is rolled to an inverted level flight position (180° bank, 0° pitch) to the angle a off the reference point. Although pitch attitude is decreasing, aircraft airspeed is continuing to decrease. Increased aileron deflection is therefore necessary to keep roll rate constant. Back pressure is still necessary during the initial portion of this maneuver segment to turn the aircraft to the proper angle off. As the aircraft approaches 135° of bank, elevator control deflection is now decreased since lift on the wings is being exerted in the same direction as the force of gravity.

Third Quarter of Roll. The roll is continued from wings-level inverted position to 90° of bank and a diving angle equal to angle a. At this 270° of roll point, the longitudinal axis of the aircraft is again in the vertical plane through the reference point. During the roll of 135° of bank, back pressure is nominal because lift is still being generated in a downward direction. As the 135° roll point is reached, back pressure is slowly increased. Aileron deflection from the 180° roll point is decreased as airspeed begins to increase to keep roll rate constant.

Fourth Quarter of Roll. The aircraft is now rolled from 270° bank and diving attitude to the erect position. The reference point should again be equal to angle a. From the 270° bank point, aileron deflection will continue to decrease while back stick pressure will increase to decrease the dive angle. Roll out of bank and back pressure should be coordinated to properly come to level flight and angle a, simultaneously.

(a) Performance Tolerances

Following are estimates of realistic performance tolerances for some of the more relevant variables of this maneuver:

Segment	Variable	Tolerance
1	RPM	90% ±1%
	Entry IAS[2]	200-230 knots
	Minimum Altitude[3]	5000 ft AGL
	Offset of nose from reference point	20° >< 60°
2-5 (4-quarters)	RPM	90% ±1%
	g Force	constant 1 >< 4g
	Angle off (alpha) between nose and reference point	±10%

(b) Significant Performance Factors

Quantitative Factors:

Variable	Range
1. Airspeed	100 to 260 knots
2. Heading	Entry Heading, 20 to 60° off reference point
3. RPM	90% ±1%
4. Degree of Bank	0 - 360°
5. Angle Off (alpha) Error	±10%
6. g Force	$1 \leq g \leq 4$

Qualitative Factors:

1. Smoothness in coordinated control movement
2. Continuity of maneuver

---

[2] It is mandatory that at least 200 knots IAS be attained for entry.

[3] Maneuver will not be started or terminated below 5000 ft.

3. Quickness in discerning and applying the required control movements in various aircraft orientations.

4. Confidence and positiveness in controlling aircraft.

c. Normal Landing

Although detailed analysis in the study was limited to the lazy 8 and barrel roll maneuvers, an analysis of the normal landing was also developed. Some preliminary work requisite to measurement research on the landing task has also been accomplished. The task analysis and preliminary follow-up analysis are documented below.

(1) General Description

A circular approach to the active runway consisting of:

1. An initial approach to the active runway 1000 ft AGL (above ground level)

2. A level 180° turn with simultaneous reduction of airspeed to a downwind position

3. Speed brake, landing gear, and flap lowering

4. A descending 180° turn to align with the active runway

5. A glide path to the touchdown point in the first 1000 ft of the runway.

This analysis assumes the student is in early stages of aircraft checkout through termination of T-37 flying.

Also assumed is that the student is capable of level flight, turning level flight with airspeed changes, and descending turns while maintaining airspeed.

Displacement from runway (ground track) cannot be taken from aircraft instrumentation[4] and would necessarily be a result of instructor verbal input.

(2) Maneuver Elements

Figure 13 illustrates the six maneuver elements of the normal landing.

(3) Maneuver Analysis

Table VIII presents the task analysis of the normal landing as developed by Air Training Command.

(4) Extended Analysis of Normal Landing

By utilizing the maneuver analysis, information in the primary flight manual (Reference 4), and personal knowledge of the normal landing task, we developed an extended analysis of the task. This was accomplished as a first step in (a) properly segmenting the maneuver for measurement purposes and (b) identifying basic ATC criteria as they apply to various segments of the task. The results are presented in Appendix V.

3. THEORETICAL MEASURES

Theoretical measures were developed using maneuver-analysis data for the lazy 8 and barrel roll maneuvers. These measures constituted a "first guess" at an appropriate set of measures and were based solely upon ATC criteria. Their computation was accomplished through the development of appropriate software, which was then used to compute the theoretical measures for a sample of flight test pilot performances. The following paragraphs are devoted to a description of the theoretical measures and the rationale underlying their development, the implementation of software for their computation, and initial tests.

---

[4] Instrumentation, for this study, did not include a means of determining ground track.

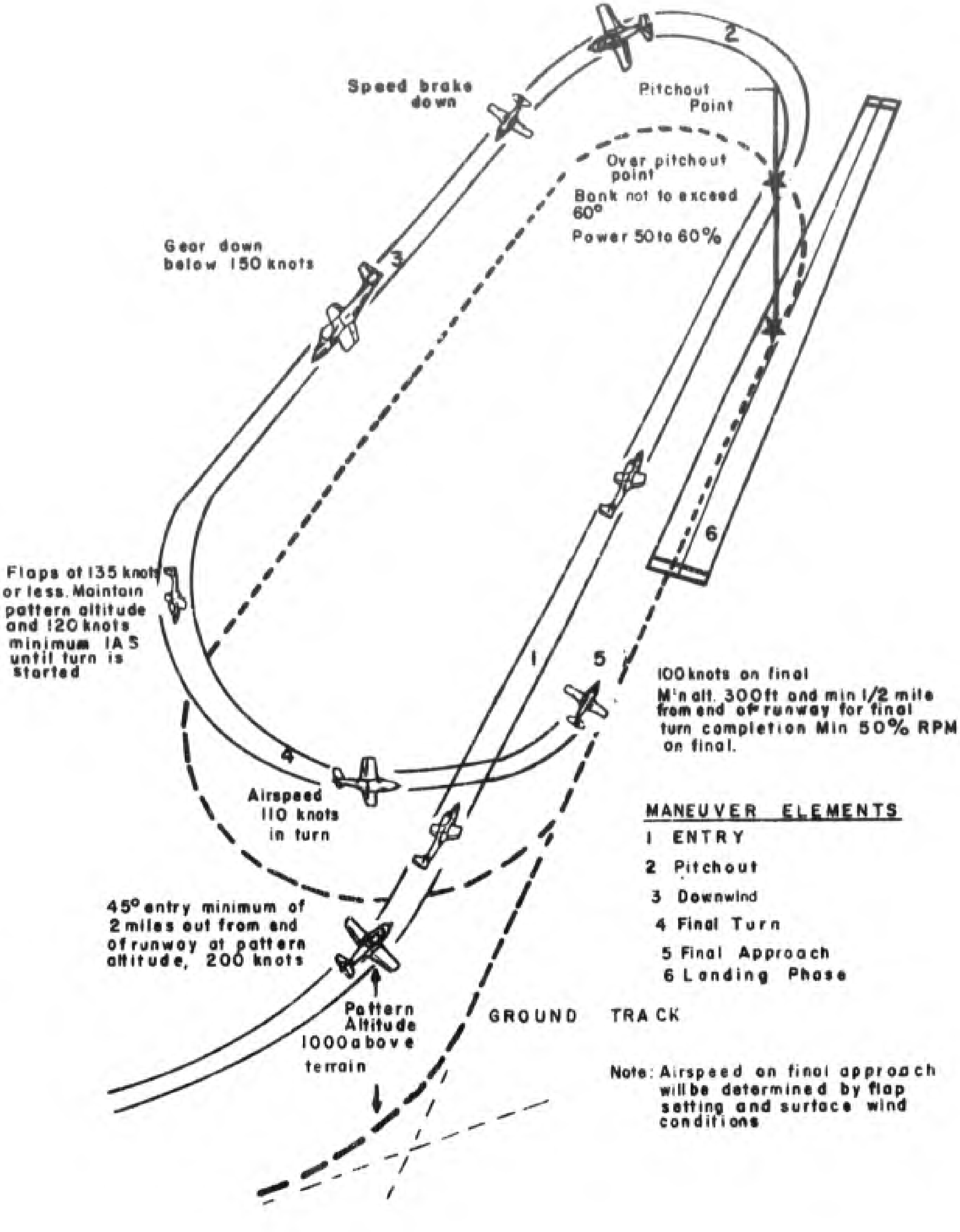


Figure 13. Normal Landing Maneuver Profile

TABLE VIII

NORMAL LANDING MANEUVER ANALYSIS

Maneuver Element Element Sub-Part	Purpose What does the crewman do? Why is it done?	Knowledge and Skill Required	Tolerance (Task criteria) How well -
1.0 Maneuver Entry Initial 1.1 Turn to initial	Aircraft is turned 45° to align with runway.	Maintain level flight in turn, 1000 ft altitude (AGL) 200 kts IAS, 45-60° of bank.	±5 kts IAS ±100 ft altitude 45° >< 60° bank
1.2 Runway alignment	Student rolls out of turn to align with extension of runway center line.	Maintain 1000 ft AGL. Judgment needed to time roll out initiation and termination to coincide with runway extension.	±100 ft altitude
1.3 Drift correction (If necessary)	Turns to and maintains a heading to compensate for crosswinds (if necessary).	Knowledge of air mass drift in relation to ground track. Straight and level flight. 200 kts IAS 1000 ft AGL.	±5 kts IAS ±100 ft altitude
1.4 Pitchout point	Initiates steep bank 180° turn to downwind. Reduces power to 50-60%.	When to pitch - usually 3000 ft from approach end to middle length of runway. Skill to roll into level turn 1000 ft AGL, bank angle 45-60°. Power requirements 50-60%.	±2% RPM ±100 ft altitude 45° >< 60° bank
2.0 Pitchout 2.1 0-90° Turn	Continues bank angle of 45°><60°. Maintain level flight 1000 ft AGL. Ensure throttles adjusted 50-60% RPM.	Skill necessary to maintain constant bank angle, holding altitude despite changing airspeed. Angle of attack will constantly increase.	Bank angle 45°>< 60° ±100 ft altitude
2.2 90° - Rollout	Continue aircraft in turn. Vary bank angle so as to roll out at pre-selected lateral distance from runway.	Skill necessary to maintain level flight 1000 ft AGL. Knowledge of ground track for downwind lateral distance from runway. Judgment when to initiate rollout.	Bank angle < 60° Altitude ±100

TABLE VIII (Contd)

NORMAL LANDING MANEUVER ANALYSIS

Maneuver Element Element Sub-Part	Purpose: What does the crewman do? Why is it done?	Knowledge and Skill Required	Tolerance (Task criteria) How well -
2.3 Rollout Termination	Rollout of turn approximately 1/2 mi laterally from runway.	Skill necessary to maintain 1000 ft AGL despite decreasing airspeed. Judge termination of rollout to hold heading of approximately 180° from landing heading.	Altitude ±100 ft Lateral distance - -0 +1/4 mi
2.4 Drift correction (If necessary)	Establish a heading necessary to hold lateral displacement from runway.	Knowledge of air mass drift problems and corrective action (heading change or crab).	
3.0 Downwind			
3.1 Speed Brake Extension	Maintain level flight 1000 ft AGL and ground track paralleling runway compensating for air mass drift (if present). Speed brake extended to decrease airspeed.	Skill necessary to maintain altitude of 1000 ft AGL despite changing airspeed and trim needs. Knowledge of speed brake extension procedures.	Altitude ±100 ft
3.2 Landing Gear Extension	Gear extended at 150 kts or below. Gear checked. Minimum IAS 120 kts, power adjusted as necessary.	Knowledge of gear lowering procedures, airspeed limitations and gear checks. Checks are: red lite in handle out, three green lites on, handle is down, warning horn has stopped blowing and hydraulic pressure is 1250-1550 psi.	Altitude ±100 ft IAS 120 >< 150 kts
3.3 Flap Extension	Flaps extended prior to initiating final turn. IAS must be 120 >< 135 kts.	Mechanics of flap lowering. Knowledge of when to initiate final turn. This is opposite an imaginary point on the extended runway centerline 1/2 mi. from approach end of runway.	Altitude ±100 ft IAS 120 >< 135 kts Turn point +1/8 mi -0 mi

TABLE VIII (Contd)

NORMAL LANDING MANEUVER ANALYSIS

Maneuver Element Element Sub-Part	Purpose: What does the crewman do? Why is it done?	Knowledge and Skill Required	Tolerance (Task criteria) How well -
3.4 Base Turn to Final Approach	Initiate descending turn toward runway. Bank angles less than 45°. Normal bank angle is 20 - 30°. Vertical velocity of less than 1000 fpm descent. IAS 120 kts.	Skill to roll into bank of less than 45°. Initiation of descent at less than 1000 feet per minute.	IAS 120 >< 135 kts Bank angle 20° >< 45°
4.0 Final Turn 4.1 0-90° of Turn	Descending turn is continued. Rate of descent for this portion of turn should be sufficient to descend approximately 350 ft. Adjust power as necessary to maintain 110 kts. Trim to reduce control pressures. Makes gear check to appropriate control agency.	Skill necessary to maintain bank angle of approximately 20-30°, rate of descent to descend 350 ft in this 90° turn and ability to adjust power to maintain 110 kts. Skill to trim aircraft and knowledge of proper terminology.	Bank 20° >< 45° Altitude ±100 IAS +10 kts -0
4.2 90° to rollout on final	Continues descending turn. Adjusts bank angle up to 45° to align with runway. Rate of descent maintained to roll out a minimum of 300 ft AGL and maximum of 500 ft. Maintains 110 kts. Maintains smooth rate of descent.	Skill necessary to judge bank necessary to rollout on runway centerline without necessity to use maximum bank angle of 45°. Throttle adjustment to maintain 110 kts. Rate of descent continued to rollout at optimum altitude of 300 ft AGL.	Bank 20° >< 45° IAS +10 kts -0
4.3 Rollout on final turn	Rolls out of turn to align with runway. Slows to 100 kts. Retrims aircraft as necessary to reduce control pressures.	Skill necessary to time rollout. Power adjustment to maintain 100 kts. Proper trim procedures.	IAS +10 kts -0 Heading ±10° of runway heading

TTABLE VIII (Contd)

NORMAL LANDING MANEUVER ANALYSIS

Maneuver Element Element Sub-Part	Purpose: What does the crewman do? Why is it done?	Knowledge and Skill Required	Tolerance (Task criteria) How well -
5.0 Final Approach 5.1 Glidepath	Establish pitch attitude to descend at steady rate of descent at 100 kts IAS. RPM adjusted as necessary. RPM must be a minimum of 50% until landing is assured.	Knowledge necessary to visualize proper aim point on runway and skill to fly aircraft in a steady rate of descent toward this aim point. Ability to adjust power to maintain 100 kts.	IAS--0 +10 kts Descent rate < 1000 fpm
5.2 Centerline alignment	Maintain ground track over extended centerline of runway. If crosswind exists, establish wing low method of drift correction. This involves using rudder to keep aircraft longitudinal axis aligned with runway centerline and aileron to hold aircraft over extended runway centerline.	Knowledge of mechanics of drift correct using wing low method and skill to maintain proper ground track.	Lateral displacement - no error Heading ±3°
6.0 Landing Phase 6.1 Roundout	As aircraft approaches runway, angle of attack is slowly increased to slow rate of descent. Power is adjusted to idle. As airspeed decreases below 100 kts, angle of attack must further increase to hold minimum rate of descent prior to touch down. Pitch attitude will be approximately 5°, wings held level, drift correction maintained, if necessary.	Judgment as to when to initiate roundout without leveling off or initiating a climb. Skill to maintain this lesser rate of descent so that aircraft will not stall out too high above runway and result in hard landing. Skill to maintain drift correction if necessary.	IAS 75 >< 100 kts Descent rate < 500 fpm Heading ±3° Lateral displacement - no error

TABLE VIII (Concluded)

NORMAL LANDING MANEUVER ANALYSIS

Maneuver Element Element Sub-Part	Purpose: What does the crewman do? Why is it done?	Knowledge and Skill Required	Tolerance (Task criteria) How well -
6.2 Touchdown	Touchdown is allowed to occur in first 1000 ft of runway at approximately 75-80 kts IAS. Drift correction and pitch of 5° maintained.	Skill to attain and maintain pitch attitude of approximately 5°, touchdown in first 1000 ft and to maintain aircraft on the runway without lateral deviations.	IAS 75-80 kts Descent rate < 200 fpm Heading ±3° Lateral displacement - no error
6.3 Rollout and Turn Off	Aircraft is gradually slowed to allow runway turnoff. Nose is gradually lowered to runway and brakes are applied in slow steady and increase of pressure. Drift correction must still be applied (if necessary) to keep T-37 from weathervaning into wind because of large tail surface and center of gravity. Aileron deflection must be maintained to keep aircraft from slipping sideways.	Skill to lower nose slowly to runway and to maintain control deflection to compensate for crosswind, if present. Skill to manipulate brake pedals at a steady pressure and to slow down at a rate to allow runway turnoff without stopping on runway.	IAS < 75 kts Heading ±3° Lateral displacement - no error

a. Description

(1) Lazy 8

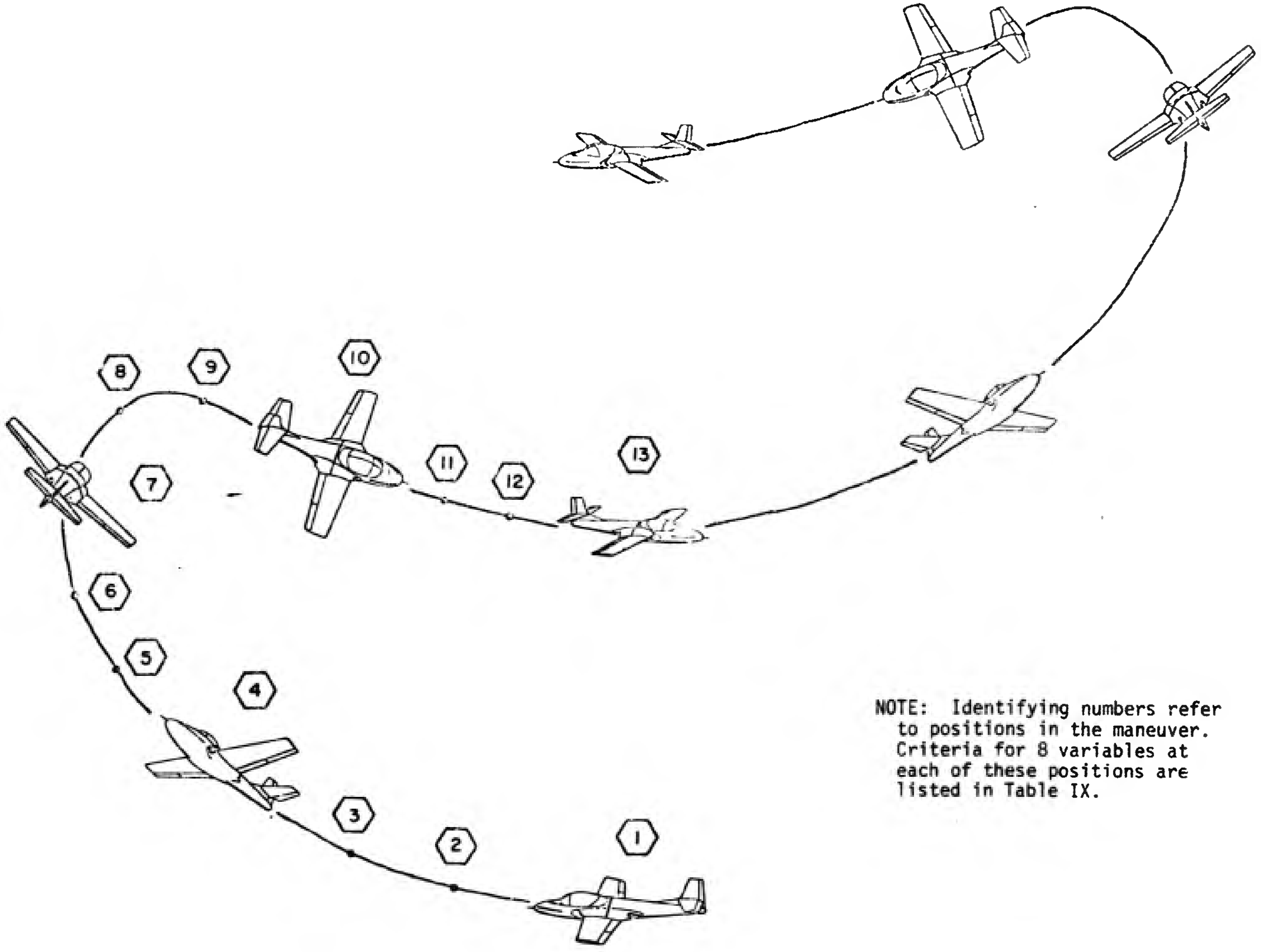
As suggested by ATC, the primary reference variable in this maneuver (for purposes of developing theoretical measures) was aircraft heading. Criteria for most other variables were functions of heading. The criterion for heading itself was computed as a function of the initial heading selected by the pilot upon entering the maneuver.

The lazy 8 is a maneuver consisting of two symmetrical parts. Therefore, criteria and initial measurement methods were developed only for the first half of the maneuver, but were applicable to the second half as well. Theoretically, we may regard the lazy 8 as two successive performances of a "half lazy 8," both done in opposite directions and with smooth transition and no hesitation between performances.

Figure 14 and Table IX together sketch the maneuver and the performance criteria suggested by ATC in their maneuver analysis. This information was used in developing mathematical expressions for the criteria and tolerances for bank, pitch, vertical velocity, airspeed, altitude, g's, and RPM. Then measures were developed based on a comparison of recorded data with criteria and, where applicable, with tolerances.

The following discussion presents, first, the individual theoretical measures (denoted S_i) developed for each aircraft variable. These S_i measures indicate how much the performance differed from ATC criteria, and where applicable, tolerances.

Next, combined theoretical measures are described. These consist of linear combinations of selected S_i measures to provide a single measure for each of several aspects of the performance. One combination measure, for instance, reflects how well the pilot's transition from descent to level flight at the 180° turn point is synchronized with the transition to zero bank angle.



NOTE: Identifying numbers refer to positions in the maneuver. Criteria for 8 variables at each of these positions are listed in Table IX.

Figure 14. Maneuver Diagram for Lazy 8

TABLE IX

PRELIMINARY LAZY 8 PERFORMANCE CRITERIA

	1 *	2	3	4	5	6	7	8	9	10	11	12	13	Tolerance
Bank	0	13-15	27-30	40-45	53-60	67-75	80-90	67-75	53-60	40-45	27-30	13-15	0	±4
Turn	0	15	30	45	60	75	90	105	120	135	150	165	190	±4
Pitch	0	1/3 H [4]	2/3 H	H	2/3 H	1/3 H	0 [2]	-1/3 H	-2/3 H	-H	-2/3 H	-1/3 H	0 [3]	±10%
Vertical Velocity	0	←	R/C ≥	0	→	→	0	←	R/C	≤ 0	→	→	0	±0
Airspeed	200 [1]	←	100 ≤	AS	≤ 200	→	100	←	100	≤ AS	≤ 200	→	200	±5
Altitude	A [5]	←	A ≤	ALT	≤ MAX	→	MAX [6]	←	A	≤ ALT	≤ MAX	→	A	---
g	1-2												1-2	---
RPM	90	90	90	90	90	90	90	90	90	90	90	90	90	±1

[1] Tolerance = ±3

[2] Tolerance = ±5

[3] Tolerance = ±3

[4] H = Maximum pitch attained in maneuver

[5] A = Starting altitude; A ≥ 5000

[6] MAX = Maximum altitude attained in maneuver

*Numbers heading columns 2-13 refer to positions in the maneuver (see Figure 14)

Finally, a "total score" is developed from the combination measures to provide a single indicant of total performance. This is a weighted sum of the combination measures, with the weights consisting of "best guesses" for this theoretical measures development.

(a) Bank Angle

To express mathematically the criteria and tolerances relevant to bank angle, linear relationships have been established between Bank (B) and Turn (T) from the information in Table IX.

When turn is 15°, bank should be 13 - 15°; when turn is 30°, bank should be 27 - 30°, etc. Since it is desirable to have a continuous bank criterion, and not just a check at discrete turn-points, a function relating bank to turn would be preferable. This also simplifies programming (easier to code one function than to do table look-ups and interpolation). The functions:

$$\text{Bank} = \text{Turn or } B = T$$

and

$$\text{Bank} = \frac{8}{9} \text{ Turn or } B = \frac{8}{9} T$$

approximately represent the upper and lower bounds for bank angle for all points of turn from 0 to 90°. Therefore, the criterion for this region is:

$$\frac{8}{9} T \leq B \leq T$$

The tolerance for bank, as provided in Table IX, is ±4°. Therefore $(T + 4)$ and $(\frac{8}{9} T - 4)$ represent the upper and lower tolerances. Similar analysis was performed for 90 to 180° turn region and the following mathematical expressions for criteria and tolerances were derived:

For $0° \leq T \leq 90°$:

$$\frac{8}{9} T - 4 \leq \left\{ \frac{8}{9} T \leq B \leq T \right\} \leq T + 4 \qquad (1)$$

For 90° < T ≤ 180°:

$$\frac{8}{9}\ (175.5 - T)\ \leq\ \left\{\frac{8}{9}\ (180 - T)\ \leq B\ \leq 180 - T\right\}\ \leq 184 - T \qquad (2)$$

where T = the degrees of turn made (i.e., degrees of heading-change) and B = the angle of bank.

In inequalities (1) and (2) above, the most extreme quantities represent tolerance limits, while the criteria themselves are represented by the portions of the inequalities within brackets.

The measures desired for bank angle should reflect (1) whether or not, and to what extent, the basic criteria are satisified, and (2) whether or not, and to what extent, the tolerances are exceeded. Separate measures are desired for each of these considerations, because different weights may be required in performance evaluations depending upon whether criteria are not satisfied, but tolerances are; or whether neither is satisfied.

Let[5]

$$M_i = \begin{cases} B_i - T_i\ , & T_i \leq 90\ , \text{ AND } B_i > T_i \\ \frac{8}{9} T_i - B_i\ , & T_i \leq 90\ , \text{ AND } B_i < \frac{8}{9} T_i \\ B_i - 180 + T_i\ , & T_i > 90, \text{ AND } B_i > 180 - T_i \\ \frac{8}{9}(180 - T_i) - B_i\ , & T_i > 90\ , \text{ AND } B_i < \frac{8}{9}(180 - T_i) \\ 0\ , & \text{otherwise} \end{cases}$$

where the subscript i refers to the value of the variable at the ith sampling instant.

---

[5] $x = \begin{cases} Y, & L \\ Z, & K \end{cases}$ is interpreted as follows: X = Y if L is true and X = Z if K is true.

Let

$$N_i = \begin{cases} B_i - T_i - 4\ , & T_i \leq 90,\ \text{AND}\ B_i > T_i + 4 \\ \frac{8}{9} T_i - 4 - B_i\ , & T_i \leq 90,\ \text{AND}\ B_i < \frac{8}{9} T_i - 4 \\ B_i - 184 + T_i\ , & T_i > 90,\ \text{AND}\ B_i > 184 - T_i \\ \frac{8}{9} (175.5 - T_i) - B_i\ , & T_i > 90,\ \text{AND}\ B_i < \frac{8}{9} (175.5 - T_i) \\ 0\ , & \text{otherwise} \end{cases}$$

The values M_i and N_i respectively provide the amount by which criteria are exceeded and the amount by which tolerances are exceeded. Integrating each of these, we obtain:

$$S_1 = \int_0^T M_i \, dT$$

$$S_2 = \int_0^T N_i \, dT$$

S_1 is an integrated error measure showing the extent to which bank criteria are exceeded; S_2, similarly, shows the extent to which bank tolerances are exceeded.

(b) Pitch Angle

The required pitch angle has been established by ATC as a function of the maximum pitch angle attained in the maneuver (Table IX). Call this maximum pitch angle H. As indicated in Table IX, pitch should reach its maximum (H) at the 45° turn point, should then decrease to zero by the 90° turn point, should reach its negative maximum (-H) at the 135° turn point, and should then return to zero again at the 180° turn point. The change in pitch should be a linear function of the degree of turn.

The following criterion inequalities were computed from the information in Table IX. As in the case of bank angle, the portions of the inequalities within brackets represents the basic criteria, whereas the portions outside the brackets represent tolerances.

Let P = Pitch Angle

and T = Degrees of Turn:

For $0^\circ \leq T \leq 45^\circ$:

$$\frac{0.9HT}{45} \leq \left\{ \frac{HT}{45} = P \right\} \leq \frac{1.1HT}{45}$$

For $45^\circ < T \leq 90^\circ$:

$$\frac{0.9H(90-T)}{45} \leq \left\{ \frac{H(90-T)}{45} = P \right\} \leq \frac{1.1H(90-T)}{45}$$

For $90^\circ < T \leq 135^\circ$:

$$\frac{1.1H(90-T)}{45} \leq \left\{ \frac{H(90-T)}{45} = P \right\} \leq \frac{0.9H(90-T)}{45}$$

For $135^\circ < T \leq 180^\circ$:

$$\frac{1.1H(T-180)}{45} \leq \left\{ \frac{H(T-180)}{45} = P \right\} \leq \frac{0.9H(T-180)}{45}$$

The performance measures desired should reflect the deviation from the criteria plus any deviation outside the tolerance limits.

Let

$$
{}^{1}M_{i} = \begin{cases}
\left| P - \dfrac{HT}{45} \right|, & T \leq 45 \text{ AND } \\
& \dfrac{0.9HT}{45} \leq P \leq \dfrac{1.1HT}{45} \\[2ex]
\left| P - \dfrac{H(90-T)}{45} \right|, & 45 < T \leq 90 \text{ AND } \\
& 0.9H + \dfrac{(T-45)(5+0.9H)}{-45} \leq P \leq 1.1H + \dfrac{(T-45)(5-1.1H)}{45} \\[2ex]
\left| P - \dfrac{H(90-T)}{45} \right|, & 90 < T \leq 135 \text{ AND } \\
& \dfrac{(T-90)(0.9H+5)}{45} - 5 \leq P \leq \dfrac{(T-90)(1.1H-5)}{45} + 5 \\[2ex]
\left| P - \dfrac{H(T-180)}{45} \right|, & T > 135 \text{ AND } \\
& \dfrac{(T-135)(3+0.9H)}{-45} + 0.9H \leq P \leq \dfrac{(T-135)(3-1.1H)}{45} + 1.1H
\end{cases}
$$

For each sampling instant, i, the ${}^{1}M_{i}$ above reflects the absolute value of the difference between the actual and criterion pitch angles whenever tolerances are not exceeded.

Let

$$
{}'N_i = \begin{cases}
P - \dfrac{1.1HT}{45}, & T \leq 45 \text{ AND } P > \dfrac{1.1HT}{45} \\[2ex]
\dfrac{0.9HT}{45} - P, & T \leq 45 \text{ AND } P < \dfrac{0.9HT}{45} \\[2ex]
P - \dfrac{1.1H(90-T)}{45}, & 45 < T \leq 90 \text{ AND } \\
 & P > \dfrac{1.1H(90-T)}{45} \\[2ex]
\dfrac{0.9H(90-T)}{45} - P, & 45 < T \leq 90 \text{ AND } \\
 & P < \dfrac{0.9H(90-T)}{45} \\[2ex]
P - \dfrac{1.1H(90-T)}{45}, & 90 < T \leq 135 \text{ AND } \\
 & P > \dfrac{1.1H(90-T)}{45}
\end{cases}
$$

and

$$
{}^{\prime}N_i = \begin{cases}
\dfrac{0.9H(90-T)}{45} - P, & 90 < T \le 135 \text{ AND } P < \dfrac{0.9H(90-T)}{45} \\[2ex]
P - \dfrac{1.1H(T-180)}{45}, & T > 135 \text{ AND } P > \dfrac{1.1H(T-180)}{45} \\[2ex]
\dfrac{0.9H(T-180)}{45} - P, & T > 135 \text{ AND } P < \dfrac{0.9H(T-180)}{45}
\end{cases}
$$

For each sampling instant, i, the ${}^{1}N_i$ above reflects the amount by which tolerances are exceeded. Integrating, we obtain the following measures:

$$S_3 = \int_0^T {}^{\prime}M_i \, dT$$

$$S_4 = \int_0^T {}^{\prime}N_i \, dT.$$

S_3 and S_4 are integrated error measures showing the extent to which pitch criteria and tolerances, respectively, are exceeded.

(c) Vertical Velocity

Based on the information in Table IX, vertical velocity (V/V) should be zero at the 0°, 90°, and 180° turn points. Further, V/V should be positive from T = 0° to T = 90° and negative from T = 90° to T = 180°. There is no tolerance for error.

Let R_1 = V/V when turn = 0°

R_2 = V/V when turn = 90°

R_3 = V/V when turn = 180°

Then one measure may be computed as:

$$S_5 = |R_1| + |R_2| + |R_3|$$

This gives us the sum of absolute vertical velocity errors at the 0°, 90°, and 180° turn points.

Let

$$R_1 = \begin{cases} |V/V|, 0 \leq T \leq 90 \text{ AND } V/V < 0 \\ V/V, 90 < T \leq 180 \text{ AND } V/V > 0 \\ 0, \text{otherwise} \end{cases}$$

Then

$$S_6 = \int_0^T R_1 \, dT / \text{TIME}$$

Where time is number of seconds for that half of the maneuver.

This gives the integral error on the V/V direction from T = 0° to T = 180°.

One other aspect of V/V needs to be checked. The V/V should become zero at the 180° turn point at the same time that the angle of bank becomes zero. Neither should occur before the other.

Let T_1 = the time at which V/V first becomes zero when 135° $\leq T \leq$ 180° and T_2 = the time at which bank first becomes zero when 135° $\leq T \leq$ 180°. If either V/V or bank does not become zero within the period designated, set T_i (i = 1 or 2) to 0.

Compute

$$S_7 = \begin{cases} |T_1 - T_2| , & T_1 \neq 0 \text{ AND } T_2 \neq 0 \\ -1 , & T_1 = 0 \text{ OR } T_2 = 0 \end{cases}$$

S_7 tells us the elapsed time, in seconds, between points where V/V and bank become zero. If S_7 is -1, this means the quantity was unmeasurable.

(d) Airspeed

Airspeed should be 200 knots on entry, i.e., at the 0° turn point, with a tolerance of ±3 knots. At the 90° and 180° turn points, airspeed should be 100 and 200 knots respectively, with a tolerance of ±5 knots. At all other points in the maneuver, airspeed must be more than 100 knots, and less than 200 knots.

Let

$$MM_1 = \begin{cases} A - 200 , & A > 200 \text{ AND } 2 \leq T \leq 178 \\ 100 - A , & A < 100 \text{ AND } 2 \leq T \leq 178 \\ 0 , & \text{otherwise} \end{cases}$$

where A = airspeed in knots.

Then compute

$$S_8 = \int_0^T MM_1 \, dT$$

S_8 is an integrated error measure showing how much the airspeed criteria are exceeded from 2 to 178° of turn. It checks for deviation below 100 knots or above 200 knots.

To check airspeed at the 0, 90, and 180° turn points, we will compute:

$$S_9 = |A_0 - 200|$$

$$S_{10} = |A_{90} - 100|$$

$$S_{11} = |A_{180} - 200|$$

where A_K = airspeed at T = K.

(e) Altitude

The main requirement on altitude is that the maximum altitude attained in the maneuver (ALT_{MAX}) should occur at the 90° turn point. We can further hypothesize that altitude should be the same at the 0° turn point as it is at the 180° turn point and the same at the 90° turn point as it is at the 270° turn point, because this is a symmetrical maneuver. Further, altitude should be monotonically increasing from T = 0° to T = 90° and monotonically decreasing from T = 90° to T = 180°.

First, a measure is needed to check that the maximum altitude is attained at the 90° turn point. Also, if ALT_{MAX} is not attained at the 90° turn point, we should record (1) where ALT_{MAX} is attained and (2) how much ALT_{MAX} differs from the altitude attained at 90°. In monitoring altitude it will be necessary to check the entire maneuver from start to completion rather than to check one half independent of the other half.

Let AA_1 = maximum altitude obtained from T = 0° to T = 360°.

Let ALT_K = Altitude obtained at T = K°

TT_1 = Degrees of turn when AA_1 occurs.

Compute

$S_{12} = | ALT_{180} - ALT_0 |$ How much does altitude at turn = 180° differ from starting altitude?

$S_{13} = | ALT_{360} - ALT_0 |$ How much does altitude at turn = 360° differ from starting altitude?

$S_{14} = | ALT_{90} - ALT_{270} |$ How much does altitude at turn = 90° differ from altitude at turn = 270°?

$S_{15} = | AA_1 - ALT_{90} |$ How much does MAX altitude differ from altitude at turn = 90°?

$S_{16} = | TT_1 - 90 |$ How far off was the pilot from 90° when MAX altitude occurred?

(f) Acceleration (g Force)

The main requirement on g force is that it be between 1 and 2 g's at the start (T = 0) and end (T = 360) of the maneuver.

Let

$$G_k = \begin{cases} G - 2, & G > 2 \text{ at } T = K \\ 1 - G, & G < 1 \text{ at } T = K \\ 0, & \text{otherwise at } T = K \end{cases}$$

Then compute

$$S_{17} = G_0$$

$$S_{18} = G_{360}$$

This gives us absolute deviations outside criteria for g's at the start and end of the maneuver.

(g) RPM

RPM must be 90% throughout the maneuver. A tolerance of ±1% is specified.

Let

$$AM_i = \begin{cases} RPM_i - 92, & RPM_i > 92 \\ 88 - RPM_i, & RPM_i < 88 \\ 0, & \text{otherwise} \end{cases}$$

Compute

$$S_{19} = \int_0^T AM_i \, dT$$

S_{19} is an integrated error measure showing how much the RPM tolerances were exceeded over the maneuver.

Table X presents a summary of the above measures S_1 - S_{19} (See Table XI for a definition of terms used in the summary table).

Figure 15 is a maneuver diagram for the lazy 8 showing which portions of the maneuver are checked by each experimental performance measure. Continuous measures, as depicted in Figure 15, are ones which monitor one or more performance variables continuously for a discrete time interval. Discrete measures monitor certain performance variables at selected discrete points in the maneuver.

(h) Combined Theoretical Measures

For experimental purposes, the following scaled measures and combinations thereof were computed and printed, in addition to the individual S_i measures. The assigned weights are based on the authors' judgment as to measure-criticality. The scaling is based on the expected ranges in Table X and is designed to produce combined measures that range from 0 to 100 to standardize the measures. For example, S_1 and S_2 are the individual theoretical measures pertaining to degree of bank. Their expected ranges are, for each, 0 to 3000 (See Table X).

TABLE X

SUMMARY OF PERFORMANCE MEASURES FOR LAZY 8

No.	Variable	Measure	Expected Range	Beg.[1] Cue	End[1] Cue	Pass[2] Count
1	Bank; Turn	$\int_o^T M_i \, dt$	0 - 3000	0	180	1
2	Bank; Turn	$\int_o^T N_i \, dt$	0 - 3000	0	180	1
3	Pitch; Turn	$\int_o^T {}'M_i \, dt$	0 - 3000	0	180	2
4	Pitch; Turn	$\int_o^T {}'N_i \, dt$	0 - 3000	0	180	2
5	Vertical Velocity	$\lvert R_1 \rvert + \lvert R_2 \rvert + \lvert R_3 \rvert$	0 - 1500	0	180	1
6	Vertical Velocity	$\int_o^T R_i \, dt$	0 - 7000	0	180	1
7	Vertical Velocity; Bank	$\left\{ \begin{array}{l} \lvert T_1 - T_2 \rvert, \; T_1 \neq 0, \text{ and } T_2 \neq 0 \\ -1, \text{ otherwise} \end{array} \right\}$	(-1) - 17	135	180	1
8	Airspeed	$\int_o^T MM_i \, dt$	0 - 120	2	178	1
9	Airspeed	$\lvert A_o - 200 \rvert$	0 - 50	0	0	1
10	Airspeed	$\lvert A_{90} - 100 \rvert$	0 - 50	90	90	1

[1] Beginning and end cues are expressed in terms of degrees of turn

[2] Estimated number of data passes required in computing the measure

TABLE X (Concluded)

SUMMARY OF PERFORMANCE MEASURES FOR LAZY 8

No.	Variable	Measure	Expected Range	Beg.[1] Cue	End[1] Cue	Pass[2] Count
11	Airspeed	$\lvert A_{180} - 200 \rvert$	0 - 70	180	180	1
12	Altitude	$\lvert ALT_{180} - ALT_{0} \rvert$	0 - 1200	0	180	1
13	Altitude	$\lvert ALT_{360} - ALT_{0} \rvert$	0 - 1200	0	360	1
14	Altitude	$\lvert ALT_{90} - ALT_{270} \rvert$	0 - 1200	90	270	1
15	Altitude	$\lvert AA_{1} - ALT_{90} \rvert$	0 - 1200	0	360	1
16	Altitude	$\lvert TT_{1} - 90 \rvert$	0 - 270	0	360	1
17	g Force	G_{o}	0 - 9	0	0	1
18	g Force	G_{360}	0 - 9	360	360	1
19	RPM	$\int_{o}^{T} AM_{i}$	0 - 190	0	180	1

TABLE XI

DEFINITIONS OF TERMS USED IN TABLE X

T = degree of turn since start of maneuver

B = angle of bank

M_i = amount by which bank-angle criteria are exceeded

N_i = amount by which bank-angle tolerances are exceeded

${}^1M_i$ = absolute value of the difference between actual and criterion pitch angles

${}^1N_i$ = amount by which pitch angle tolerances are exceeded

R_1 = V/V when $T = 0°$

R_2 = V/V when $T = 90°$

R_3 = V/V when $T = 180°$

R_i = error in direction of Vertical Velocity

T_1 = time when V/V becomes zero at $135° \leq T \leq 180°$

T_2 = time when bank becomes zero at $135° \leq T \leq 180°$

A = airspeed

MM_i = absolute value of airspeed error at $2° \leq T \leq 178°$

A_K = airspeed at $T = K$

AA_1 = maximum altitude obtained at $0 \leq T \leq 360°$

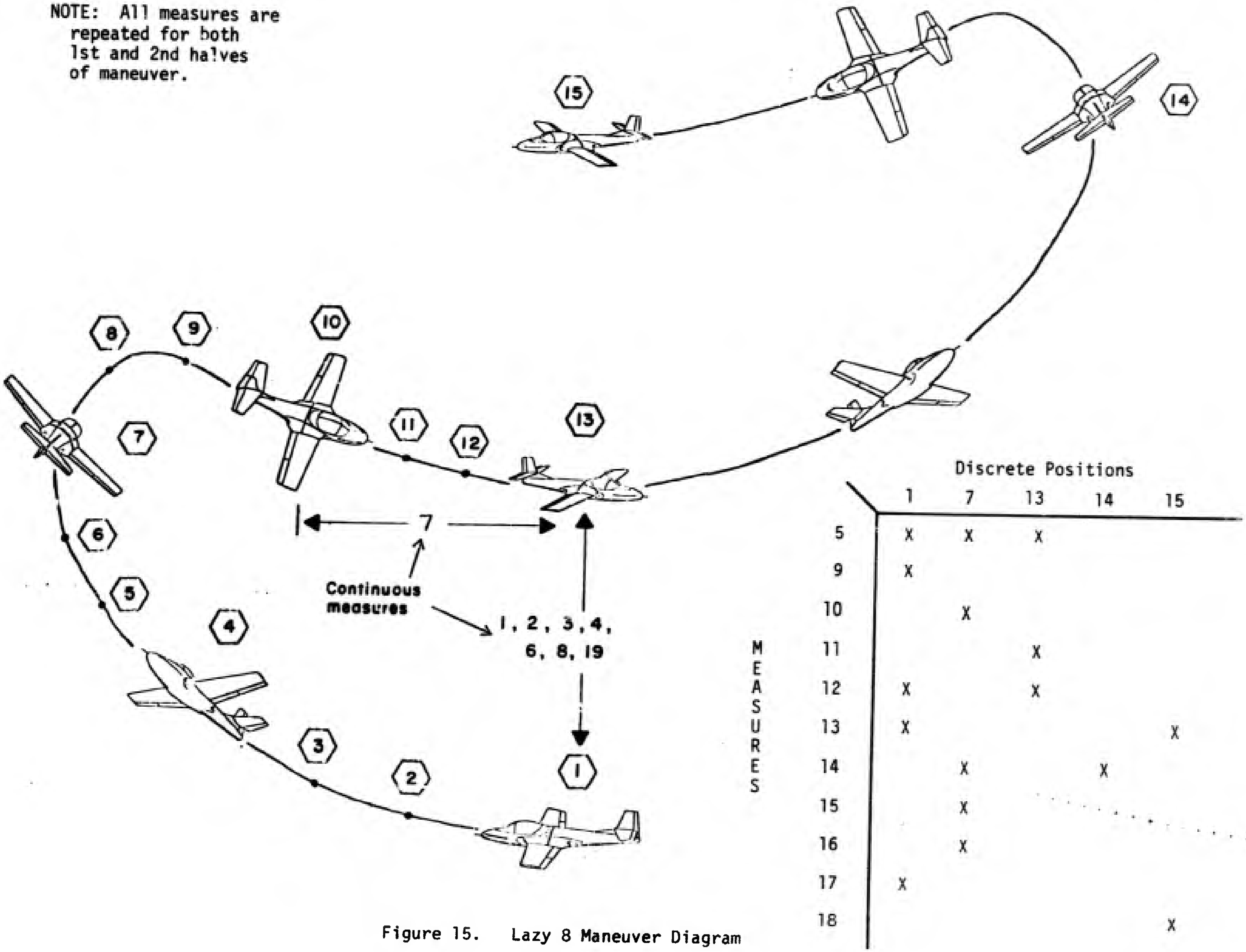
TT_1 = turn when AA_1 occurs

ALT_K = altitude at $T = K$

G_K = absolute value of g force at $T = K$

AM_i = RPM error at ith sampling instant

NOTE: All measures are repeated for both 1st and 2nd halves of maneuver.



MEASURES	Discrete Positions 1	7	13	14	15
5	X	X	X		
9	X				
10		X			
11			X		
12	X		X		
13	X				X
14		X		X	
15		X			
16		X			
17	X				
18					X

Figure 15. Lazy 8 Maneuver Diagram

The weights assigned to them are 1 for S_1 (which tells how much criteria are exceeded) and 3 for S_2 (which tells how much tolerances are exceeded). Therefore $S_1 + 3S_2$ is a linear weighted combination of S_1 and S_2. Since both are expected to range from 0 to 3000, $(S_1 + 3S_2)$ could range from 0 to 12,000. By dividing $S_1 + 3S_2$ by 120, the range would be from 0 to 100; e.g.,

$$0 \leq \frac{S_1 + 3S_2}{120} \leq 100$$

Since this is an error-measure (the higher the value the worse, theoretically at least, the performance), we can convert it to a score by substracting it from 100; e.g.,

$$0 \leq 100 - \frac{S_1 + 3S_2}{120} \leq 100$$

The combined theoretical measures, each derived as explained above, are presented below for each of several measurable characteristics of performance. They are referred to as "scores" because of the scaling applied, but essentially they are measures of performance computed by combining various individual theoretical measures.

Degree-of-Bank Score (DBS). Measure of how well the pilot's bank angle compares with ATC criteria as a function of degrees of turn. (Separate measure for each half of maneuver.)

$$DBS = 100 - \frac{S_1 + 3S_2}{120}$$

Pitch Angle Score (PAS). Measure of how well the pilot's pitch angle compares with ATC criteria as a function of degrees of turn. (Separate measures for each half of maneuver.)

$$PAS = 100 - \frac{S_3 + 3S_4}{120}$$

The weights assigned to them are 1 for S_1 (which tells how much criteria are exceeded) and 3 for S_2 (which tells how much tolerances are exceeded). Therefore $S_1 + 3S_2$ is a linear weighted combination of S_1 and S_2. Since both are expected to range from 0 to 3000, $(S_1 + 3S_2)$ could range from 0 to 12,000. By dividing $S_1 + 3S_2$ by 120, the range would be from 0 to 100; e.g.,

$$0 \leq \frac{S_1 + 3S_2}{120} \leq 100$$

Since this is an error-measure (the higher the value the worse, theoretically at least, the performance), we can convert it to a score by substracting it from 100; e.g.,

$$0 \leq 100 - \frac{S_1 + 3S_2}{120} \leq 100$$

The combined theoretical measures, each derived as explained above, are presented below for each of several measurable characteristics of performance. They are referred to as "scores" because of the scaling applied, but essentially they are measures of performance computed by combining various individual theoretical measures.

Degree-of-Bank Score (DBS). Measure of how well the pilot's bank angle compares with ATC criteria as a function of degrees of turn. (Separate measure for each half of maneuver.)

$$DBS = 100 - \frac{S_1 + 3S_2}{120}$$

Pitch Angle Score (PAS). Measure of how well the pilot's pitch angle compares with ATC criteria as a function of degrees of turn. (Separate measures for each half of maneuver.)

$$PAS = 100 - \frac{S_3 + 3S_4}{120}$$

Vertical Velocity Score 1 (VVS1). Measure of how well the pilot's transitions from climb to descent, and the reverse, are synchronized with the 0, 90, and 180° turn points. (Separate measures for each half of maneuver.)

$$VVS1 = 100 - \frac{S_5 + 3S_6}{225}$$

Vertical Velocity Score 2 (VVS2). Measure of how well the pilot's transition from descent to level flight (momentarily) at the 180° turn point is synchronized with his transition to a zero bank angle. (Separate measures for each half of maneuver.)

$$VVS2 = 100 - 5.8\ S_7$$

Airspeed Score (ASS). Measure of how well the pilot's airspeed at the 0, 90, and 180° turn points compares with ATC criteria, and how well his airspeed throughout the maneuver remains within the bounds specified by ATC. (Separate measures for each half of maneuver.)

$$ASS = 100 - \frac{S_8 + 4(S_9 + S_{10} + S_{11})}{8}$$

Altitude Score 1 (AS1). Measure of the symmetry of the pilot's performance of the maneuver as judged by comparing his altitudes at the 0 and 180° turn points, the 0 and 360° turn points, and the 90 and 270° turn points. (One measure for entire maneuver.)

$$AS1 = 100 - \frac{S_{12} + S_{13} + S_{14}}{36}$$

Altitude Score 2 (AS2). Measure comparing the maximum altitude in the entire maneuver with the altitude attained at the 90° turn point; and comparing the degrees of turn achieved when the highest altitude was attained with 90°. (Separate measures for each half of maneuver.)

$$AS2 = 100 - \frac{S_{15} + S_{16}}{14.7}$$

g force Score (GFS). Measure of how well pilot's g force at start and end of maneuver remained within bounds specified by ATC. (One measure for entire maneuver.)

$$GFS = 100 - 5.5\ (S_{17} + S_{18})$$

RPM Score (RPMS). Measure of how well pilot maintains the required RPM on both engines throughout the maneuver. (Separate measures for each half of maneuver.)

$$RPMS = 100 - 0.53\ S_{19}$$

Total Score. Measure how well all of the criteria are satisfied.

$$SCORE = \frac{1}{TOT^*}\Big[7\big((DBS) + (PAS)\big) + 6(AS1) + 5(AS2) + 4(VVS1 + VVS2^*) + 3(ASS) + 2(RPMS) + GFS\Big](100)$$

$$\text{where} \quad VVS2^* = \begin{cases} VVS2, & VVS2 \le 100 \\ 0, & VVS2 > 100 \end{cases}$$

$$\text{and} \quad TOT^* = \begin{cases} 3900, & VVS2 \le 100 \\ 3500, & VVS2 > 100 \end{cases}$$

Miscellaneous Data

1. Time to complete maneuver
2. Maximum and minimum pitch angles in each half of maneuver
3. Maximum altitude and corresponding T
4. Number of data samples in each half of maneuver
5. Number of inflections in the roll and pitch curves
6. The S_i measures averages over the entire maneuver.

Let H_1 = the pilot's initial heading

H_2 = the heading attained during the maneuver which differs most, in absolute value, from H_1

and P_1 = the pilot's largest positive pitch angle.

It is hypothesized that in the perfect maneuver, a plot of heading versus pitch angle, suitably scaled, should result in a perfect circle. What we do not know about this criterion circle is its size, although we know it must pass through the point $(H_1, 0)$, i.e., the starting position for heading and pitch angle.

To construct a projected criterion circle, we may use the starting position and one other position. For one criterion circle, we select H_1 and H_2. This assumes that the pilot's heading is correct at (1) the start of the maneuver and (2) the end of the second quarter of the maneuver. The criterion circle would thus have its center heading at

$$C_1 = \frac{1}{2}\left(\left[H_1 + H_2\right] \text{ MOD } 360\right)$$

and would have a radius of

$$R_1 = \begin{cases} \left|H_1 - C_1\right| , & \left|H_1 - C_1\right| \leq 180 \\ \left|360 - H_1 + C_1\right| , & \left|H_1 - C_1\right| > 180 \end{cases}$$

Let X_i = sampled heading at T = i

Y_i = sampled pitch angle at T = i

Then the criterion circle is

$$(X_i - C_1)^2 + Y_i^2 = R_1^2 \qquad (3)$$

Now, to construct a second (alternative) projected criterion circle, we may use the starting position, H_1, and the pilot's largest positive pitch angle, P_1. This assumes that (1) the pilot's heading is correct at the start of the maneuver, and (2) the pilot's pitch is correct at the end of the first quarter of the maneuver.

This criterion circle would have its center heading at $C_2 = B$, where B is the heading held when P_1 is recorded. The radius of the circle would be $R_2 = P_1$.

Then the second criterion circle is

$$(X_1 - C_2)^2 + Y_1^2 = R_2^2 \tag{4}$$

The measure we want is the variance of the actual flight path from each of the alternative criterion circles:

$$S_1 = \int_0^T \left| R_1^2 - \left(X_1 - C_1 \right)^2 - Y_1^2 \right| dT \tag{5}$$

$$S_2 = \int_0^T \left| R_2^2 - \left(X_1 - C_2 \right)^2 - Y_1^2 \right| dT \tag{6}$$

Attitude Measure B. This attitude measure checks the symmetry of the performed maneuver. First we define the following:

H_1 = initial heading

H_2 = heading when bank first becomes 90°

H_3 = heading when bank becomes 180°

H_4 = heading when bank becomes 270°

H_5 = heading when bank returns to 0°

P_1 = initial pitch angle

P_2 = pitch angle when bank becomes 90°

P_3 = pitch angle when bank becomes 180°

P_4 = pitch angle when bank becomes 270°

P_5 = pitch angle when bank returns to 0°

For perfect symmetry in the maneuver, the following should hold:

1. $|H_1 - H_2| \text{ MOD } 360 = |H_3 - H_2| \text{ MOD } 360$
2. $H_1 = H_5$
3. $H_2 = H_4$
4. $P_1 = P_3 = P_5 = 0$
5. $|P_2| = |P_4|$
6. $20° \leq |H_2 - H_1| \text{ MOD } 360 \leq 30°$
7. $P_2 > P_1 \vee P_3 \vee P_4 \vee P_5$
8. $P_4 < P_1 \vee P_2 \vee P_3 \vee P_5$
9. ALT when H_1 is obtained = ALT when H_3 is attained
10. $|\text{ALT when } H_1 \text{ is obtained} - \text{MAX ALT}|$
    $= |\text{ALT when } H_1 \text{ is obtained} - \text{MIN ALT}|$

The specific measures to be taken to reflect the degree to which the above criteria are met are given below:

1. $S_3 = \big|\, |H_1 - H_2| \text{ MOD } 360 - |H_3 - H_2| \text{ MOD } 360 \,\big|$
   (Checks heading symmetry for half of maneuver.)
2. $S_4 = |H_1 - H_5| \text{ MOD } 360$
   (Checks heading equality at start and end of maneuver.)
3. $S_5 = |H_2 - H_4| \text{ MOD } 360$
   (Checks heading symmetry at 90° and 270° Roll points.)
4. $S_6 = |P_1| + |P_3| + |P_5|$
   (Checks that Pitch = 0 when it should.)
5. $S_7 = \big|\, |P_2| - |P_4| \,\big|$
   (Checks for pitch symmetry.)
6. $$S_8 = \begin{cases} 0, & 20° \leq |H_2 - H_1| \text{ MOD } 360 \leq 30° \\ \big|\, |H_2 - H_1| \text{ MOD } 360 - 20 \,\big|, & |H_2 - H_1| \text{ MOD } 360 < 20° \\ \big|\, |H_2 - H_1| \text{ MOD } 360 - 30 \,\big|, & |H_2 - H_1| \text{ MOD } 360 > 30° \end{cases}$$

(Checks that reference point is initially 20 to 30° off the longitudinal axis of the aircraft.)

7. $S_9 = \left| \text{MAX } (P_i) - P_2 \right|$ $(i = 1, 3, 4, 5 \text{ if MAX} > P_2\text{; else } 0)$

(Checks that MAX Pitch is achieved at Roll = 90°.)

8. $S_{10} = \left| P_4 - \text{MIN } P_i \right|$ $(i = 1, 2, 3, 5 \text{ if MIN} < P_4\text{; else } 0)$

(Checks that MIN Pitch is achieved at Roll = 270°.)

9. $S_{11} = \left| ALT_a - ALT_b \right|$ where $ALT_a = ALT$ at H_1

and $ALT_b = ALT$ at H_5

(Checks for altitude symmetry.)

10. $S_{12} = \left| \left| ALT_a - ALT_x \right| - \left| ALT_a - ALT_n \right| \right|$

where ALT_x = MAX ALT

and ALT_n = MIN ALT

(Check for altitude symmetry.)

Attitude Measure C. This attitude measure involves computing a projected criterion flight path based upon a type of "best fit" of a correctly shaped flight path to the observed flight path. The major assumption is that the starting point for the maneuver is accurate. This is reasonable, since the pilot selects his own starting point in relation to his reference point, or vice versa. Surely, the true criterion flight path is a circle passing through the starting point H_1. Furthermore, a diameter of the circle passes through H_1 and is parallel to the earth. Figure 16 illustrates some of the possible criterion flight paths based on this information alone. The idea here is to compute a single criterion flight path, and the method selected for so doing is to minimize the integral error between the observed fligh path and the criterion. Figure 17 illustrates several hypothetical observed flight paths and the approximate criterion flight path that would be computed in each case.

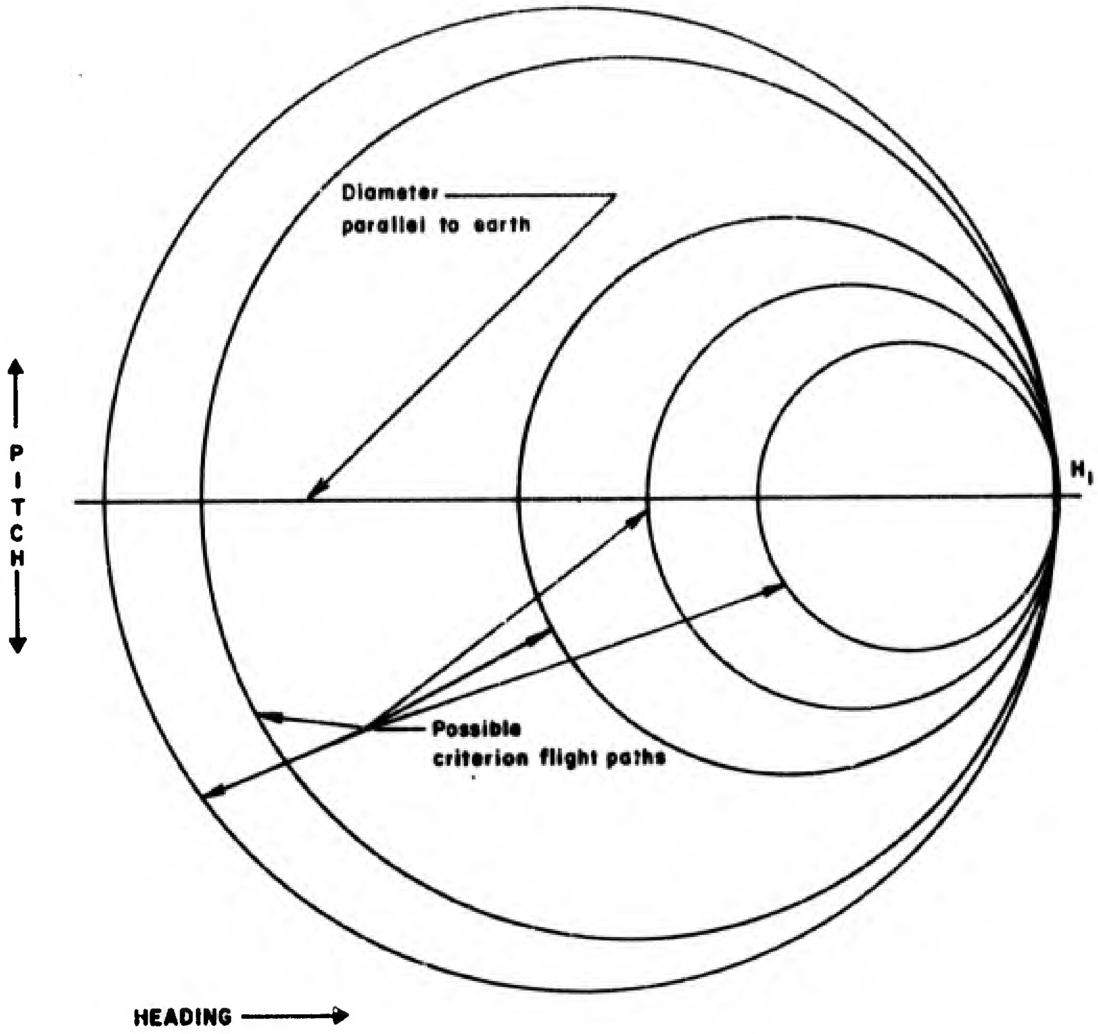


Figure 16. Possible Criterion Flight Paths for Barrel Roll

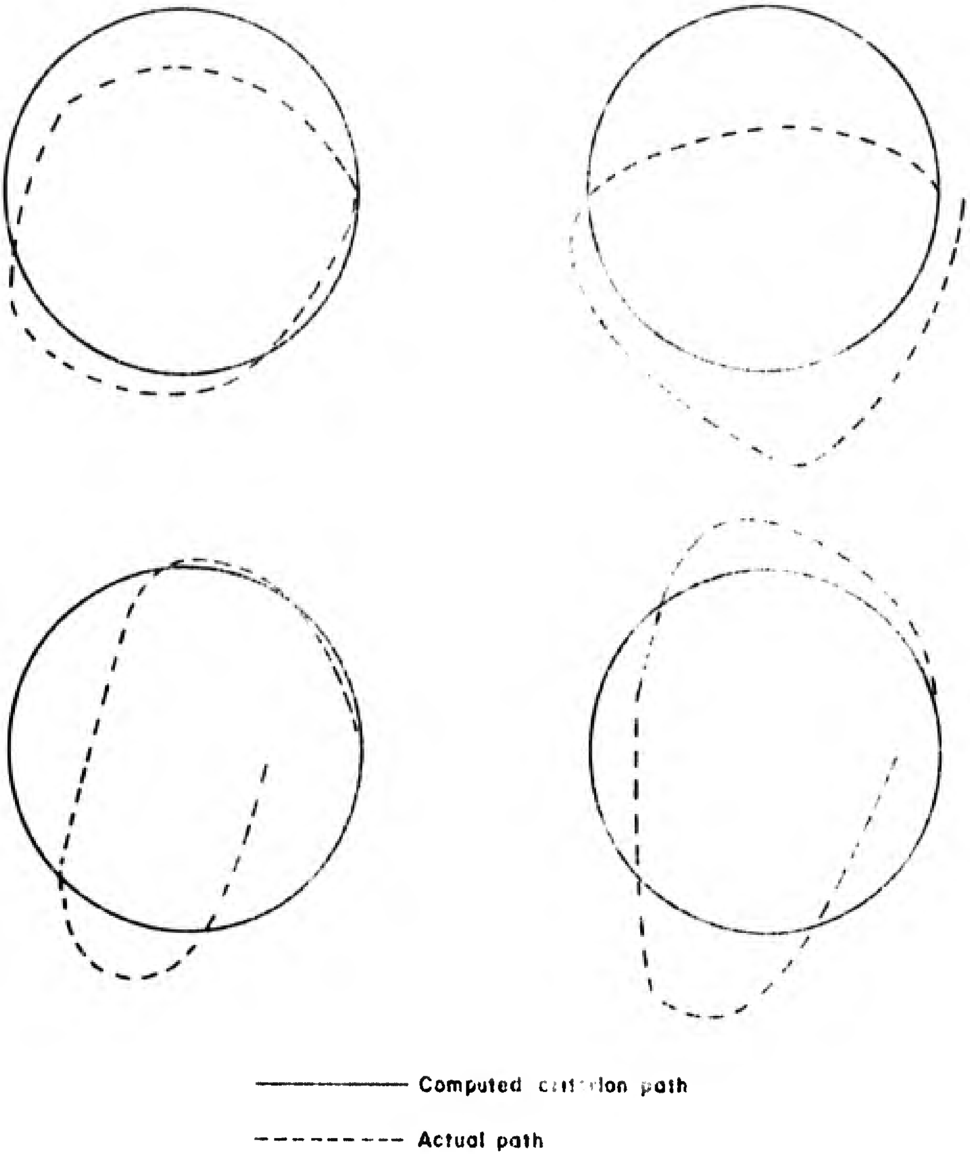


Figure 17. Criterion vs Actual Flight Paths for Barrel Roll

Let X_i = observed heading at T = i

Y_i = observed pitch angle at T = i

H_1 = heading at start of maneuver

and R = radius of the criterion circle.

Then the equation of the criterion circle is:

$$\left(X_i - \left[H_1 \pm R\right]\right)^2 + Y_i^2 = R^2 \tag{7}$$

where R is unknown at the present and the + or - sign in the first term is determined by whether the barrel roll is performed to the right (+) or to the left (-). (In computing $H_1 \pm R$, appropriate modifications would need to be made if a crossing of 0° heading occurs, i.e., use modulo 360°.) Now we shall expand the terms in Equation 7 and solve for R in terms of X_i, Y_i, and H_1:

$$X_i^2 + \left[H_1 \pm R\right]^2 - 2X_i\left[H_1 \pm R\right] + Y_i^2 = R^2$$

$$X_1^2 + H_1^2 + R^2 \pm 2H_1R - 2H_1X_1 \mp 2X_1R + Y_1^2 - R^2 = 0$$

$$\pm 2H_1R \mp 2X_1R = 2H_1X_1 - X_1^2 - H_1^2 - Y_1^2 \tag{8}$$

$$R = \frac{2H_1X_1 - X_1^2 - H_1^2 - Y_1^2}{2\left(\pm H_1 \mp X_1\right)}$$

Now the integral equation we wish to minimize in order to arrive at a value for R is

$$\int_0^T \left| R - \frac{2H_1X_1 - X_1^2 - H_1^2 - Y_1^2}{2\left(\pm H_1 \mp X_1\right)} \right| dT$$

To do this, we select

$$R = \frac{1}{n} \sum_{i=1}^{n} \frac{2H_i X_i - X_i^2 - H_i^2 - Y_i^2}{2\left(\pm H_i \mp X_i\right)} \qquad (9)$$

The measure desired is the variance of the actual flight path from the criterion circle, now fully determined by the derivation of R:

$$S_{13} = \int_0^T \left| R^2 - \left(X_i - \left[H_i \pm R\right]\right)^2 - Y_i^2 \right| dT$$

This is an integrated error measure of the deviation between criterion and actual flight paths, as determined by roll and heading angles.

(b) RPM

RPM must be maintained at 90% (±1%) throughout the maneuver. A straightforward measure may be taken:

Let

$$M_i = \begin{cases} \left|RPM_i - 90\right|, & \left|RPM_i - 90\right| \geq 1 \\ 0, & \left|RPM_i - 90\right| < 1 \end{cases}$$

where RPM_i is the actual value of RPM at T = i.

Then the RMS error is

$$S_{14} = \left(\frac{1}{n} \sum_{i=1}^{n} M_i^2\right)^{\frac{1}{2}}$$

where n is the number of samples taken in which $M_i \neq 0$.

This measures the average RPM error when tolerances are exceeded.

(c) Airspeed

No definite restrictions are placed upon airspeed except during entry to the maneuver. On entry, airspeed must be at least

200 knots and should not exceed 230 knots. Straightforward measures may be taken as follows:

Let T_1 and T_n represent the times at which entry to the maneuver is begun and completed, respectively. Let

$$M_1 = \max_{1 \le i \le n} \left| AIRSP_i - 200 \right|$$

$$M_2 = \max_{1 \le i \le n} \left| AIRSP_i - 230 \right|$$

Then compute

$$S_{15} = \begin{cases} 0, & AIRSP_i \ge 200 \\ M_1, & AIRSP_i < 200 \end{cases} \qquad \underline{\text{Entry airspeed deviation under 200 knots.}}$$

$$S_{16} = \begin{cases} 0, & AIRSP_i \le 230 \\ M_2, & AIRSP_i > 230 \end{cases} \qquad \underline{\text{Entry airspeed deviation over 230 knots.}}$$

(d) g Force

g-force is to be maintained at $1 \le G \le 4$ throughout the maneuver. The measure we shall take will reflect the integrated error on g when it exceeds the bounds, i.e., when $G < 1$ or $G > 4$.

$$S_{17} = \int_0^T D_G \, dT$$

$$\text{Where } D_G = \begin{cases} 0, & 1 \le G \le 4 \\ G-4, & G > 4 \\ 1-G, & G < 1 \end{cases}$$

(e) Roll Rate

Roll rate is to be held constant throughout the maneuver. A measure of constancy may be obtained by differentiating Roll Rate (RR) with respect to time. Thus, we shall compute

$$S_{18} = \frac{1}{n} \sum_{i=1}^{n} \left| \frac{dRR}{dT} \right|$$

<u>Measure of the constancy of roll rate.</u>

(Note that the absolute value of the derivative is used to avoid term-cancelling.)

Table XII presents a summary of the measures S_1 through S_{18} (See Table XIII for a definition of terms used in the summary table.)

(f) Combined Theoretical Measures

Figure 18 is a maneuver diagram for the barrel roll with indications of the portions of the maneuver checked by each experimental performance measure. The "continuous measures" indicated in Figure 18 are ones which monitor one or more performance variables every sampling instant over a discrete time interval. Other measures monitor performance variables at several discrete positions during the maneuver.

For experimental purposes, the following scaled measures and combinations thereof were computed and printed in addition to the individual S_i measures. As described in the section on the lazy 8, the weights were determined by the authors based on the judged criticality of individual measures; and scaling was performed to produce combined measures ranging from 0 to 100.

<u>Entry Airspeed Score (EAS).</u> Measure of how well the pilot holds the correct entry airspeed to the maneuver. Failure to hold at least 200 knots is weighted more heavily than failure to remain below 230 knots.

$$EAS = 100 - \frac{3S_{15} + S_{16}}{2}$$

TABLE XII

SUMMARY OF PERFORMANCE MEASURES FOR BARREL ROLL

No.	Variable	Measure	Expected Range	Beg.[1] Cue	End[1] Cue	Pass[2] Count
1	Heading; Pitch	$\int_0^T \left\| R_1^2 - (X_i - C_1)^2 - Y_i^2 \right\| dT$	0 - 30,000	SQ1	EQ4	2
2	Heading; Pitch	$\int_0^T \left\| R_2^2 - (X_i - C_2)^2 - Y_i^2 \right\| dT$	0 - 30,000	SQ1	EQ4	2
3	Heading	$\left\| \left\| H_1 - H_2 \right\| \text{MOD } 360 - \left\| H_3 - H_2 \right\| \text{MOD } 360 \right\|$	0 - 30°	SQ1	EQ2	1
4	Heading	$\left\| H_1 - H_5 \right\| \text{ MOD } 360$	0 - 60°	SQ1	EQ4	1
5	Heading	$\left\| H_2 - H_4 \right\| \text{ MOD } 360$	0 - 60°	SQ2	EQ3	1
6	Pitch	$\left\| P_1 \right\| + \left\| P_3 \right\| + \left\| P_5 \right\|$	0 - 90°	SQ1	EQ4	1
7	Pitch	$\left\| \left\| P_2 \right\| - \left\| P_4 \right\| \right\|$	0 - 60°	SQ2	EQ3	1
8	Heading	$\left\{ \begin{array}{ll} 0, & 20° \leq \left\| H_2 - H_1 \right\| \text{MOD } 360 \leq 30° \\ \left\| \left\| H_2 - H_1 \right\| \text{MOD } 360 - 20 \right\|, & \left\| H_2 - H_1 \right\| \text{MOD } 360 < 20° \\ \left\| \left\| H_2 - H_1 \right\| \text{MOD } 360 - 30 \right\|, & \left\| H_2 - H_1 \right\| \text{MOD } 360 > 30° \end{array} \right\}$	0 - 30°	SQ1	EQ1	1
9	Pitch	$\text{MAX } (P_i) - P_2 \quad (i = 1, 3, 4, 5)$	0 - 60°	SQ1	EQ4	1
10	Pitch	$P_4 - \text{MIN } (P_i) \quad (i = 1, 2, 3, 5)$	0 - 60°	SQ1	EQ4	1

[1] Beginning and end cues refer to start (S) or end (E) of quarters (Q) 1, 2, 3, or 4 of the maneuver.

[2] Estimated number of data-passes required in computing the measures

TABLE XII (Concluded)

SUMMARY OF PERFORMANCE MEASURES FOR BARREL ROLL

No.	Variable	Measure	Expected Range	Beg. Cue[1]	End Cue[1]	Pass Count[2]
11	Altitude	$\lvert ALT_a - ALT_B \rvert$	0 - 3000 ft	SQ1	EQ2	1
12	Altitude	$\lvert \lvert ALT_a - ALT_x \rvert - \lvert ALT_a - ALT_n \rvert \rvert$	0 - 3000 ft	SQ1	EQ4	1
13	Heading; Pitch	$\int_0^T \lvert R^2 - \left(X_i - \left[H_1 \pm R\right]\right)^2 - Y_i^2 \rvert dT$	0 - 30,000 ft	SQ1	EQ4	2
14	RPM	$\left(\frac{1}{n} \sum_{i=1}^{n} M_i^2\right)^{1/2}$	0 - 10%	Entry	EQ4	1
15	Airspeed	$\left\{\begin{matrix} 0, & Airsp_i \geq 200 \\ M_2, & Airsp_i < 200 \end{matrix}\right\}$	0 - 50 kts	Start Entry	End Entry	1
16	Airspeed	$\left\{\begin{matrix} 0, & Airsp_i \leq 230 \\ M_3, & Airsp_i > 230 \end{matrix}\right\}$	0 - 50 kts	Start Entry	End Entry	1
17	g force	$\int_0^T D_G \, dT$	0 - 3T	Entry	EQ4	1
18	Roll rate	$\frac{1}{n} \sum_{i=1}^{n} \left\lvert \frac{dRR_i}{dT} \right\rvert$	0 - 10°/sec^2	SQ1	EQ4	1

TABLE XIII

DEFINITIONS OF TERMS USED IN TABLE XII

R_1 = radius of computed criterion circle No. 1

X_i = sampled heading at $T = i$

C_1 = center heading of computed criterion circle No. 1

Y_i = sampled pitch at $T = i$

R_2 = radius of computed criterion circle No. 2

C_2 = center heading of computed criterion circle No. 2

H_1 = initial heading

H_2 = heading when bank becomes 90°

H_3 = heading when bank becomes 180°

H_4 = heading when bank becomes 270°

H_5 = heading when bank returns to 0°

P_1 = initial pitch angle

P_2 = pitch angle when bank becomes 90°

P_3 = pitch angle when bank becomes 180°

P_4 = pitch angle when bank becomes 270°

P_5 = pitch angle when bank returns to 0°

ALT_a = altitude when H_1 is obtained

ALT_B = altitude when H_3 is obtained

ALT_x = maximum altitude obtained

ALT_n = minimum altitude obtained

R = radius of computed criterion circle No. 3

$$M_i = \left\{ \begin{array}{ll} RPM_i - 90 , & | RPM_i - 90 | \geq 1 \\ 0 , & | RPM_i - 90 | < 1 \end{array} \right\}$$

$$M_2 = \max_{1 \leq i \leq n} | AIRSP_i - 200 |$$

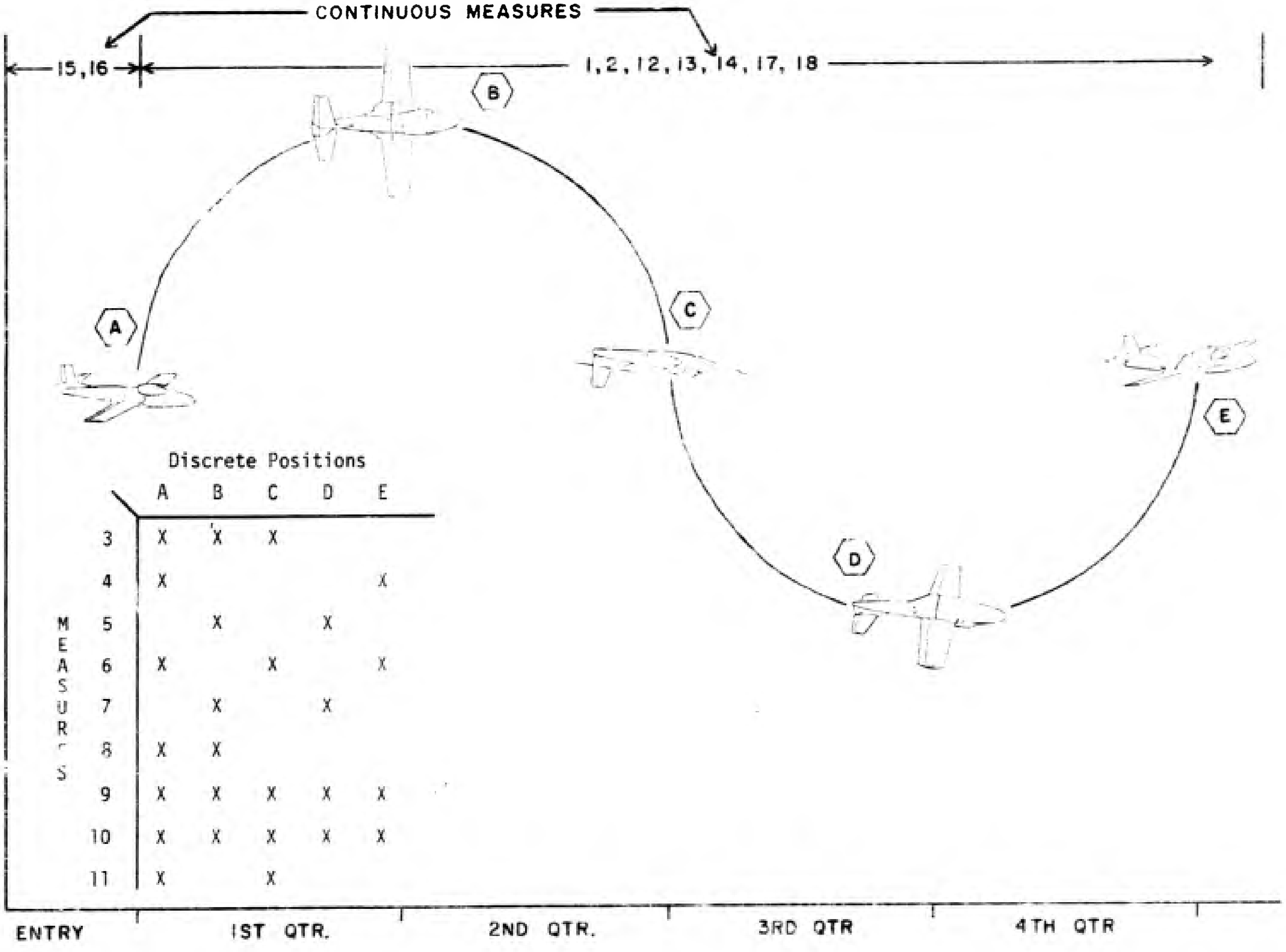
TABLE XIII (Concluded)

DEFINITION OF TERMS USED IN TABLE XII

$$M_3 = \max_{1 \leq i \leq n} | AIRSP_i - 230 |$$

$$D_g = \left\{ \begin{array}{ll} 0 , & 1 \leq G \leq 4 \\ G - 4 , & G > 4 \\ 1 - G , & G < 1 \end{array} \right\}$$

RR_i = roll rate at ith sampling instant



Discrete Positions

MEASURES	A	B	C	D	E
3	X	X	X		
4	X				X
5		X		X	
6	X		X		X
7		X		X	
8	X	X			
9	X	X	X	X	X
10	X	X	X	X	X
11	X		X		

Figure 18. Barrel Roll Maneuver Diagram.

Attitude Score 1 (AS1). Measure of how well the pilot's flight path compares with a criterion flight path based on the assumption that the pilot's attitude and position are optimum at the start of the maneuver and at the end of the second quarter.

$$AS1 = 100 - \frac{S_1}{300}$$

Attitude Score 2 (AS2). Measure of how well the pilot's flight path compares with a criterion flight path based on the assumption that the pilot's attitude and position are optimum at the start of the maneuver and the end of the first quarter.

$$AS2 = 100 - \frac{S_2}{300}$$

Attitude Score 3 [Heading] (AS3H). Measure of the symmetry of the pilot's performance of the maneuver as judged by aircraft heading at various points. This includes checks on (a) comparison of heading change over first and second quarters; (b) comparison of headings at start and end of maneuver; (c) comparison of headings at "top" and "bottom" of maneuver; and (d) the pilot's reference angle to the chosen reference point.

$$AS3H = 100 - \frac{4S_3 + 3S_4 + 2S_5 + S_8}{4.5}$$

Attitude Score 3 Pitch (AS3P). Measure of the symmetry of the pilot's performance of the maneuver as judged by aircraft pitch angle at various points. This includes checks on (a) zero pitch at 0, 180, and 360° roll points; (b) comparison of pitch magnitudes at "top" and "bottom" of maneuver; (c) whether maximum and minimum pitch angles are attained at the 90 and 270° roll points, respectively.

$$AS3P = 100 - \frac{3S_7 + 2S_9 + 2S_{10} + S_6}{5.1}$$

Attitude Score 3 [Altitude] (AS3A). Measure of the symmetry of the pilot's performance of the maneuver as judged by aircraft altitude at various points. This includes checks on (a) altitude at 0 and 180° roll points and (b) comparison of the maximum and minimum altitude excursion with respect to the starting altitude.

$$AS3A = 100 - \frac{S_{11} + S_{12}}{60}$$

Attitude Score 3 [Total] (AS3T). Measure of the symmetry of the pilot's performance of the maneuver as judged by aircraft heading, pitch angle, and altitude at various points. This is composed of a scaled combination of the preceding three attitude measures.

$$AS3T = \frac{AS3H + AS3P + AS3A}{3}$$

RPM Score (RPMS). Measure of how well the pilot achieves and maintains the required RPM on both engines throughout the maneuver.

$$RPMS = 100 - 10\,S_{14}$$

g Force Score (GFS). Measure reflecting the amount by which the pilot exceeds the g-limits during the maneuver.

$$GFS = 100 - \frac{100\,S_{17}}{3T}$$

where T = total time to complete maneuver (seconds).

Roll Rate Score (RRS). Measure of the constancy of roll rate throughout the maneuver.

$$RRS = 100 - \frac{S_{18}}{15}$$

Attitude Score 4 (AS4). Measure of how well the pilot's flight path compares with a criterion flight path based on a "best fit" of a correctly shaped flight path to the actual performance.

$$AS4 = 100 - \frac{S_{13}}{300}$$

Total Score. Measures how well all criteria are met.

$$\text{SCORE} = \frac{1}{29}\Big[6(\text{AS4}) + 5(\text{AS3T}) + 4(\text{RRS}) + 4(\text{AS1}) + 4(\text{AS2}) + 3(\text{GFS}) + 2(\text{EAS}) + \text{RPMS}\Big]$$

Miscellaneous Data:

1. Time to complete maneuver
2. Center headings of criterion circles 1 and 2
3. Radius of criterion circle 3
4. $H_1 - H_5$
5. $P_1 - P_5$

b. Software Implementation

(1) Lazy 8 Program

A lazy 8 measurement program consisting of an executive routine and a large subroutine was written in FORTRAN IV and implemented on an IBM 7094 computer. The executive routine required approximately 300 FORTRAN statements and performed the following major functions:

1. Search magnetic tape for the event number corresponding to the maneuver to be analyzed.

2. Read the data.

3. Generate basic plotting data.

4. Print all pertinent data at intervals of 1/2 second.

5. Call the measurement subroutine that computes the theoretical measures described previously.

A listing of the executive routine is provided in Appendix VI.

The plotting data generated were for producing plots of the following variables:

1. Roll vs Pitch
2. Roll and Pitch vs Time
3. Altitude vs Time
4. Airspeed vs Time
5. Heading vs Time
6. Approximate Ground Track[6]
7. Cockpit Stick Position

The data selected for print-out at two samples per second are:

1. Roll
2. Pitch
3. Heading
4. Altitude
5. Airspeed
6. Left RPM
7. Right RPM
8. Longitudinal Stick Position
9. Lateral Stick Position
10. Degrees of Turn into Maneuver
11. Approximate Ground-Speed
12. Vector for Computing Ground Track (ALTX)
13. Acceleration

---

[6] This plot was generated using heading and a computed, approximate groundspeed (GS). The GS was calculated using simple trigonometric functions for the airspeed vector and pitch angle, and is accurate only for no-wind, small-angle-of-attack conditions.

The measurement subroutine required about 500 FORTRAN statements and performed the function of computing and printing the theoretical performance measures.

Program execution required setup of two magnetic tapes, one of which contained the calibrated flight data and the other of which was a scratch tape for plotting-data. Program execution resulted in generation of (1) a plotting-tape, (2) data print-out, (3) theoretical measures, and (4) an estimate of the time requirement for the off-line plotting job. Subsequently, a request for plotting had to be submitted. Plotting time for each of the seven plots averaged 10.8 minutes, using a Calcomp magnetic tape plotting system (30-inch drum).

(2) Barrel Roll Program

The barrel roll measurement program was implemented analogously to that for the lazy 8. The executive routine was nearly identical, the major differences being (1) a change in one of the plots produced, i.e., heading vs pitch instead of roll vs pitch; and (2) the variables were printed at 10 per second instead of 2 per second.

The measurement subroutine required about 300 FORTRAN statements. The major functions of the subroutine are described in Appendix VII.

Program execution procedures were the same as those described for the lazy 8 program.

(3) Initial Tests

Initial tests were made by analyzing the theoretical measurement program results of approximately 30 lazy 8 and barrel roll performances, flown by both Flight Test pilots and an instructor pilot. For each performance, a condensed print-out of critical variables, seven plots, and the previously described theoretically based measures were generated. This data was used in making a decision about formal analysis and measurement requirements for subsequent data to be collected in the study.

Appendix VIII illustrates representative print-outs and theoretical measures from the lazy 8 and barrel roll measurement programs. In the illustrated print-out for the barrel roll, the reader will note that two columns are devoted to each of the angles roll, pitch, and heading. This was done to provide space for printing both the recorded angles and Euler angles, designed to be computed using recorded body-axis rates. This was considered desirable to perform a dual check on the recording of angular rates and the recorded angles. Unfortunately, one of the rate gyros developed problems during the study, and the Euler angles effort was abandoned to the priority of other matters. In the print-out, the columns containing all zeros were the ones intended to hold Euler angle data.

Figures 19 through 32 illustrate the set of plots produced for two sample lazy 8 performances. For each set of plots, indication is given thereon of the subjective rating assigned in-flight to the corresponding maneuver performance, the first having been rated a high "Good" and "Fair" for the second one. The performing pilot (a PIT instructor) illustrated typical performances and provided the subjective ratings himself subsequent to flying the maneuver.

Two of the plots deserve special comment. The stick-position plot emulates the movement of the control-stick as "viewed" from the pilot's position in the cockpit. The plot is generated by graphing lateral (right/left) versus longitudinal (fore/aft) stick position. The roll versus pitch plot is overlaid on a linearized approximation of ATC criteria, as specified in the maneuver analysis.

Early in the flight test and initial data analysis phase, it was realized that recorded aircraft heading (See Figures 24 and 31) would present problems. The directional gyro from which the recording was taken had the normal precession and lead-lag errors to be expected in an instrument of its type and age. As a result, true aircraft heading could, at best, be only estimated during and immediately after aerobatic maneuvers. In addition, the method of instrumentation technique for

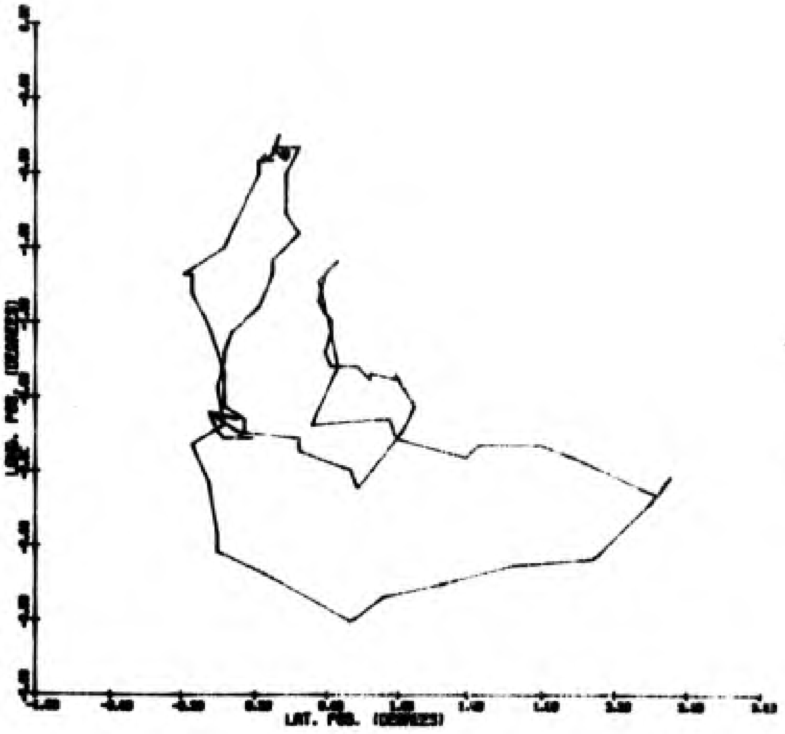


Figure 19. Stick Position Plot for Lazy 8

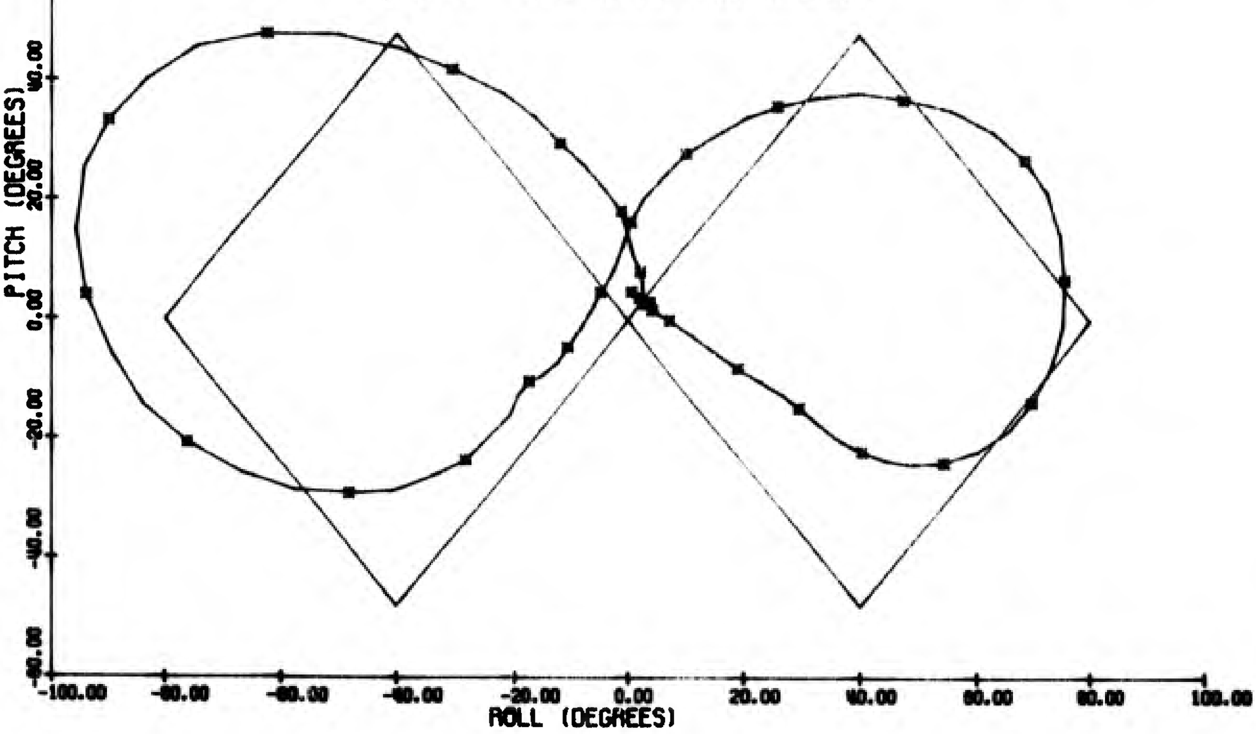


Figure 20. Roll vs Pitch for Lazy 8 (12-17-69-20/High Good)

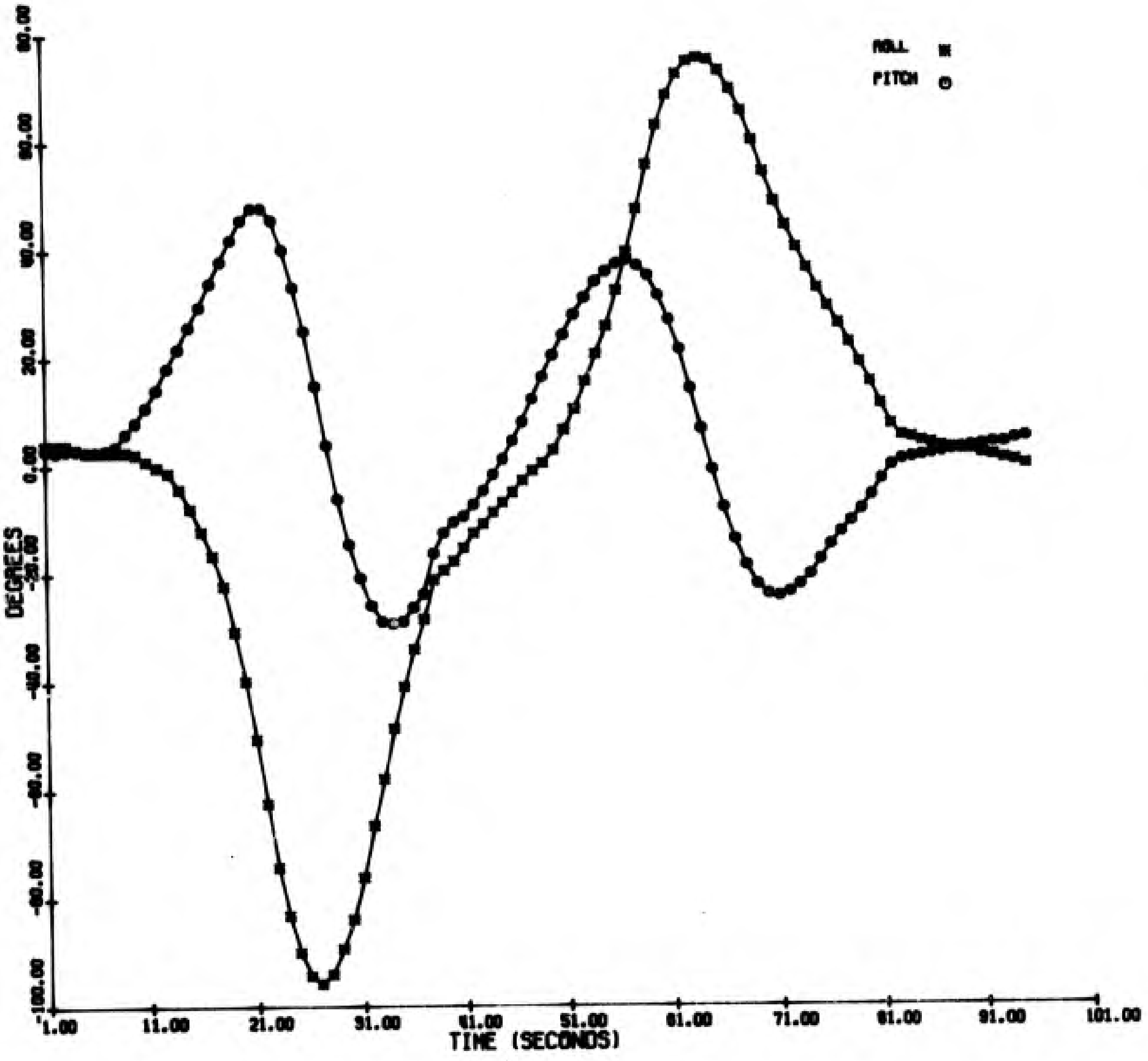


Figure 21. Roll and Pitch vs Time for Lazy 8

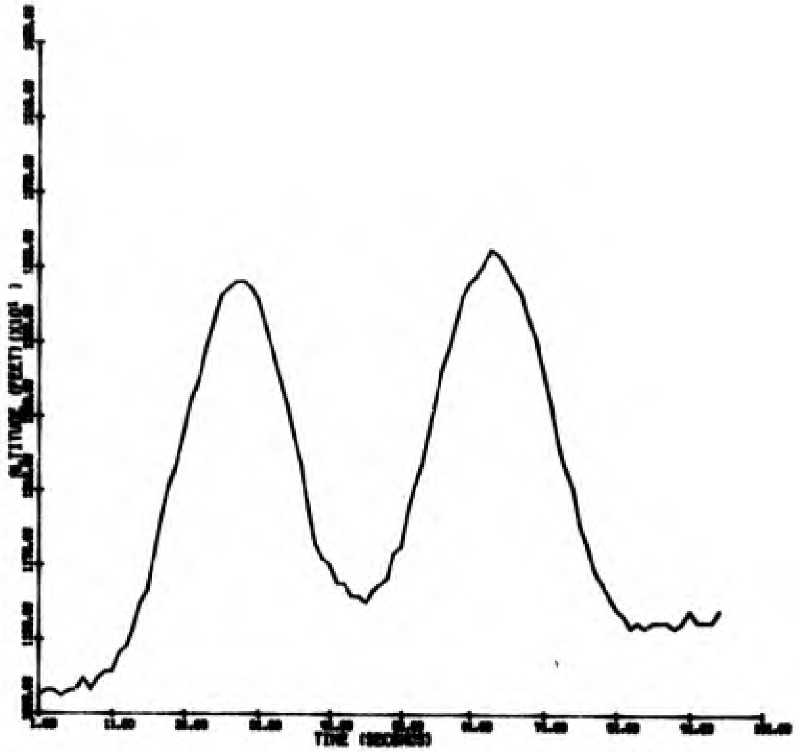


Figure 22. Altitude vs Time for Lazy 8

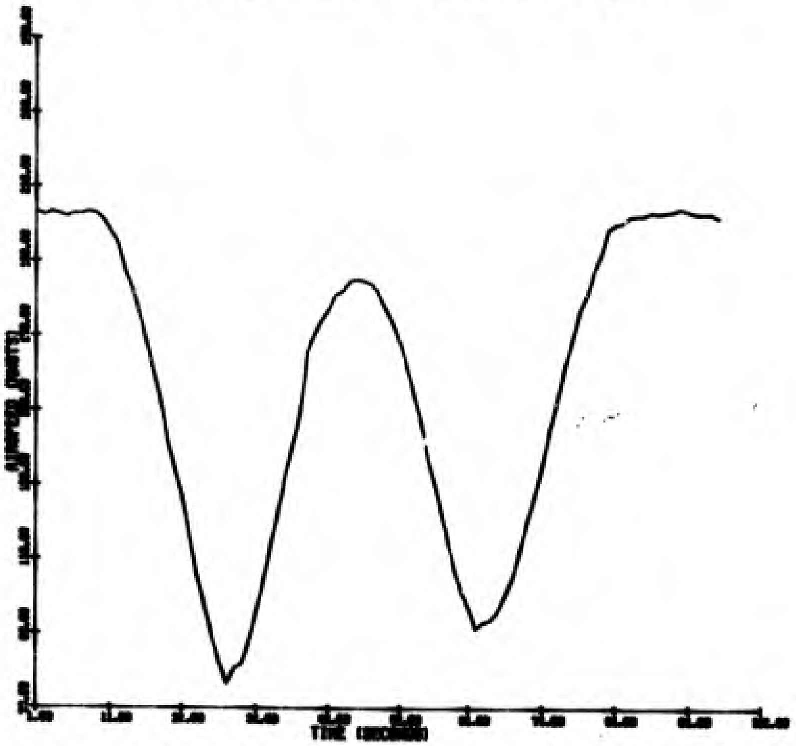


Figure 23. Airspeed vs Time for Lazy 8

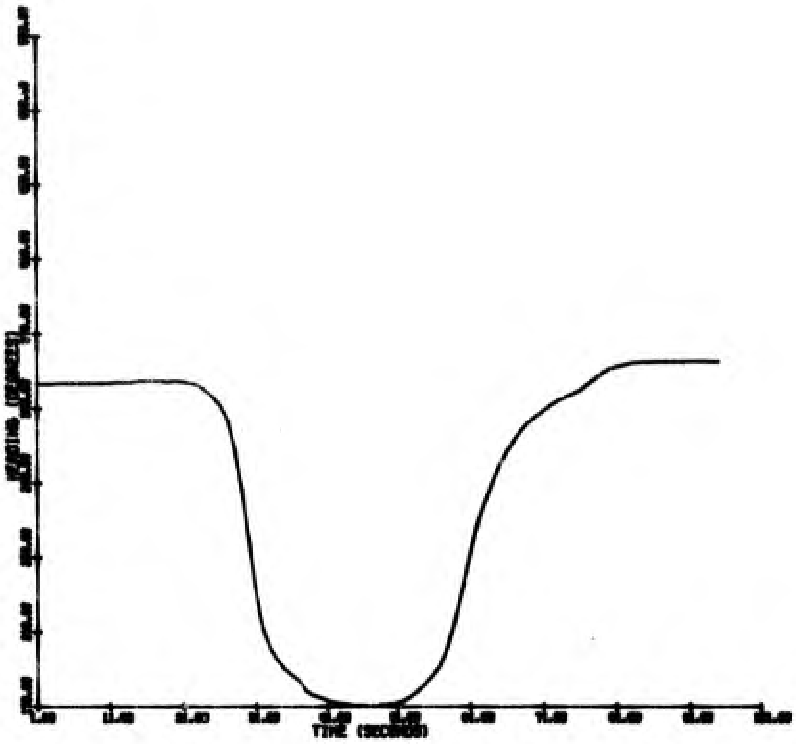


Figure 24. Heading vs Time for Lazy 8

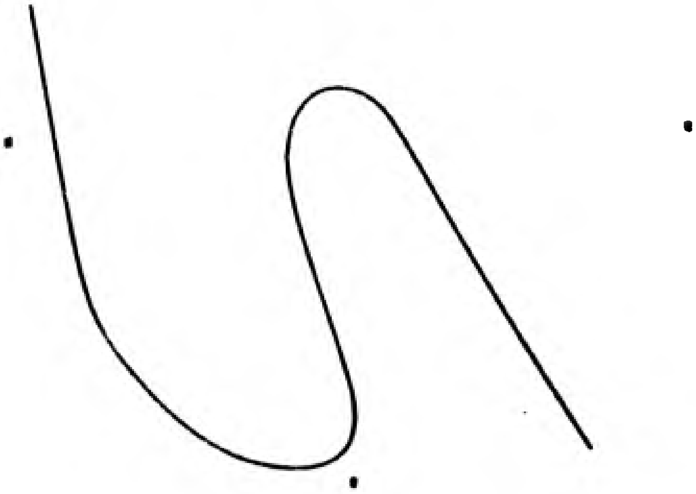


Figure 25. Ground Track for Lazy 8

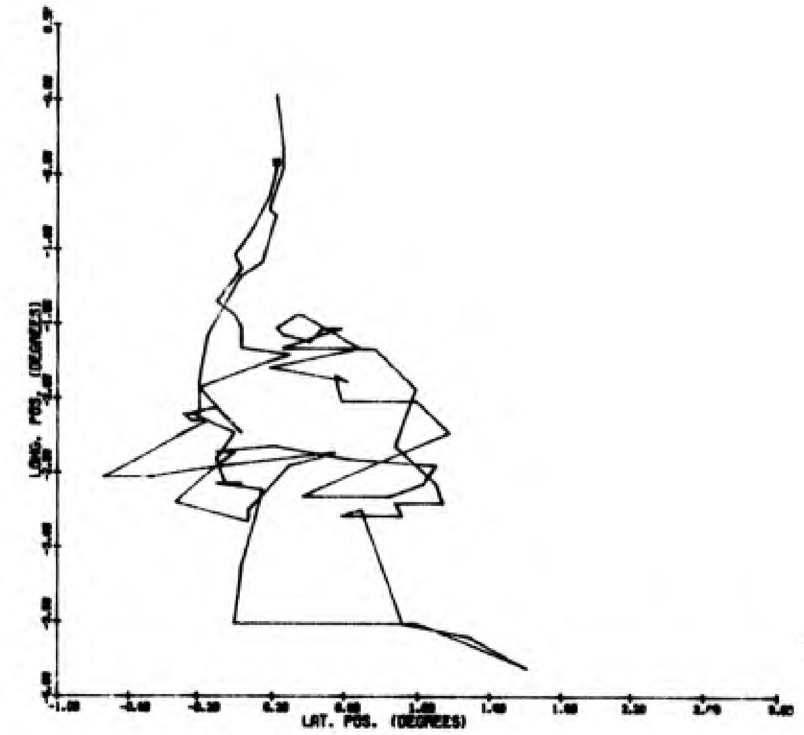


Figure 26. Stick Position Plot for Lazy 8

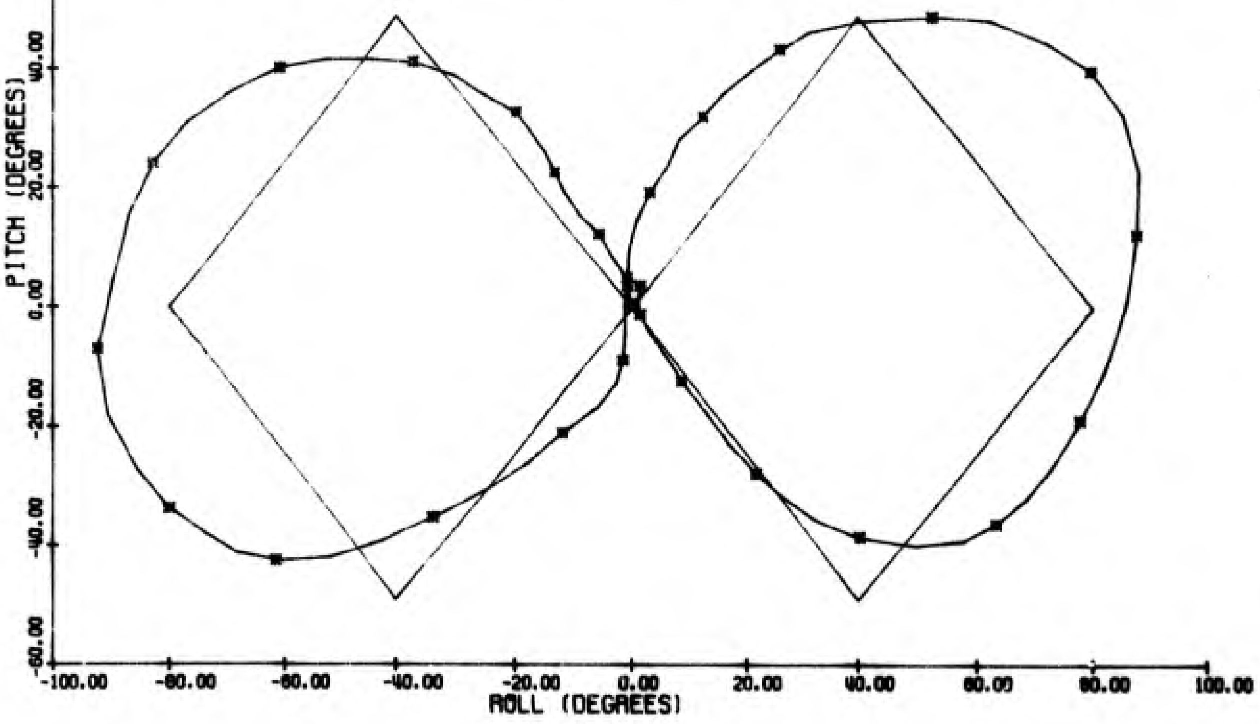


Figure 27. Roll vs Pitch for Lazy 8 (12-19-69-27/Fair)

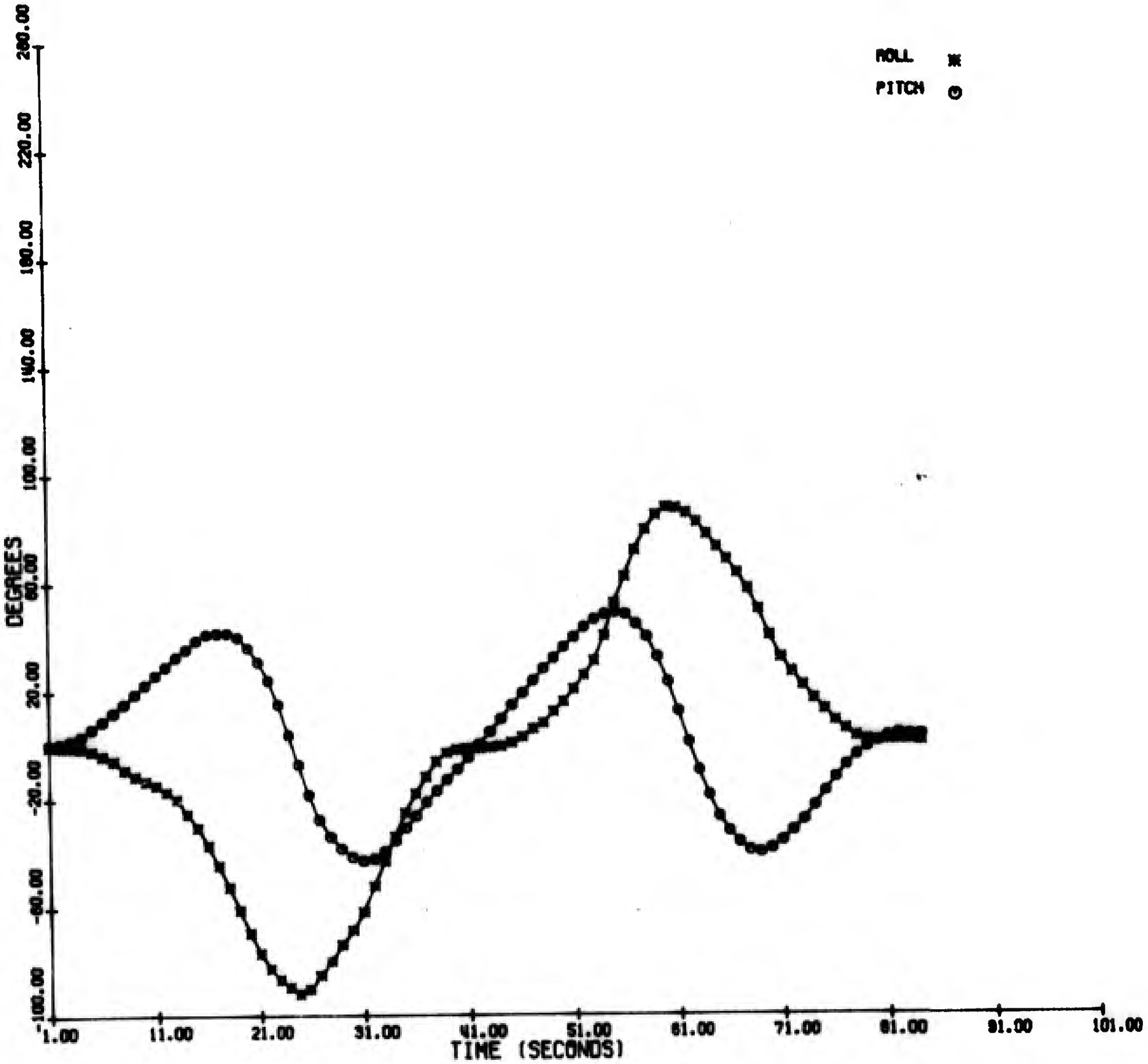


Figure 28. Roll and Pitch vs Time for Lazy 8

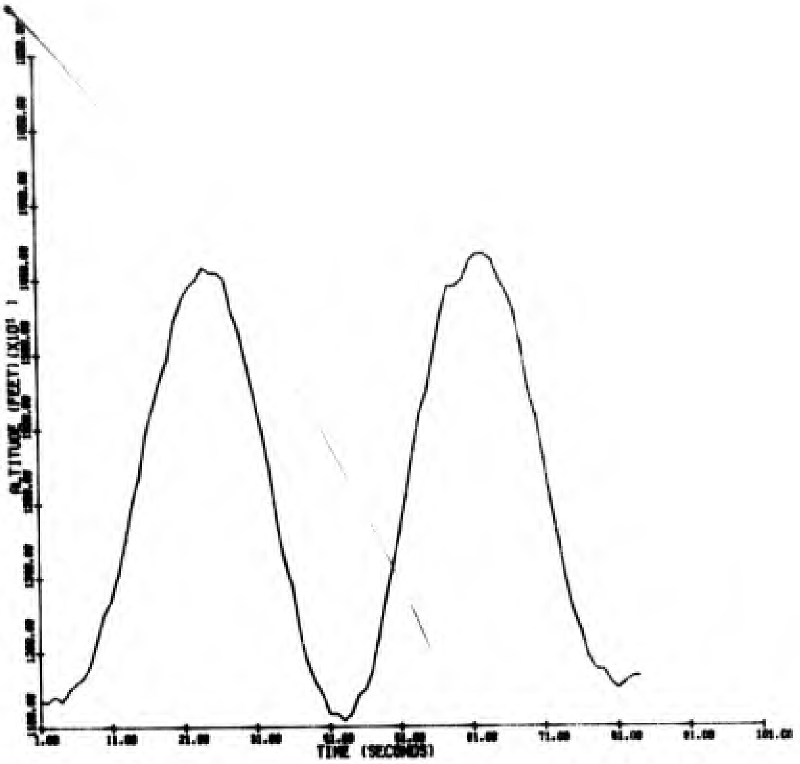


Figure 29. Altitude vs Time for Lazy 8

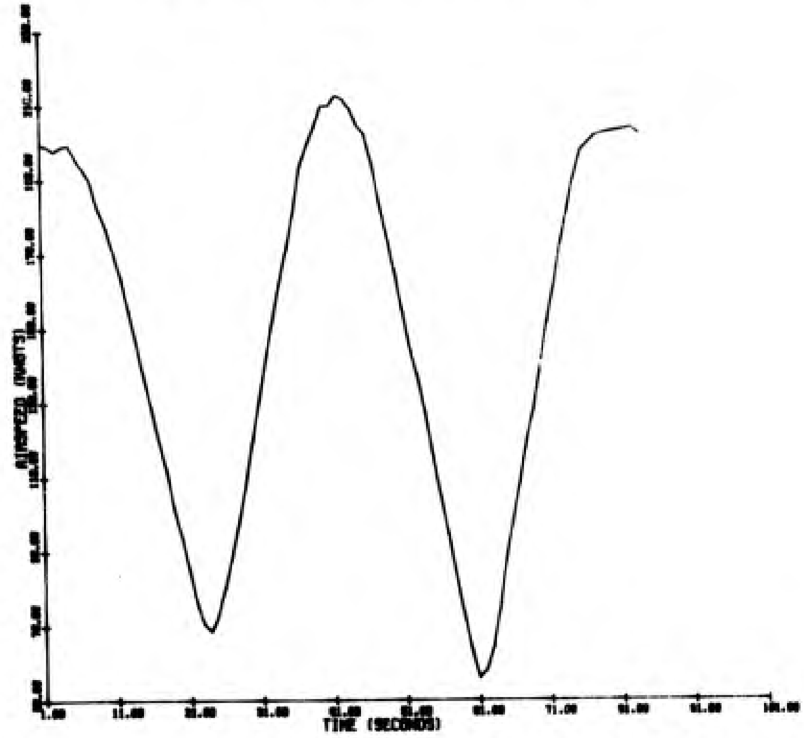


Figure 30. Airspeed vs Time for Lazy 8

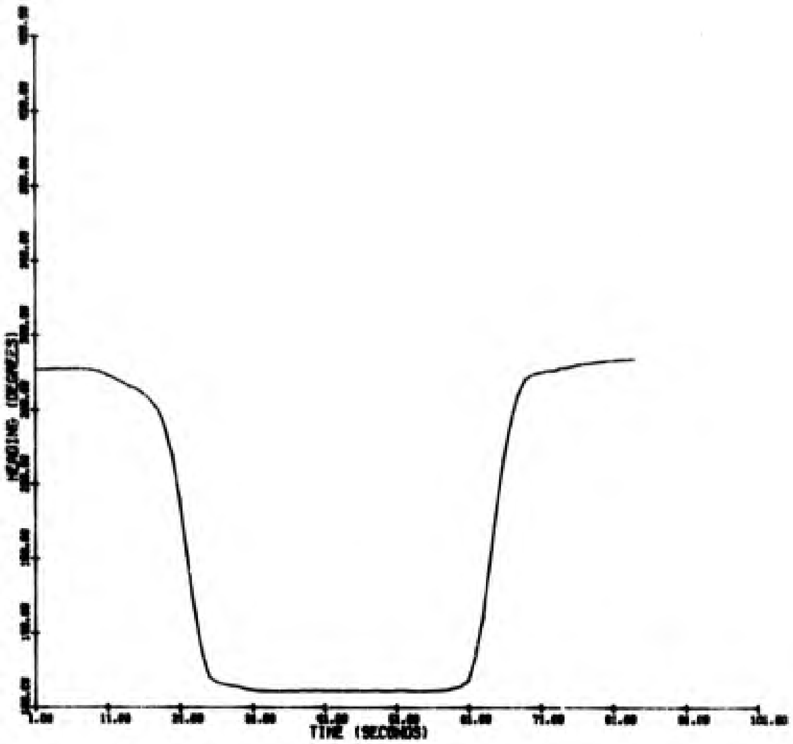


Figure 31. Heading vs Time for Lazy 8

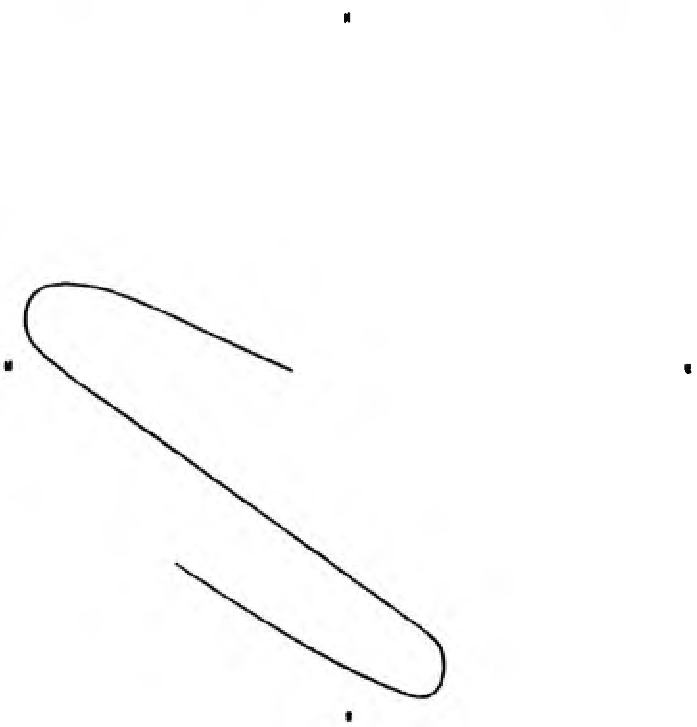


Figure 32. Ground Track fcr Lazy 8

recording aircraft heading (See Section II) with the inherent limitation of the synchro-follower caused erroneous readings in the 0-90° arc.

Although the task-analysis data for the lazy 8 indicated that heading should be the basic measurement reference variable, we elected to omit it from the list of measurement variables for two reasons: (1) the problems experienced with its accurate recording, and the lack of time and money with which to correct the problems; and (2) the dependent nature of heading as a variable. We postulated that the variables roll, pitch, time, and airspeed would provide performance-relevant data which is inclusive of the information that aircraft heading provides. (In part, this was a rationalization of the problem at the time the decision was made; after-the-fact, however, it appears to have been a justifiable move considering the scope of the effort.)

Appendix IX illustrates nine additional sets of lazy 8 plots, excluding heading versus time and the heading-based plot of ground track. Again, the corresponding subjective ratings are indicated on the plots, and they are arranged in order of decreasing skill, as judged by the instructor pilot.

The theoretical measures and plots, such as those in Appendix IX, were used in making a number of the observations which helped to form a basis for specification and development of a revised measurement program. No attempt was made to thoroughly test the validity of the theoretical measures other than to correlate them superficially with the instructors' subjective ratings. Primarily, their usefulness consisted of supplementing the plots to provide a better descriptive indication of the nature of the performance and in providing a preliminary indication of the utility of ATC-criterion-referenced measures. The observations that were made will be discussed now through reference to the sample plots in Appendix IX, numbered consecutively 1-45 for aid in reference.

First consider the stick position plot. Selected plots of stick position were annotated by hand to show where various events took place, such as where the largest pitch angles occurred and where the maneuver was half-completed. The most significant observation was that as the aircraft initially approaches about 40 - 50° of turn in each half of the maneuver, the direction of movement of the stick was reversed. Apparently, this illustrates the pilot's attention to the over-banking tendency of the aircraft. A stick position plot which annotates these points could be of value in basic flying instruction. A slight indication of increased stick movement as skill degrades was also noticed. An example of this may be seen by comparing Plot 1 with Plot 41 (Appendix IX). This trend was not always consistent, however, and could easily be caused by varying environmental factors in-flight.

The analysis of stick position resulted in the decision to abandon its further consideration in this study. Without scientific evidence, we propose that stick position analysis would be most applicable in (a) basic flying training studies and (b) take off and landing studies. For documentation and possible reader interest, several additional stick position plots are presented in Appendix X.

The roll versus pitch plot proved to be the most singularly informative plot of those considered. Consider Plot 2 in Appendix IX. This performance began to the left (can be seen from the initial roll direction in Plot 3). Initially, the pilot pitched up without rolling, then completed a roll to -90° with relatively little change in pitch. He reached -90° of roll and began a decrease in roll prior to attaining his zero pitch position. In the roll-out of the first half of the maneuver, he returned to zero pitch prior to wings level. In the second half, he attained maximum positive pitch at roughly 30° roll and held this pitch angle while he continued to roll through about 70°. Again, he reached maximum bank and began to roll out prior to zero pitch. Upon ending the maneuver, he reached zero pitch prior to wings level. In both halves of the maneuver, he pitched up further than he pitched down, which is contrary to the ATC criteria as presented in the task analysis.

The performance represented by Plot 2 was rated low "Excellent." Comparing Plot 2 with Plots 12, 17, 22, 27, 32, 37, and 42 ("fair" and "unsatisfactory" performances), one can gain some immediate insights to measurement of the lazy 8 maneuver. For example, plot 2 exhibits symmetry, about the same pitch excursions in each half of the maneuver, and a relatively smooth, continuously changing roll/pitch relationship. All or some of these characteristics are lacking to some degree in the other plots. In plot 32, for instance, roll is held relatively constant at the MAX-roll points in the maneuver, and pitch is allowed to reduce from a MAX plus to a MAX minus all at once. In plot 37, very little change in pitch is exhibited while a rapidly changing roll is evident. In plots 12 and 17, lack of symmetry is obvious. In plot 42, uneven change in roll with respect to pitch is seen at the end of the left half of the maneuver. Additionally, by considering the roll-pitch plot and the airspeed plot together, it is possible to postulate precisely why (or why not) the airspeed criteria are met by a given performance. As will be discussed later, it appears likely that an individual trained in interpreting the plots can accurately discriminate at least four skill levels using only the roll-pitch and airspeed plots.

The plot of roll and pitch versus time provided little contributing information relevant to measurement that could not be deduced from other plots. The altitude plot was considered possibly relevant because in the better performances there was a consistent overall altitude gain that was not observed consistently in the less skilled performances. Also, the reason for this altitude gain in correct performance of the lazy 8 was an intriguing question. Appendices XI and XII present additional roll versus pitch plots and airspeed plots which represent the same group of performances shown in Appendix X.

c. Summary of Theoretical Measures Investigation

Theoretical measures were determined using the ATC maneuver analyses, in which criteria and tolerances were estimated for various flight parameters. The measures consisted of comparisons of flight data with these criteria and tolerances.

Programs were written to (1) compute and print out the theoretical measures; (2) print the raw data itself; and (3) plot selected variables. The programs were run using a small amount of flight test and instructor pilot performance data.

Essentially, the theoretical measures investigation was an initial "shot-in-the-dark" using, as a basis for trial measurement, the ATC information available at the start of the program. For launching the study and bringing to light both the operational and theoretical problems regarding measurement of the lazy 8 and barrel roll, the investigation was 100% successful. However, for demonstrating any kind of validity of the theoretical measures (and, thus, encouraging the investigators at that time), the results may be considered disastrous.

A serious problem occurred that was not originally anticipated with regard to the use of aircraft heading as a primary reference variable. Due in part to instrumentation problems, and due in remainder to the lead/lag characteristics of the heading gyro from which the recording was taken, heading itself was unreliable. Therefore, any measure which relied on heading as a reference was unreliable.

From the data plotted in the theoretical measures investigation, it was possible to discern a number of questionable characteristics of the ATC criteria that were applied. A prime example is the criterion that maximum and minimum pitch angles be equal in magnitude. Other criteria appeared to be valid and to represent a sound basis for measurement, e.g., the "circle" measures for the roll/pitch relationship in the barrel roll.

Based on observations such as these, it was concluded that textbook criteria very definitely cannot be assumed to represent an adequate basis for quantitative measurement, although it may provide initial guidelines. Rather than pursue this avenue further, (i.e., attempt to legitimately validate or disprove the original set of ATC criteria), the decision was made to formulate a new set of measures. This new set was based not on ATC criteria, but on (1) a logical analysis of that criteria made possible through the initial application; and (2) insights into the performance of the maneuvers gained through examination of actual data.

The new set of measures and other related program outputs considered necessary to conduct the study constitute the measurement system ultimately applied to a broad spectrum of student and instructor data. This measurement system is described next.

4. MEASUREMENT SYSTEM

This subsection describes the measurement system designed for analyzing performance and computing measures for a broad spectrum of student and instructor lazy 8's and barrel rolls. Prior to the specification of this system and the associated measures, an investigation was made of a set of theoretical measures based solely upon ATC criteria. As discussed in the preceding summary, this investigation laid the groundwork for identification of the measures and other desirable program-outputs to be described below. To differentiate the measures to be described below from the theoretical measures previously discussed, the new ones will be referred to as experimental measures. (This name also attests to the fact that the new set of measures is experimental in nature.) The measurement system consisted of separate programs for the lazy 8 and barrel roll which (1) computed experimental measures, (2) plotted key performance variables, and (3) produced a summary print-out of measurement-relevant raw data. In addition, initiating programs were developed to record significant data on cards for each maneuver, which was then used as input to the actual measurement programs.

a. Punched Card Records of Maneuvers

Considerable difficulty was encountered in locating and reading maneuver data on magnetic tape. This difficulty was attributed to three factors: (1) the magnetic tapes were not new, (2) the identifying event numbers for the maneuvers were often not recorded correctly on the tape due to instrument errors, and (3) the data typically contained "glitches" apparently caused by intermittent noise on the recording channels. Because the data would require more than one "pass" for analysis, and because it was to be retained for other future studies, it was necessary to "deglitch" the data and store it on punched cards. The variables to be thus recorded were selected on the basis of their expected usefulness in measurement of performance.

The variables selected for storage on cards were as follows (shown in the order punched):

Lazy 8	Barrel Roll and Other Maneuvers
Roll	Roll
Pitch	Pitch
Heading	Heading
Altitude	Altitude
Airspeed	Airspeed
	Normal Acceleration
($\Delta T = 0.5$ secs)	($\Delta T = 0.4$ secs)

The program which accomplished the punching and which, additionally, printed out selected variables is listed in Appendix XIII. For the lazy 8, 1.5 seconds of data could be represented on each punched card, resulting in approximately 40 or 50 cards per performance. For the barrel roll (and all other maneuvers), one card represented .8 seconds of data, resulting in about 40 cards per performance of the barrel roll.

In addition to the recorded data, cards were punched to document the month, day, year, and event-number of the maneuver, the total number of data points punched, the subjective rating provided for the maneuver, and, when applicable, the direction in which the maneuver was performed.

Data "deglitching" was accomplished partly by the program and partly by hand. The program, prior to punching, checked for obvious recording errors (e.g., variables out of range) and corrected the data at that point by setting it equal to the preceding values. Hand analysis was then required to remove "glitches" overlooked by the program and, when necessary, smooth out the step-function effect sometimes resulting from corrective action of the program over a longer-than-ordinary time interval. This process worked satisfactorily but was extremely time consuming.

The format in which the cards were punched is as follows:

Card 1:	Month, Day, Year, Event Number	3I5,F7.0
Card 2:	Number of recorded points	I5
Card 3:	Rating, Direction	2I5
Remaining Cards:	Data for lazy 8	3(F5.0,F4.0,F5.0, F7.0,F5.0)
	Data for barrel roll and others	2(F5.0,F4.0,F5.0, F7.0,F5.0,F5.1)

b. Lazy 8 Experimental Measures

Following is a description of forty-one measures designed to be computed for each performance of the lazy 8 maneuver:

(1) MAX_1 - Maximum positive pitch in first half of maneuver

(2) MIN_1 - Minimum pitch in first half of maneuver

(3) MAX_2 - Maximum pitch in second half of maneuver

(4) MIN_2 - Minimum pitch in second half of maneuver

(5-8) $ROLL_i$ $(i = 1, 4)$

(9-12) $ARSP_i$ $(i = 1,4)$

(13-16) $ALTX_i$ $(i = 1,4)$

Roll, airspeed, and altitude change [since start of maneuver] at points of MAX_1, MIN_1, MAX_2, and MIN_2.

(17) MAX + ROLL - Maximum positive roll

(18) MAX - ROLL - Maximum negative roll

(19) Time Half 1

(20) Time Half 2

Time (seconds) required to perform each half of the maneuver.

(21) Total Time - Total maneuver time

(22) E_1 - Starting airspeed minus 200

(23) E_2 - First minimum airspeed minus 100

(24) E_3 - MAX airspeed at middle of maneuver minus 200

(25) E_4 - Second minimum airspeed minus 100

(26) E_5 - Ending airspeed minus 200

(27) $$E_6 = \sum_{i=1}^{5} |E_i|$$

(28) $$E_7 = \sum_{i=1}^{3} |E_i|$$

(29) $$E_8 = \sum_{i=3}^{5} |E_i|$$

(30) E_9

(31) E_{10}

(32) E_{11}

(33) E_{12}

Absolute value of the airspeed-change between the five local maxima and minima (e.g., E_9 = abs. val. of difference between starting airspeed and first local minimum airspeed).

(34) E_{13}

(35) E_{14}

(36) E_{15}

(37) E_{16}

|Change in airspeed| divided by change in time over the four intervals of the maneuver referenced above by E_9 through E_{12}.

(38) T_1

(39) T_2

Time (seconds) during intervals referenced above by E_9 through E_{12} and E_{13} through E_{16}.

(40) T_3

(41) T_4

In addition, measures of roll, airspeed, and altitude excursion are computed at specified points throughout the maneuver. The points are composed of all local maximum and minimum pitch values plus intermediate points at multiples of 1/3 times the local extrema.

The measures program produces for each performance of the lazy 8, (1) a print-out of roll, pitch, heading, altitude, and airspeed at $\Delta T = 0.5$; and (2) the experimental measures. In addition, the program computes means and standard deviations of all measures for selected groups of performances. Sample output is shown in Appendix XIV.

c. Barrel Roll Experimental Measures

Following is a description of thirty-six measures designed to be computed for each performance of the barrel roll maneuver.

(1) Symmetry Measures

Let X_i = pitch values sampled at $|\text{roll}|$ = 10°, 20°, ...,
180°, 170°, ...,
10°.

$(i = 1,\ 35)$

$$M_1 = \frac{1}{9}\sqrt{\sum_{i=1}^{9}\left(|x_i| - |x_{36-i}|\right)^2}$$

Measures symmetry of quarters 1 and 4

$$M_2 = \frac{1}{9}\sqrt{\sum_{i=9}^{17}\left(|x_i| - |x_{36-i}|\right)^2}$$

Measures symmetry of quarters 2 and 3

$$M_3 = \frac{1}{17}\sqrt{\sum_{i=1}^{17}\left(|x_i| - |x_{36-i}|\right)^2}$$

Measures symmetry of halves 1 and 2

(2) Roll/Pitch Circle Measures

Let Roll_i and Pitch_i $(i = 1, 71)$ be the sampled roll values and corresponding pitch angles at Roll = 5°, 10°, ..., 180°, 175°, ..., 5°.

Let

$$X_i = |\text{ROLL}_i| - 90$$

$$Y_i = \frac{90\,(\text{PITCH}_i)}{|\text{PITCH}_{\text{MAX}}|}$$

where $\text{Pitch}_{\text{MAX}}$ = maximum absolute value of all Pitch_i

$$Z_i = \frac{|\text{PITCH}_{\text{MAX}}|}{90}\left[\sqrt{X_i^2 + Y_i^2} - 90\right]$$

Then

$$M_4 = \frac{1}{36}\sqrt{\sum_{i=1}^{36} Z_i^2}$$

Compares roll and pitch with circle criterion over half 1

$$M_5 = \frac{1}{36}\sqrt{\sum_{i=36}^{71} Z_i^2}$$

Compares roll and pitch with circle criterion over half 2

$$M_6 = \frac{1}{71}\sqrt{\sum_{i=1}^{71} Z_i^2}$$

Compares roll and pitch with circle criterion over maneuver

(3) Constancy - Measures on Rates and g's

These measures check the constancy of roll rate, pitch rate, and g's by computing regression coefficients and correlation.

Let Roll_i, Pitch_i, and G_i be the values of roll (arranged to go from 0 to 360°), pitch, and g's at time-increments of 0.4 seconds $(i = 1, K)$. Using a 5-point Lagrange formula, compute:

Y_{1i} = roll rate

Y_{2i} = pitch rate

and denote

$$Y_{3i} = G_i$$

$$X_i = \text{Roll}_i$$

Define

$$B_L = \frac{K\left(\sum_{i=1}^{K} x_i\, Y_{Li}\right) - \left(\sum_{i=1}^{K} x_i\right)\left(\sum_{i=1}^{K} Y_{Li}\right)}{K\left(\sum_{i=1}^{K} x_i^2\right) - \left(\sum_{i=1}^{K} x_i\right)^2}$$

$$A_L = \frac{\sum_{i=1}^{K} Y_{Li} - B_L \sum_{i=1}^{K} x_i}{K}$$

$$R_L = \frac{K \sum_{i=1}^{K} x_i\, Y_{Li} - \left(\sum_{i=1}^{K} x_i\right)\left(\sum_{i=1}^{K} Y_{Li}\right)}{\sqrt{K \sum_{i=1}^{K} x_i^2 - \left(\sum_{i=1}^{K} x_i\right)^2}\ \sqrt{K \sum_{i=1}^{K} Y_{Li}^2 - \left(\sum_{i=1}^{K} Y_{Li}\right)^2}}$$

Then

$$\left.\begin{array}{l} M_7 = A_1 \\ M_8 = B_1 \end{array}\right\} \text{Roll rate regression coefficients}$$

$$M_9 = R_1 \qquad \text{Roll vs. roll rate correlation}$$

$$\left.\begin{array}{l} M_{10} = A_2 \\ M_{11} = B_2 \end{array}\right\} \text{Pitch rate regression coefficients}$$

$$M_{12} = R_2 \qquad \text{Roll vs. pitch rate correlation}$$

$$\left.\begin{array}{l} M_{13} = A_3 \\ M_{14} = B_3 \end{array}\right\} \text{Normal acceleration regression coefficients}$$

$$M_{15} = R_3 \qquad \text{Roll vs. normal acceleration correlation}$$

Let M be the value of i at the point where Roll_i first becomes ≥ 45°, and let N be the value of i at the point where Roll_i last is ≥ 45°. Set j = 1 at i = M, and j = K = N-M+1 at i=N. Compute M_i, for i = 16, 24 by replacing i with j in the foregoing analysis. Then M_{16} to M_{24} are the same measures as M_7 to M_{15} over the interval $|\text{Roll}| \geq 45$.

(4) Miscellaneous Measures

(1) M_{25} - Maximum g's in first half

(2) M_{26} - Maximum g's in second half

(3) M_{27} - Minimum g's in whole maneuver

(4) M_{28} - $|\text{Roll}|$ at MAX positive pitch

(5) M_{29} - $|\text{Roll}|$ at MAX negative pitch

(6) M_{30} - Maximum roll rate

(7) M_{31} - Minimum roll rate

(8) M_{32} }

(9) M_{33} } = MAX. and MIN. pitch rate

(10) M_{34} - Total time for maneuver

(11) M_{35} }

(12) M_{36} } = Time for first and second halves

In addition, measures of pitch, roll rate, pitch rate, roll-pitch "error" (based on circle criterion), heading excursion, altitude excursion, and airspeed excursion are computed for every 10° of roll.

The measures program produces, for each performance of the barrel roll (1) a printout of roll, pitch, heading, altitude, airspeed, and g's at $\Delta T = 0.4$; and (2) all experimental measures described above. Sample output is shown in Appendix XV.

d. Debriefing Plots

A debriefing plot, as the term is used in this study, is a graph of one or more flight variables which, when supplemented by selected performance measures, assists one in evaluating the performance diagnostically. Through a select combination of debriefing plots and measures, the authors' intent was to show that performance can be evaluated after-the-fact more diagnostically and with better skill discrimination than is possible (or at least feasible) in-flight.

Three such plots were developed for the lazy 8:

1. Airspeed vs time
2. Pitch vs roll
3. Altitude vs time

In addition to generating the plots themselves, computer programs also annotated each plot with measurement-relevant information. For example, the airspeed plot was designed to include the location and value of local maximum and minimum pitch values.

Examples of these plots for four laxy 8 performances are presented in Appendix XVI. In addition to the computer generated graphs and annotations, additional comments are included on the plots to (1) explain the annotations and (2) point out some highlights illustrating the type of diagnostic information contained in the plots.

Eight debriefing plots were designed for the barrel roll:

1. Roll, pitch, airspeed, and altitude vs time
2. Heading vs time
3. g's vs time
4. |Roll| vs Pitch
5. Roll/Pitch Polar Plot

   θ = Roll

$R = |\text{Pitch}|$

Plot $X = R \cos \theta$ vs $Y = R \sin \theta$

6. Pitch vs Roll
7. Altitude vs Roll
8. g's vs Roll

Examples of these plots for two performances of the barrel roll are illustrated in Appendix XVII.

e. Summary of Experimental Measures

Section VIII of this report discusses the results of applying the experimental measures to a broad selection of student and instructor performances. For convenience in reference, the experimental measures are summarized below:

(1) Lazy 8

No.	Units	Experimental Measures
1	Deg	Max. (positive) pitch in half 1 (max. 1)
2	Deg	Min. (negative) pitch in half 1 (min. 1)
3	Deg	Max. (positive) pitch in half 2 (max. 2)
4	Deg	Min. (negative) pitch in half 2 (min. 2)
5	Deg	Roll at max. 1
6	Deg	Roll at min. 1
7	Deg	Roll at max. 2
8	Deg	Roll at min. 2
9	Kt	Airspeed at max. 1
10	Kt	Airspeed at min. 1
11	Kt	Airspeed at max. 2
12	Kt	Airspeed at min. 2

No.	Units	Experimental Measures
13	Ft	Altitude excursion at max. 1
14	Ft	Altitude excursion at min. 1
15	Ft	Altitude excursion at max. 2
16	Ft	Altitude excursion at min. 2
17	Deg	Max. positive roll
18	Deg	Max. negative roll
19	Sec	Time to perform half 1
20	Sec	Time to perform half 2
21	Sec	Total time for maneuver
22	Kt	Start airspeed - 200
23	Kt	1st min. airspeed - 100
24	Kt	Max. airspeed, end 1st half, - 200
25	Kt	2nd min, airspeed - 100
26	Kt	End airspeed - 200
27	Kt	Sum of measures 22-26 (all maneuver)
28	Kt	Sum of measures 22-24 (half 1)
29	Kt	Sum of measures 24-26 (half 2)
30	Kt	Airspeed excursion 1st quarter
31	Kt	Airspeed excursion 2nd quarter
32	Kt	Airspeed excursion 3rd quarter
33	Kt	Airspeed excursion 4th quarter
34	Kt/Sec	Rate of change of airspeed 1st quarter
35	Kt/Sec	Rate of change of airspeed 2nd quarter
36	Kt/Sec	Rate of change of airspeed 3rd quarter
37	Kt/Sec	Rate of change of airspeed 4th quarter
38	Sec	Time 1st quarter

No.	Units	Experimental Measures
39	Sec	Time 2nd quarter
40	Sec	Time 3rd quarter
41	Sec	Time 4th quarter

(2) Barrel Roll

No.	Units	Experimental Measures
1	Non-Dim.	Symmetry between quarters 1 and 4
2	Non-Dim.	Symmetry between quarters 2 and 3
3	Non-Dim.	Symmetry between halves 1 and 2
4	Non-Dim.	Comparison with circle - half 1
5	Non-Dim.	Comparison with circle - half 2
6	Non-Dim.	Comparison with circle - maneuver
7	Non-Dim.	Roll rate regression coefficients
8	Non-Dim.	
9	Non-Dim	Correlation: roll vs roll rate
10	Non-Dim.	Pitch rate regression coefficients
11	Non-Dim.	
12	Non-Dim.	Correlation: roll vs pitch rate
13	Non-Dim.	Normal acceleration regression coefs.
14	Non-Dim.	
15	Non-Dim.	Correlation: roll vs normal acceleration
16-24	Non-Dim.	Same as 7-15, but for |Roll| ≥ 45°
25	g	Max. g half 1
26	g	Max. g half 2
27	g	Min. g whole maneuver
28	Deg	Roll at max. positive pitch

No.	Units	Experimental Measures
29	Deg	Roll at max. negative pitch
30	Deg/Sec	Max. roll rate
31	Deg/Sec	Min. roll rate
32	Deg/Sec	Max. pitch rate
33	Deg/Sec	Min. pitch rate
34	Sec	Total time for maneuver
35	Sec	Time half 1
36	Sec	Time half 2

SECTION VI

FLIGHT TESTING AND DATA COLLECTION

The calibration of the data acquisition system was conducted principally at Wright-Patterson AFB, whereas the data collection flights on maneuver performance were accomplished predominantly at Williams AFB. Specifically, a total of 40 calibration flights and 51 maneuver data collection flights were conducted throughout the program. However, 17 of the flights flown in support of the Pilot Performance Measurement Program resulted in no useful data being obtained due to system malfunction or weather. The total flying time on 948 was 114.7 hours over 91 sorties.

Maintenance support for the aircraft and data acquisition system was provided by Flight Test at Wright-Patterson AFB and by Air Training Command technicians assigned to the Directorate of Maintenance at Williams AFB. Pilots from the Fighter Test Squadron and AFHRL research psychologists flew the calibration flights. All of the UPT student data collection flights were flown at Williams AFB with one of the AFHRL instructor pilots.

1. OPERATING PROCEDURES

The procedures discussed in this section have evolved from operational experience with the data acquisition system and resulted in the development of the most efficient method of recording calibration and maneuver data, within specific restrictions, for pilot performance measurement research.

a. Tape Handling

Prior to each flight, the one inch mag tape was installed in the Leach tape recorder according to the following procedures:

1. Check that all cockpit switches on the Recorder Control Panel are in the OFF position.

2. Apply 28 VDC ground power to the aircraft.

3. Turn the recording system MASTER SW to the ON position on the cockpit Recorder Control Panel.

4. Raise the guard on the GROUND TO FLIGHT switch and move this switch to the GROUND position.

5. Turn the TAPE RECORDER POWER switch to the ON position.

6. Remove the cover on the Leach tape recorder located in the lower fuselage bay area.

7. Check that the recorder POWER switch is in the ON position (When power is on, the STOP button will be RED).

8. Load the mag tape on the recorder with the supply reel on the right and take up reel on the left.

9. Actuate the FAST FORWARD switch and allow the tape to run for five seconds before activating the STOP button.

10. Place cover on tape recorder.

11. Return the TAPE RECORDER POWER switch to OFF position on cockpit Recorder Control Panel.

12. Return the GROUND TO FLIGHT switch to ON position (guard down).

13. Return COUNTER to zero.

14. Return MASTER SW to OFF position.

Subsequent to the flight, the tape was down-loaded and transported to the Data Reduction Branch of Flight Test. At Williams, the tapes were boxed and shipped via commercial air the same day of the flight. It became imperative to reduce the tape and print-out the data as quickly as possible in order to ascertain if all the parameter sensor systems and the tape recorder were operating properly. A minimum of three days was normally required between the student data flight at Williams AFB and a check of the data that was performed by the authors at Wright-Patterson.

b. Recorder Operating Procedures

Upon taxiing to the number one position for takeoff, the data acquisition system was turned to a standby mode and an automatic calibration cycle initiated as follows:

1. MASTER SW - ON
2. INVERTER switch - ON, red light out
3. PCM/DAS switch - ON
4. RECORDER POWER switch - ON,
   (TAPE OFF amber light on)
5. Check GROUND TO FLIGHT switch - ON
   (guard down), green light on
6. TIME CODE switch - ON
7. RECORDER CONTROL switch - ON
8. Complete equipment calibration check;
   (rapid sequence)
    a. Change record number
    b. Depress AUTO CAL button
    c. Change record number
9. RECORDER CONTROL switch - OFF

After flying under radar control to the designated area where the calibration tests or maneuvers were to be performed, the instructor pilot commenced the data collection by turning the RECORDER CONTROL switch to the ON position and changing the record number by depressing the RECORD NO. button. The record number was changed at the beginning and end of each maneuver in order to facilitate the visual examination of the data print-out and provide discrete events for computer data processing. The recorder was turned off during extended periods of time when data was not being scored, such as climb and descent. By employing this method of tape conservation, the 60 minute mag tape was of sufficient duration to record in excess of the average mission flying time of 1.3 hours.

Frequently the audio tape recorder was utilized on the mission. It proved to be an effective method for obtaining the instructor pilot's comments and critique of the student's performance narrative account of a maneuver being demonstrated by the IP, weather information, system malfunctions, and other qualitative data pertinent to describing the quantitative recording of performance.

2. CALIBRATION PROCEDURES

Precise procedures were established for the calibration of the flight and engine parameters with the corresponding cockpit instrument. The flight crew was briefed on the parameters and method of calibration prior to each flight. A Test Data Card was used to indicate the parameters to be calibrated and the value and record number of each data point. Additional information that was written on the Test Data Card included:

1. Aircraft type and number (T-37B/948)
2. Flight test project number (7184/604)
3. Date
4. Flight number
5. Pilot
6. Data recorder
7. Takeoff time
8. Landing time
9. Mission duration
10. Current altimeter setting
11. Auto calibration record number

The basic parameter calibration procedures were provided to the flight crew in the form of a checklist:

1. Set current altimeter setting in left altimeter and record setting on Test Data Card.

2. Prior to recording any calibration data, depress the AUTO CAL. button for one second with the recorder on.

3. Turn recorder on for the entire period that one parameter is being calibrated, so that data will reflect transition from one step to another.

4. Obtain a minimum of 5 seconds' scoring for each incremental step after the parameter is stabilized at the desired value.

5. Upon stabilizing at a new parameter step, depress RECORD NO. button to advance the counter, which signals the beginning of a 5-second' scoring period.

6. Write counter reading on Test Data Card for each parameter step.

7. Complete the scoring in succession when two steps are designated by a bracket.

8. Any deviations from normal calibration procedures should be noted on the data card or audio tape recorder.

Checklist item number 7 refers to a procedure used during the calibration of a parameter of reversing the established trend to determine if the resolution of the sensor system would be able to identify a small change in the opposite direction. Another technique used was to calibrate the parameter entirely in one direction (e.g., increasing airspeed) and then repeat the same data points but proceeding in the opposite direction (e.g., decreasing airspeed). Thus, two recorded data points could be compared for the same parameter value so that an assessment could be made of the reliability of the sensor system.

Table XIV indicates those parameters that were able to be calibrated in-flight, the range over which the calibration occurred, incremental steps established, and the magnitude of the reversal interjected in the general trend of the parameter.

3. MANEUVER DATA COLLECTION PROCEDURES

Flights conducted to gather maneuver performance data from instructor pilots and UPT students utilized the same operational procedures previously described in this section, plus several additional procedures.

The AFHRL instructor pilots provided descriptive information regarding the student on the Test Data Card as follows:

1. ATC Syllabus Instructional Unit flown (Sorties were all from the Contact, Dual, Advanced Maneuvers Instructional Units).

2. Number of last Contact, Advanced Maneuver Instructional Unit Flown, including date of flight, and whether flight was dual or solo.

3. Total hours of T-37 flying time accumulated by the student to date.

4. Prevailing weather: ceiling, visibility, turbulence.

5. Instructor comments on capability of student with respect to the class norm at that stage of training (e.g., low average, outstanding, solid and smooth student).

6. Mid-phase (contact) check ride grade.

7. Coded description of the maneuver performed such as L-8-L, a lazy-8 initiated to the left; B-R-R, a barrel roll to the right; PATT-L, a normal 360° overhead traffic pattern with a left break.

Instructor's grade on each maneuver performed by a student, another instructor pilot, or a maneuver demonstrated by the AFHRL IP.

TABLE XIV

PARAMETERS CALIBRATED IN-FLIGHT

PARAMETER	CALIBRATED RANGE	INCREMENTAL STEP CHANGE	REVERSED INCREMENTAL
1. Heading	0-360°	10°	5°
2. Altitude	1,200-20,000 ft	100 ft	50 ft
3. Airspeed	80-280 kt	10 kt	2 kt
4. Pitch Angle	0-70 (climb and dive)	5°	5°
5. Roll Angle	0-90° (left and right)	5°	5°
6. g Force	0 to +4.0 g	0.5g	0.5g
7. Longitudinal Stick Position	Neutral to Full Deflection Forward and Aft		
8. Lateral Stick Position	Neutral to Full Deflection Left and Right		
9. Rudder Position	Neutral to Full Deflection Left and Right		
10. RPM	60-100%	1%	1%
11. Flaps	0-100%	20%	50%
12. Landing Gear	Up and Down		
13. Speed Brakes	In and Out		
14. Elevator Trim Tab Up	On and Off		
15. Elevator Trim Tab Down	On and Off		
16. Time	0-60 sec	10 sec	

The rating system employed on the maneuver data collection flights was the standard ATC rating scale. This is an absolute rating scale whereby the student's performance is judged against the perfectly flown maneuver whether he is an experienced instructor or a neophyte student pilot. No consideration is given to the type or amount of training the student has received. The categories of the rating scale are:

Excellent (E) - The student performed the maneuver correctly, quickly, and efficiently.

Good (G) - The student performed the maneuver with little hesitation and no assistance.

Fair (F) - The student performed the maneuver, but made some false starts, repetitions, or minor errors of omission or commission.

Unable to Accomplish (U)[1] - The student lacked sufficient knowledge, skill, or ability to perform the maneuver without assistance.

Another procedure instituted for the maneuver data collection flights was a brief calibration of several parameters during the climb or immediately after level off. The purpose of this calibration procedure was to ascertain, on a regular basis, that the more important sensor systems and magnetic tape recorder were operating properly. The instructor recorded a single data point and record number on the Test Data Card while the student flew the aircraft in a steady-state condition on the following parameters:

1. Heading
2. Altitude
3. Airspeed
4. Pitch Angle
5. Roll Angle

---

[1] Sometimes referred to in the report as unsatisfactory.

6. g Force
7. RPM

Immediately upon receipt of the computer print-out from these maneuver data flights, the authors would visually examine each of these seven parameters at the specific record numbers indicated on the Test Data Card. A comparison was made of the recorded data point and the instrument reading to determine if the data point fell within the normal resolution capability for that parameter. Also, a flight-by-flight plot of each parameter was accomplished to provide trend information on the reliability of the parameter sensor system. If any malfunction was revealed in the data acquisition system during these cursory calibration checks, the data collection flights were temporarily suspended until the equipment problem had been analyzed and corrected by the instrumentation technicians. The infrequent system malfunctions usually required the magnetic tape recorder head to be cleaned or the tape drive unit to be repaired.

a. UPT Student Data

A total of 31 UPT student pilots from the classes of 7105 and 7106 flew aircraft 948 on maneuver data collection flights conducted by the two AFHRL instructor pilots. Table XV presents a summary of these flights.

The original plan developed for the UPT data collection phase was that nine to twelve UPT student pilots would be randomly selected from two flights from each of the two classes. The intent was to collect maneuver data from these students at approximately four intervals during their Contact, Advanced Maneuver phase of flying. In this manner, the authors felt that representative data would be acquired to reflect the learning process on the two primary maneuvers, lazy 8 and barrel roll. However, as shown in Table XV, only six of 31 students flew more than one data collection flight in 948. Such factors as the rapid rate of student progression in the T-37 phase, conflict in scheduling missions for the appropriate ATC instructional units, turn-around capability

TABLE XV

SUMMARY OF UPT STUDENT DATA COLLECTION FLIGHTS

STUDENT	FLIGHTS	LAZY 8	BARREL ROLL	TRAFFIC PATTERN	OTHER MANEUVERS
1	2	4	5	2	
2	1	3	1	5	
3	1	3	2	0	
4	1	2	2	1	Immelmann - 2
5	1	2	2	4	
6	4	10	8	4	Cloverleaf-2, Aileron Roll-1
7	1	3	3	1	Immelmann -1, Cuban 8-1
8	1	2	4	1	
9	2	3	4	1	Cuban 8-1
10	1	3	0	1	
11	1	3	3	1	Immelmann-1
12	2	5	4	7	Immelmann-1
13	1	2	0	0	
14	2	6	4	1	Loop-1
15	1	2	1	3	Cloverleaf-2, Immelmann-3
16	1	2	1	1	
17	1	1	1	4	Immelmann-2
18	1	2	2	0	Loop-1, Immelmann-1
19	1	2	3	0	
20	1	2	3	0	
21	1	2	2	0	Immelmann-1
22	3	6	5	2	Vertical S, Immelmann-1
23	1	2	3	1	
24	1	0	4	2	
25	1	2	6	1	
26	1	2	0	4	
27	1	2	3	1	Cloverleaf-1
28	1	2	4	1	Cuban 8-1
29	1	4	3	0	
30	1	2	2	0	
31	1	1	1	3	Cloverleaf-2, Immelmann-1
TOTALS	40	87	86	52	

of 948, and the requirement to fly UPT students on a non-interference basis all posed serious limitations to the achievement of the original goals for student data collection. In effect, the data acquired provided a larger sample size and thus a more representative range of skill level of UPT student pilots, from which to draw lazy 8 and barrel roll maneuver data for the analysis and development of performance measures. However, measurement validation was hampered due to lack of sufficient data per individual student.

b. Instructor Pilot Data

Maneuver data was collected from five T-37 instructor pilots and is summarized in Table XVI. A highly qualified instructor from the T-37 Pilot Instructor Training (PIT) program was temporarily assigned to the Pilot Performance Measurement System program for the purpose of flying lazy 8 and barrel roll maneuvers that represented the range of skill manifested by UPT student pilots on these maneuvers. The PIT IP flew at least 10 lazy 8's and 10 barrel rolls for each of the four skill rating categories - E, G, F, and U. Additionally, the IP described the maneuver verbally as he was performing it. Recorded on the audio tape, the narrative consisted of pointing out the significant parameters and criterion points utilized to teach the maneuver in ATC, normal range of values around the criterion points, factors that affect the IP's rating of the maneuver, and common errors experienced by UPT students. Examples of the IP's description of the maneuvers can be found in the following Section.

Instructors 1 and 2 were the AFHRL IP's that conducted the student data collection flights while Instructors 3 and 4 were line ATC IP's. The maneuver data from these five instructor pilots provided the authors with base-line data with which to formulate performance measures for the quantitative assessment of student pilot performance.

TABLE XVI

SUMMARY OF INSTRUCTOR DATA COLLECTION FLIGHTS

INSTRUCTOR	FLIGHTS	LAZY 8	BARREL ROLL	TRAFFIC PATTERN	OTHER MANEUVERS
PIT	7	48	47	7	Loop -1
IP -1	21	12	11	2	Immelmann-3
IP -2	27	11	12	1	Immelmann-2
IP -3	1	0	0	1	Vertical S, Immelmann-1
IP -4	1	3	2	1	
TOTALS	57	74	72	12	

c. Summary

Several factors were encountered in the flight testing and data collection phase that, to a certain extent, altered the design of the Pilot Performance Measurement System program. Primarily these factors consisted of limitations in the recording of the heading parameter, reduced resolution capability for altitude, reliability problems experienced with the magnetic tape recorder, and the difficulty in the timely scheduling of UPT student pilots. This in no way detracts, however, from the achievements and effectiveness of the program which, in retrospect, is considered to have been quite successful.

SECTION VII

MEASUREMENT ANALYSIS

In this Section, final measures are developed for recommended applications in measurement of the lazy 8 and barrel roll. Also included are some relevant observations that unfolded regarding standardization within and between instructors in both their performance and rating of the maneuvers, performance criteria, and methods that should be employed in developing and validating measures in future efforts.

The authors have elected to present these findings in the general order in which they developed during the investigation. First, lazy 8 measures for the instructor pilot from the ATC Pilot Instructor Training (PIT) school are summarized and discussed. The measures are correlated with the subjective ratings, which were provided in-flight by the performing pilot. This is done for the purposes detailed on pages 16-17 of this report. With the guidance of these correlations, and with the added benefit of observing trends of the measures (mean and standard deviations) across different skill levels, a simple combination of selected measures is then developed and shown to account, in itself, for at least 67% of the variance in subjective ratings.

The AFHRL instructor pilots' lazy 8 performances are then examined. Due to a deficit in the amount of data collected on instructors as well as a lack of even distribution of the performances across all four subjective rating categories (as judged by the instructors themselves in-flight), the only topic pursued is inter- and intra-instructor variance in performance. For this investigation, the PIT instructor pilot is compared with AFHRL and ATC instructor pilots. It can be shown, for example, that if two different IP's demonstrated the lazy 8 for a given student, one could expect as much as 27 knots difference in the value of airspeed at one critical point in the maneuver.

Next, experimental measures for student performances of the lazy 8 are examined. As in the case of the PIT IP data, correlations are computed between measures and subjective ratings. Contrary to the PIT data, few of the correlations are significant, and the simple combined measure which discriminated skill levels quite well in the PIT case appears worthless when applied to the student data.

At this point, the subject of validation technique is addressed. The authors propose (and, but for lack of sufficient data, would have used) within-subject sampling as an ultimate basis for validation as well as development of measures. This validation technique is demonstrated by using data for one student, for which, fortunately, sufficient data were collected to at least illustrate the concept. Despite the complete lack of validity of the combined-error measure seen in its application to student data and comparison with subjective ratings, validity is supported by the trend of the measure, as it varies across one student's performances.

To further support the lack of confidence that should be placed in subjective ratings as evidence of measurement validity, a comparison is made of instructors' rating standards. This is pursued by comparing the correlations between measures and subjective ratings for one IP with those for a second IP. It is shown that while the number of significant correlations does not increase appreciably when considering one IP at a time, the strength of the correlations for various measures differs markedly between the two IP's. This suggests a difference in emphasis that is placed by the two IP's on various aspects of the performance.

Finally, for the lazy 8 at least, a set of final measures is recommended along with a summary of related findings.

The barrel roll is treated next, but not as extensively as the lazy 8, due to lack of sufficient data. The experimental measures for student data are presented as well as their correlations with subjective ratings. The indications are that to a much greater extent than in the lazy 8, standards must be determined for the barrel roll. Based on the data examined, specific measures are recommended for validity testing in future studies.

Finally, some plots of selected variables for other maneuvers are presented. The maneuvers are:

Loop

Stall

Cloverleaf

Max. Performance Climbing Turn

Immelmann

Cuban 8

These maneuvers were not addressed from a measurement standpoint, but are briefly presented here merely for possible reader interest.

With this introduction, the next topic presented is the measurement analysis, beginning with the lazy 8.

1. LAZY 8

a. PIT Instructor/Pilot

For 47 performances by a single PIT instructor, the experimental measures were computed. The performances were rated in-flight by the performing pilot, and the ratings are distributed across the four rating categories as shown in Figure 33.

For each measure, the mean and standard deviations were plotted as shown in Figures 34 through 39. In addition, each measure was correlated with the subjective ratings assigned to each performance. The resulting correlation coefficients are presented for all performances, all right performances, and all left performances in Table XVII.

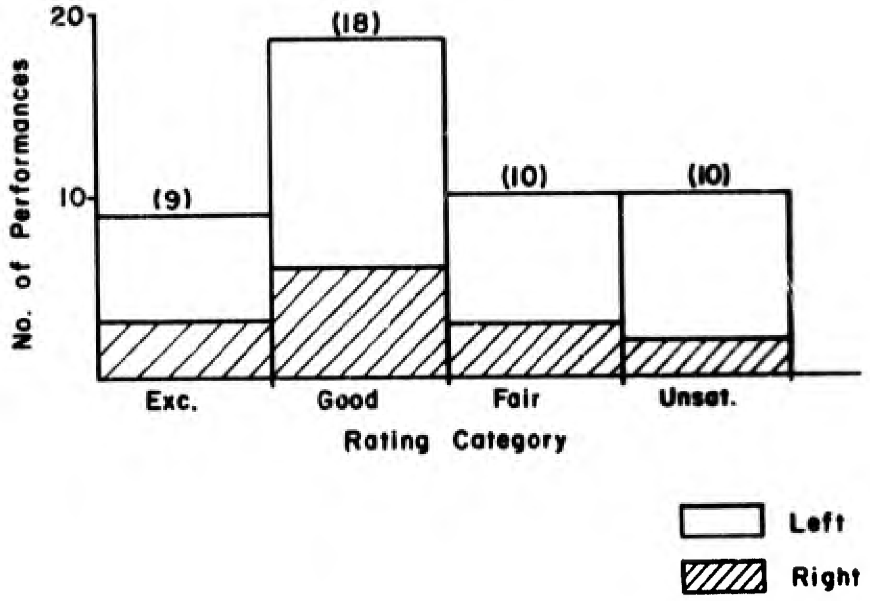


Figure 33. Distribution of PIT Instructor Lazy 8's Across Rating Categories

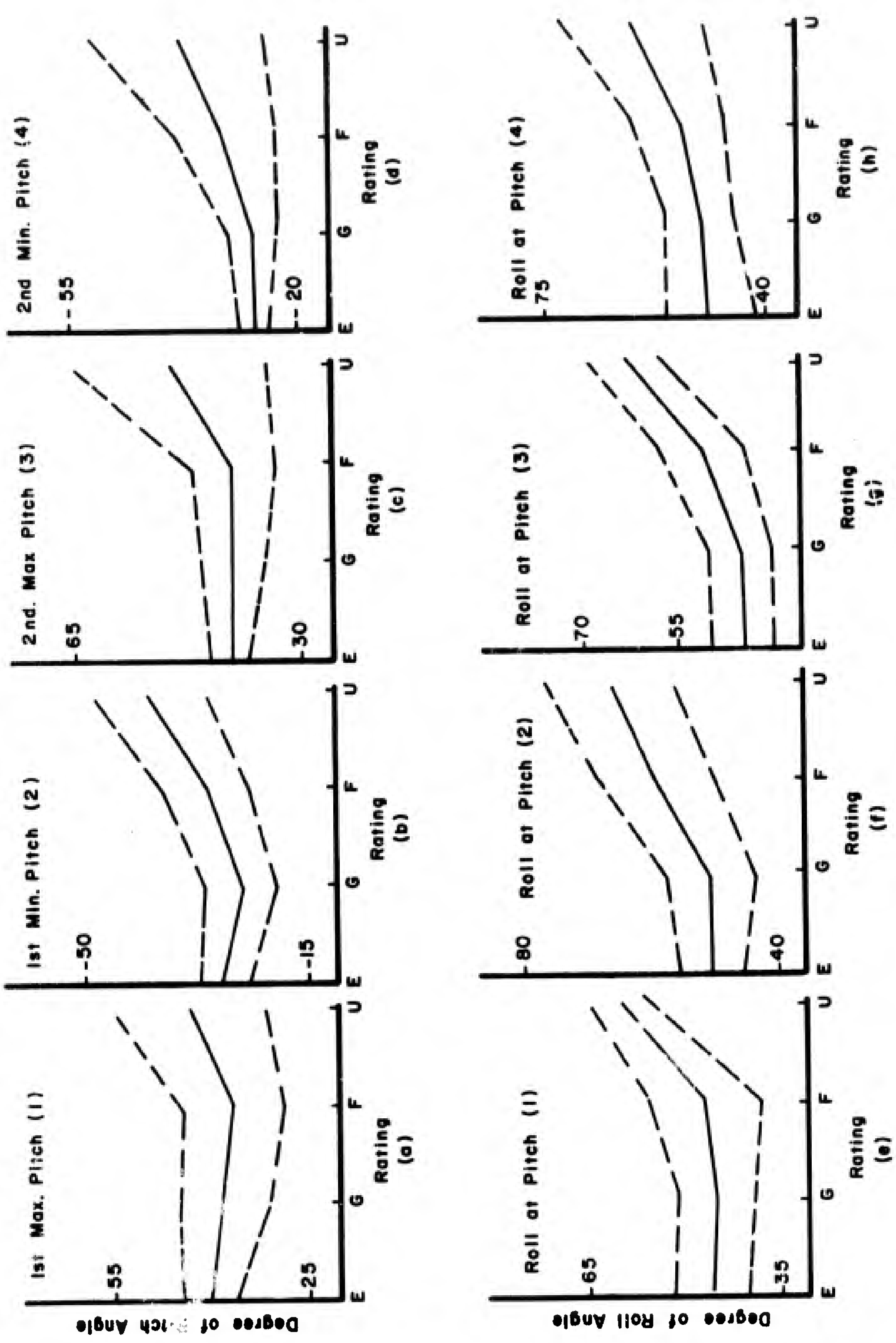


Figure 34. Pitch and Roll Measures for PIT Instructor Lazy 8's [Mean $\pm 1\sigma$]

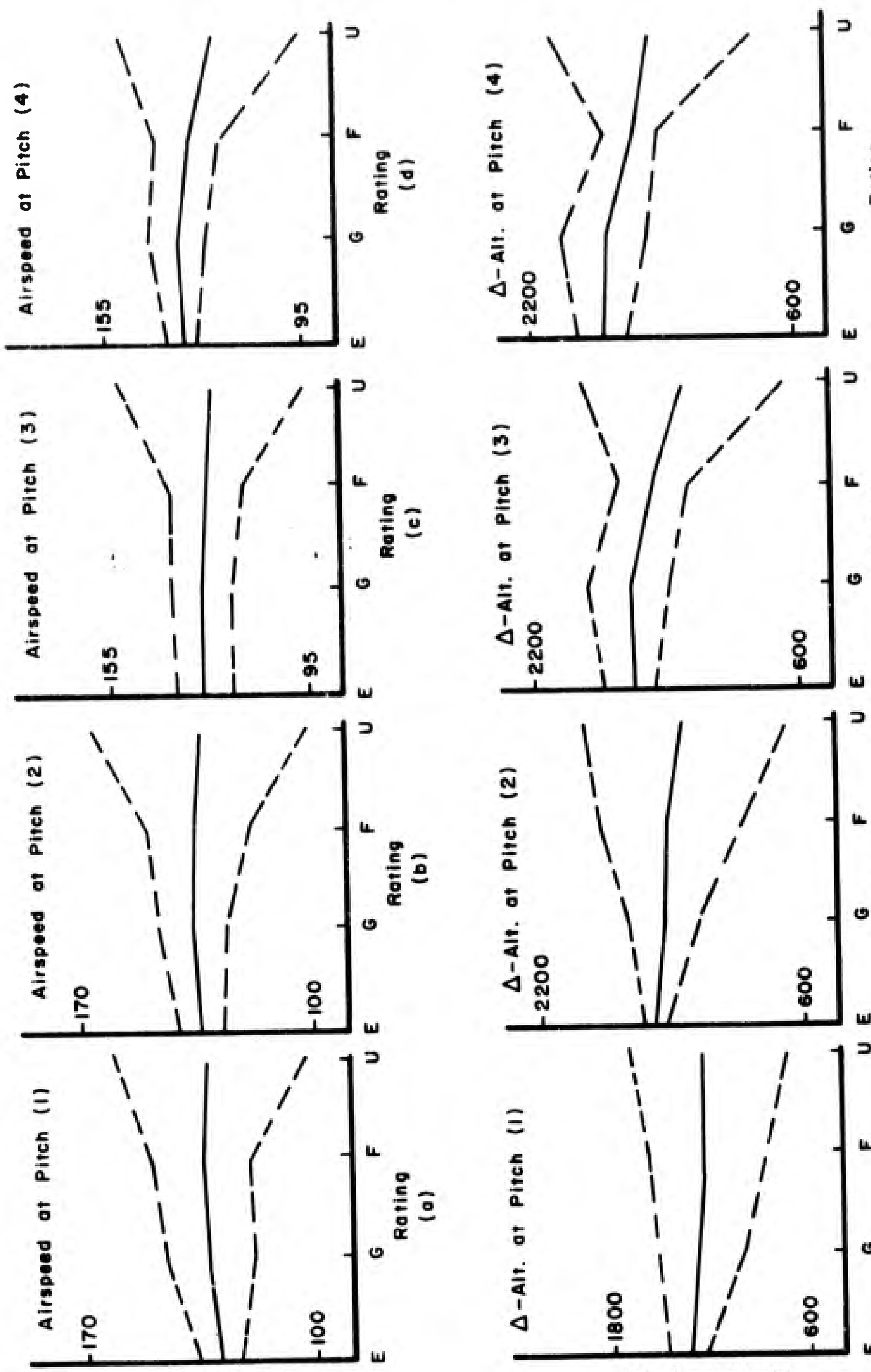


Figure 35. Airspeed and Altitude Measures for PIT Instructor Lazy 8's [Mean $\pm 1\sigma$]

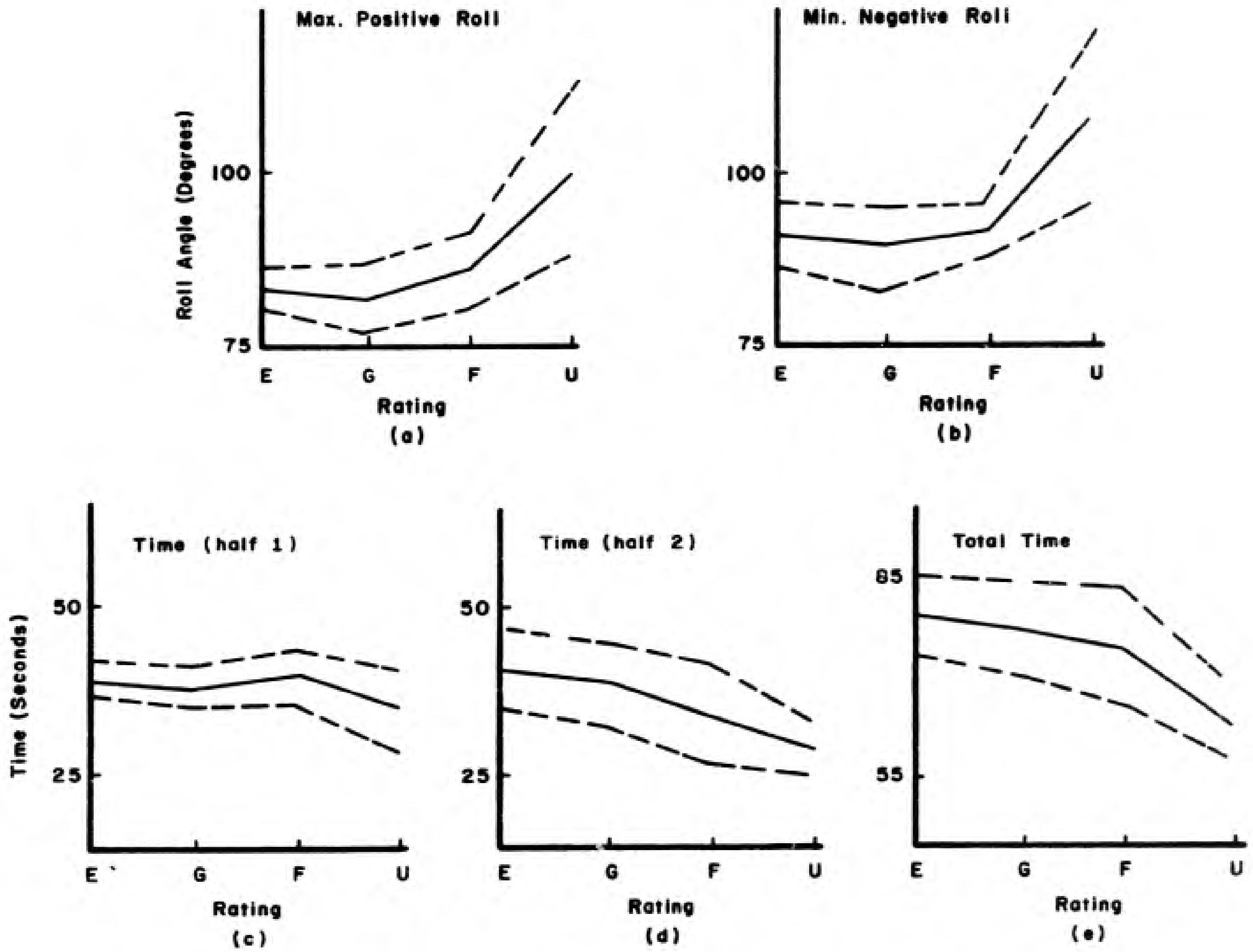


Figure 36. Roll and Time Measures for PIT Instructor Lazy 8's
[Mean ± 1σ]

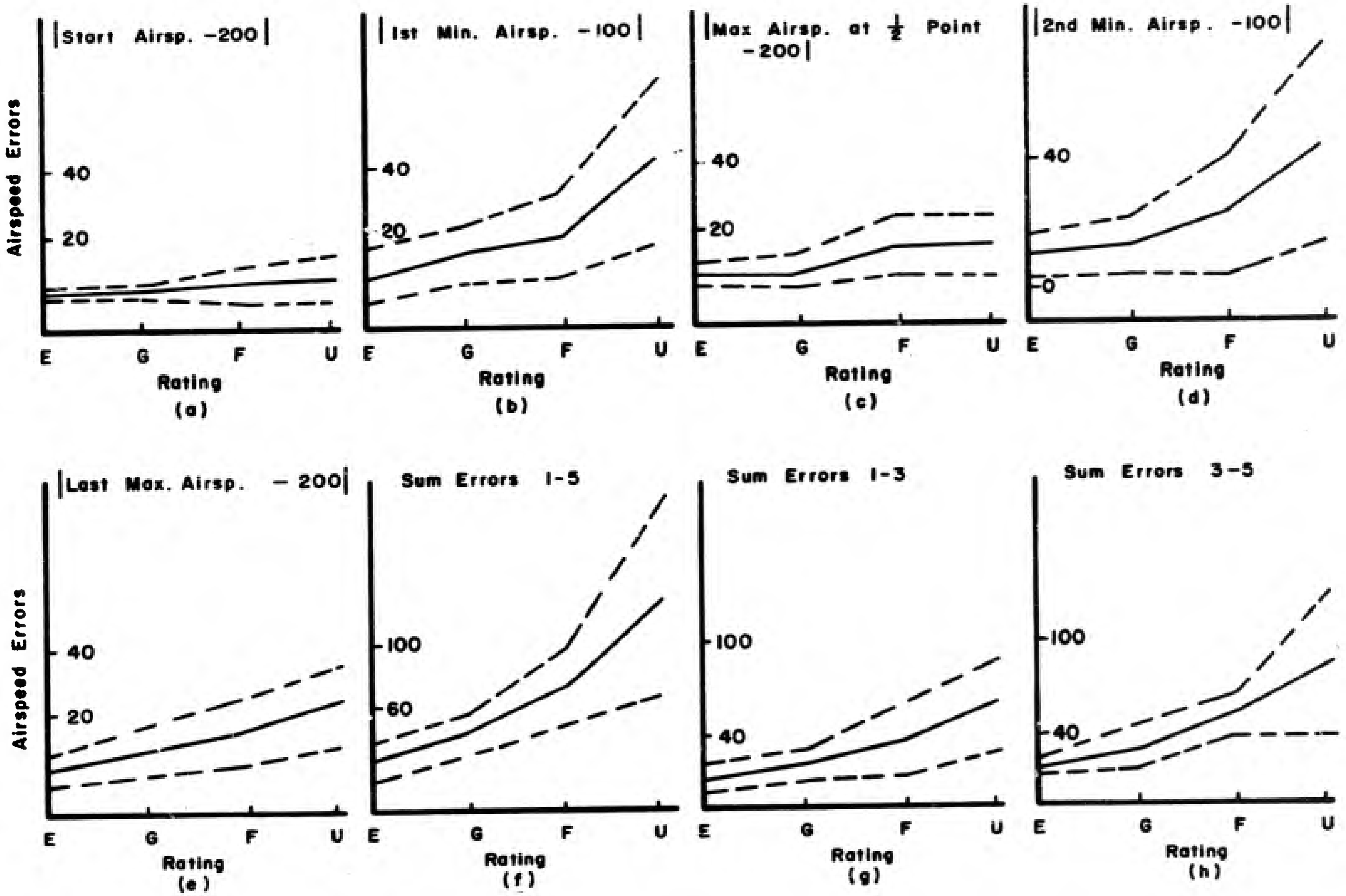


Figure 37. Airspeed Error Measures for PIT Instructor Lazy 8's [Mean ± 1σ]

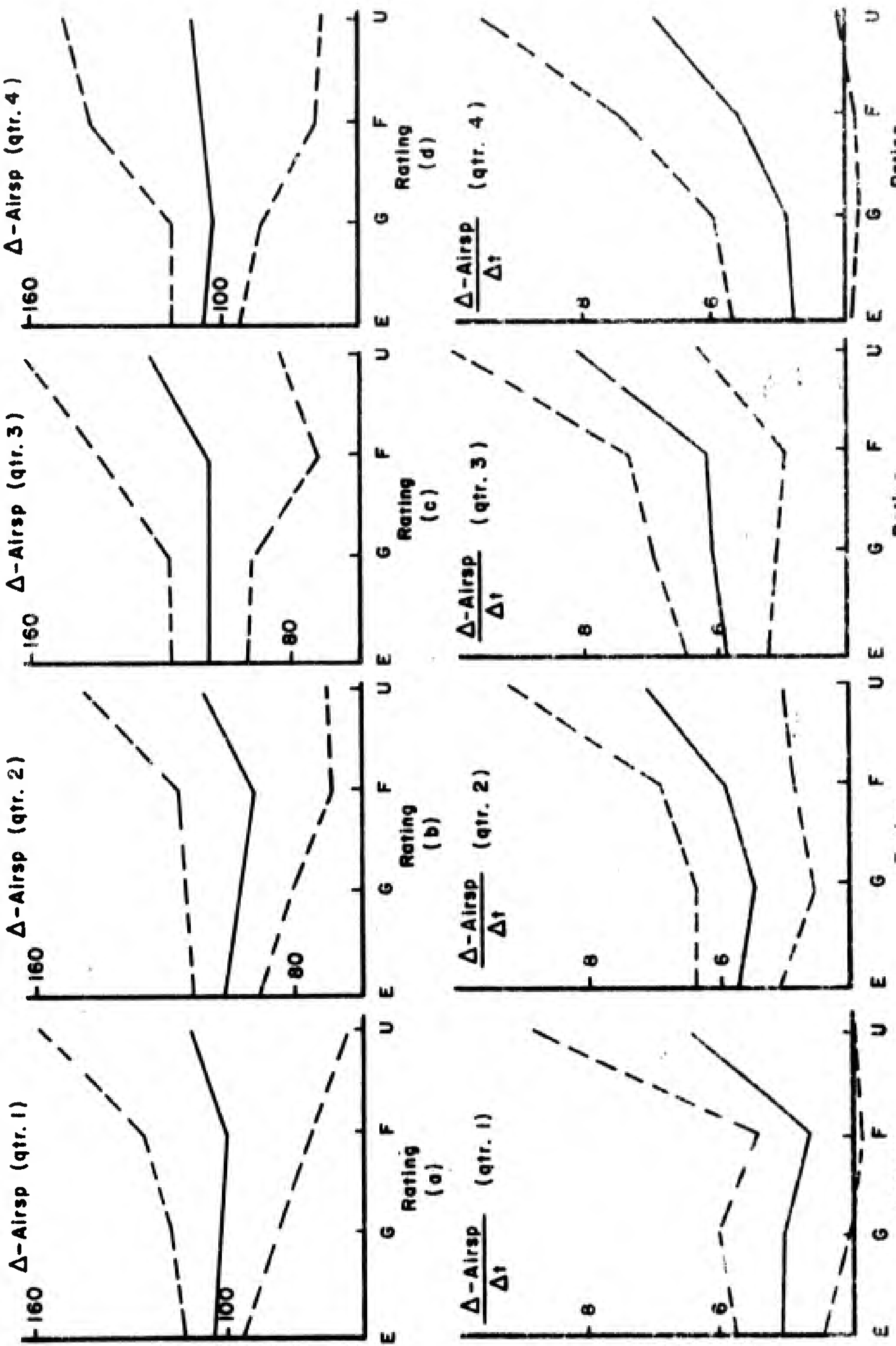


Figure 38. Airspeed Excursion and Rate Measures for PIT Instructor Lazy 8's [Mean $\pm$ 1 σ]

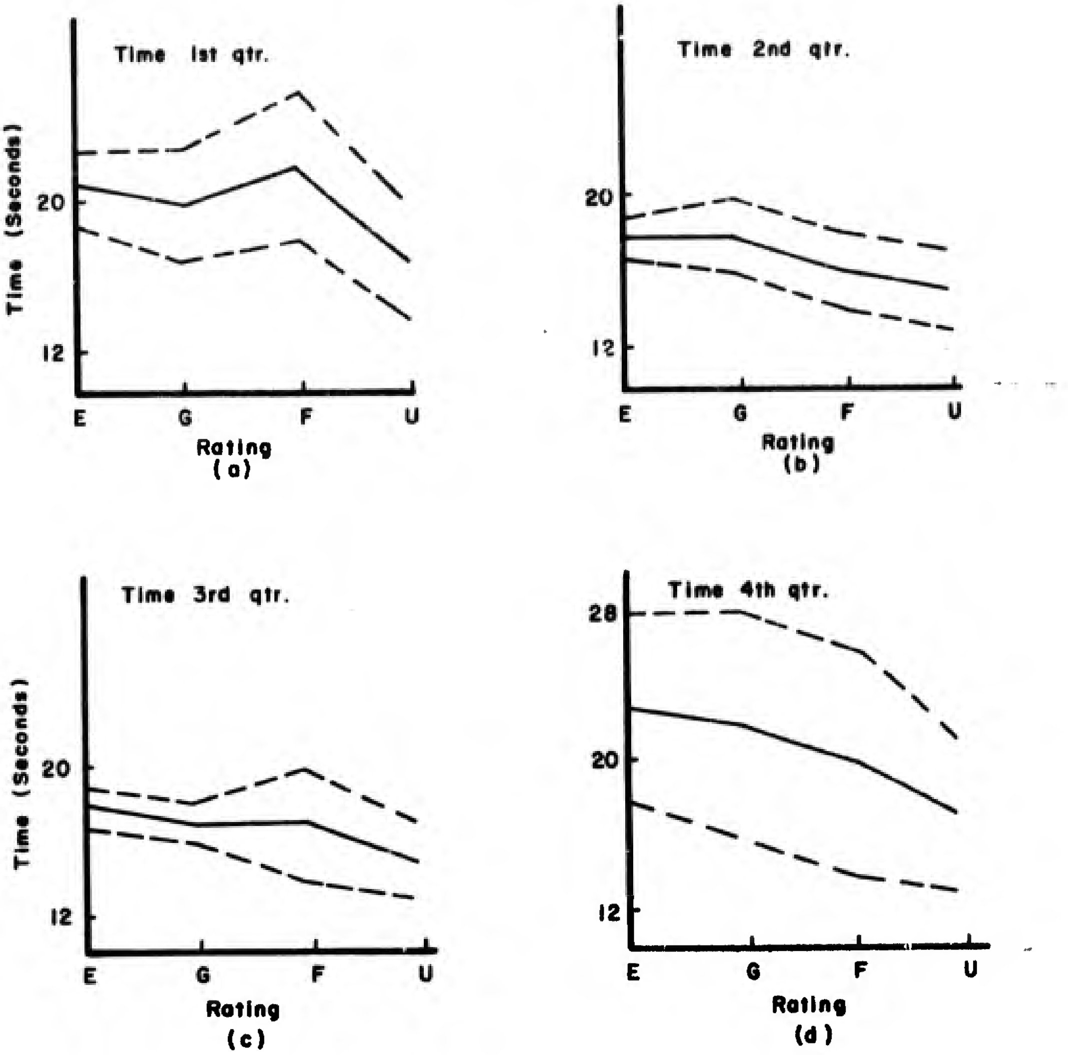


Figure 39. Time Measures for PIT Instructor Lazy 8's [Mean $\pm 1\sigma$]

TABLE XVII

CORRELATIONS BETWEEN MEASURES AND SUBJECTIVE RATINGS FOR PIT INSTRUCTOR LAZY 8 PERFORMANCES

Measure	Correlation Coefficients		
	All	Right	Left
1. Max. 1 Pitch (1)	-0.11	-0.16	-0.09
2. Min. 1 Pitch (2)	0.51*	0.48	0.53*
3. Max. 2 Pitch (3)	-0.29	-0.66	-0.15
4. Min. 2 Pitch (4)	0.46*	0.72*	0.40
5. Roll (1)	-0.54*	-0.32	-0.60*
6. Roll (2)	-0.60*	-0.59	-0.73*
7. Roll (3)	-0.74*	-0.56	-0.80*
8. Roll (4)	-0.48*	-0.52	-0.60*
9. Airspeed (1)	-0.06	0.17	-0.09
10. Airspeed (2)	0.00	0.24	-0.05
11. Airspeed (3)	0.09	0.67	-0.14
12. Airspeed (4)	0.25	0.64	0.14
13. Altitude (1)	0.27	-0.06	0.12
14. Altitude (2)	0.15	0.05	0.18
15. Altitude (3)	0.31	-0.06	0.40
16. Altitude (4)	0.33	0.13	0.37
17. Max. Roll	-0.64*	-0.31	-0.72*
18. Min. Roll	0.60	0.66	0.56*
19. Time (half 1)	0.23	-0.33	0.56*
20. Time (half 2)	0.60*	0.47	0.57*
21. Total Time	0.61*	0.42	0.68*
22. Airspeed Error 1	-0.41*	-0.41	-0.42
23. Airspeed Error 2	-0.62*	-0.66	-0.62*
24. Airspeed Error 3	-0.43*	-0.47	-0.43
25. Airspeed Error 4	-0.58*	-0.87*	-0.48*
26. Airspeed Error 5	-0.58*	-0.70	-0.54*
27. Sum (1-5)	-0.74*	-0.87*	-0.70*
28. Sum (1-3)	-0.69*	-0.74*	-0.67*
29. Sum (3-5)	-0.71*	-0.87*	-0.66*
30. Delta Airspeed (1)	-0.09	-0.35	-0.02
31. Delta Airspeed (2)	-0.07	-0.28	-0.02
32. Delta Airspeed (3)	-0.22	-0.59	-0.05
33. Delta Airspeed (4)	-0.05	-0.64	0.15
34. Airspeed Rate (1)	-0.27	-0.33	-0.29
35. Airspeed Rate (2)	-0.38*	-0.47	-0.36
36. Airspeed Rate (3)	-0.51*	-0.63	-0.46*
37. Airspeed Rate (4)	-0.40*	-0.68	-0.27
38. Time (1)	0.31	-0.04	0.40
39. Time (2)	0.57*	0.49	0.59*
40. Time (3)	0.50*	0.05	0.61*
41. Time (4)	0.40*	0.36	0.44

*Significant to 0.01 level

Debriefing plots for each performance were also produced and used as an aid in the analysis. Where available the pilot's voice transcript was attached to the appropriate set of plots. Sample plots for one of the performances are presented in Figures 40 through 42. (Refer to Appendix XVI for interpretation of the plots.)

Using this data it was possible to make a number of general observations that provide insight to general performance of the lazy 8 as well as to its measurement. These observations are presented next. They are based primarily on the data in Figures 34 through 39.

(1) General Observations

The following observations are based exclusively on the PIT Instructor performance data as shown in Figures 34 to 39, Table XVII, and (although not shown) the debriefing plots. In the ensuing presentation of the observations, this qualification prevails. No use will be made of additional qualifiers (e.g., "it appears...") as is the normal tendency when presenting data of this type.

In performance of the lazy 8, positive pitch excursions exceed negative pitch excursions by at least 10 (Figure 34, a-d). This is not in accordance with the original maneuver analysis performed by ATC. Since the airspeed should vary between 200 and 100 knots, the probable reason for positive and negative pitch excursions being unequal is (a) the pilot attends to airspeed and not to pitch and (b) the aircraft accelerates and gains airspeed in a nose-down configuration faster than it decelerates and loses airspeed in a nose-up configuration.

Generally, greater pitch excursions, both positive and negative, are experienced in the poorer performances. Also much more variance in pitch occurs in the second half of the maneuver than in the first half for poor performances. This is probably due to the accumulated effect of errors on other parameters incurred in the first half (especially airspeed errors) and the ensuing attempt on the part of the pilot to "make up" for these errors in the second half. Pitch variance

12-19-69
ENVO- 70
(1 LEFT)

(12-19-69 EVNO 71 1 LEFT)

The student pilot turns up almost to the north to do a lazy 8 to the left. This time the student is starting out almost exclusively with pitch and very little bank change. Now with the pitch attitude of about 60°, he is rolling into the bank, slicing the nose down through after approximately 90° of turn, down below the point of the configuration, rolls out, makes a straight-ahead pullup by proceeding to come through with approximately 200 knots. He is essentially making the maneuver easier for himself by not changing all the parameters at once. That would have been an unsatisfactory lazy 8.

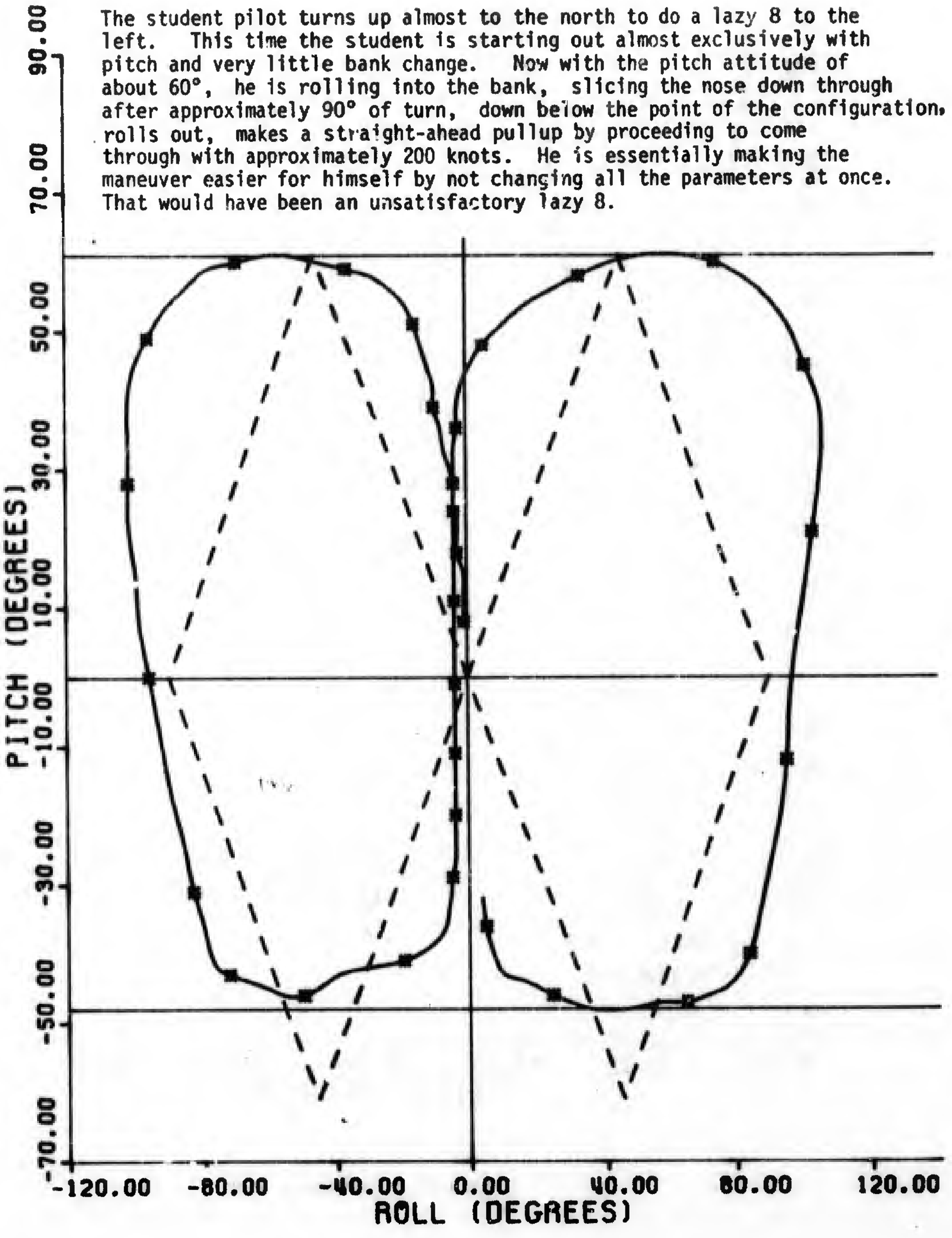


Figure 40. Roll vs Pitch Plot

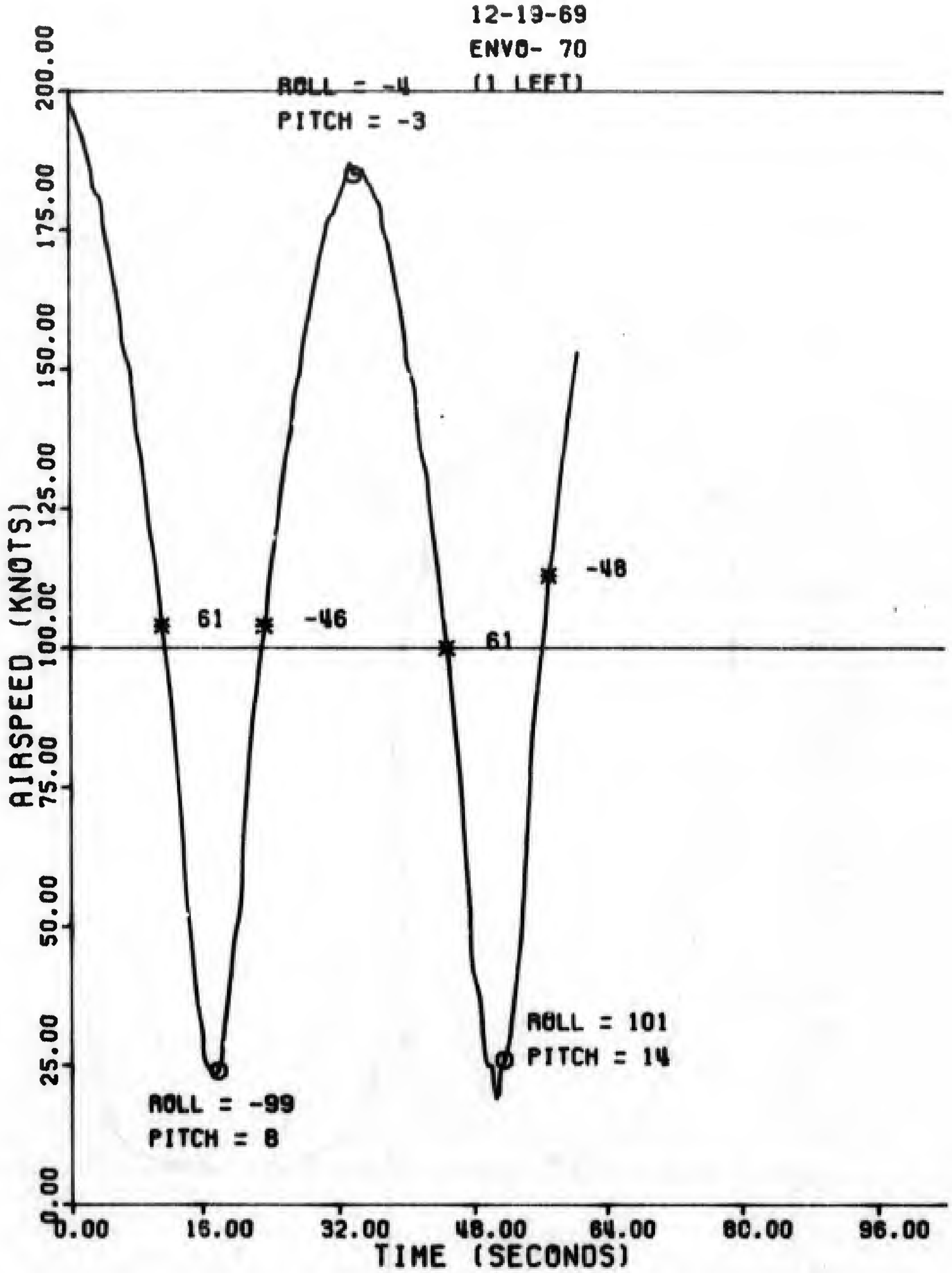


Figure 41. Airspeed Plot

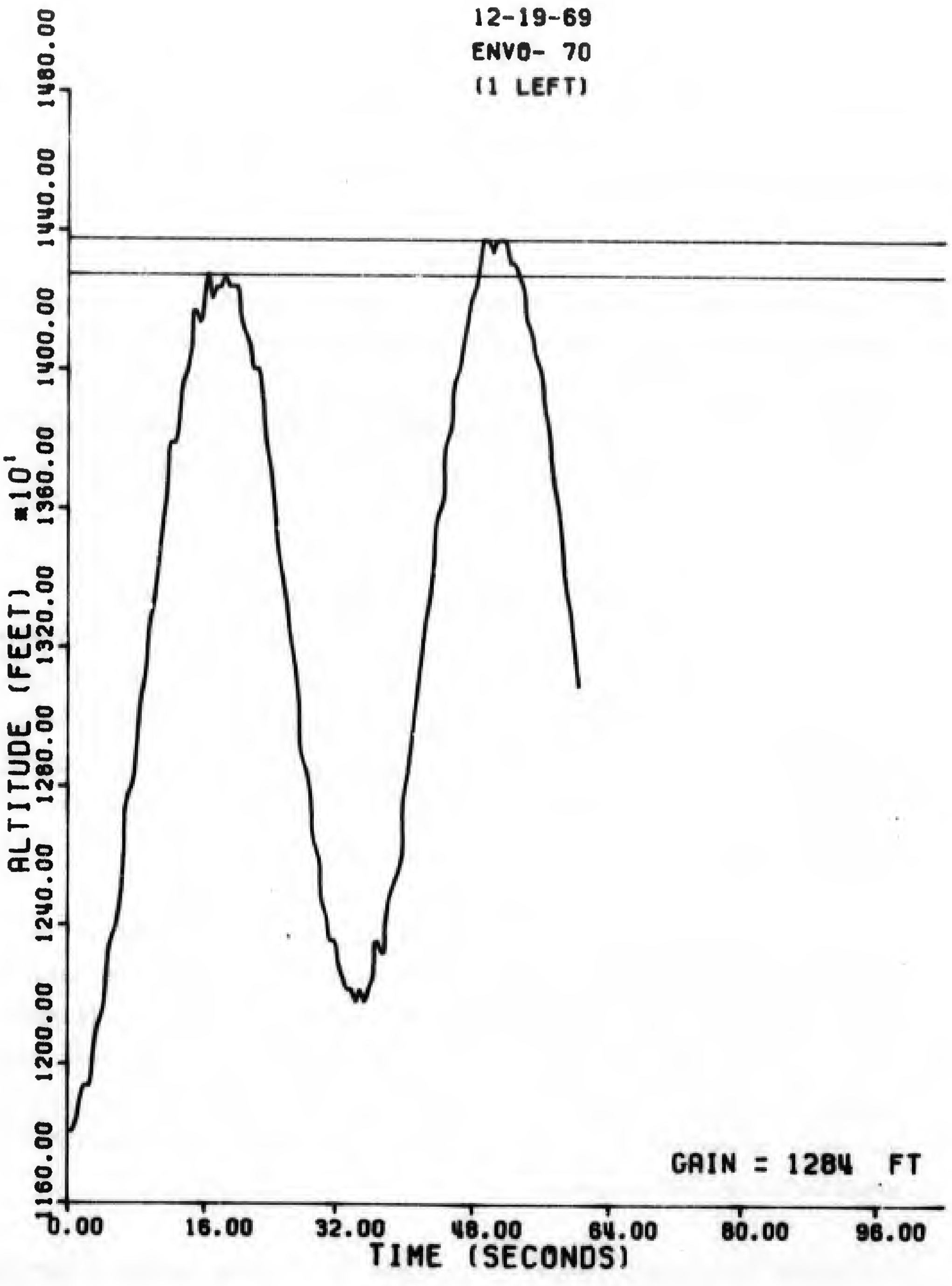


Figure 42. Altitude Plot

noticeably increases as skill ratings decrease (e.g., as ratings proceed from excellent to unsatisfactory).

As skill ratings decrease, there is a noticeable increase in the value of roll angle achieved at the points of local maximum and minimum pitch (Figure 34, e-h). Thus, both roll and pitch exhibit wider excursions for lower skilled performances.

There is a very evident increase in the variance on airspeed measures as skill ratings decrease (Figure 35, a-d). This is particularly obvious in discriminating fair from unsatisfactory performance. However, there is little change in the actual airspeed measures themselves, the only possible exception being in the fourth quarter of the maneuver where the measures are lower for unsatisfactory performances.

There is an observable increase in the variance on altitude excursions as skill ratings decrease, but this is true for only the first half of the maneuver (Figure 35, e-h). In the second half, the same tendency is observed only from fair to unsatisfactory degradation. Over the whole maneuver, an overall altitude gain ranging from 100 to 1000 ft is usually observed, but there is no apparent correlation between altitude gained and skill level.

The maximum positive and negative roll angles achieved in the maneuver show a definite increase in value as skill ratings vary from the excellent or good category to fair and unsatisfactory (Figure 36, a-b). Again, this supports previously discussed observations regarding greater parameter excursions in general as skill ratings decrease. The variance on maximum roll angles shows an increase only from fair to unsatisfactory performances.

There is a general decreasing trend in the time taken to perform the maneuver as skill ratings decrease, but there is no significant change in variance (Figure 36, c-e). This illustrates a tendency to perform the maneuver faster (and with wider pitch and roll excursions) in the lower skill categories; however, time as a measure is not expected to be significant.

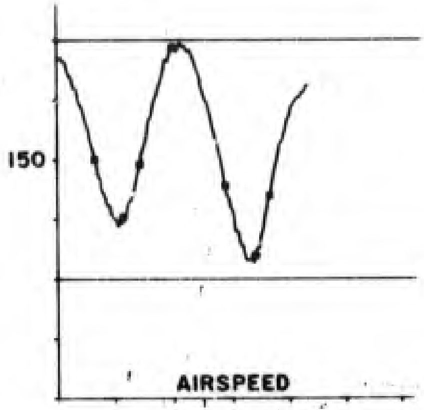
Airspeed errors and the variances thereof show a noticeable increase as skill ratings decrease, particularly at the points of maximum positive or negative roll (i.e., at the end of the first and third quarters of the maneuver, Figure 37, a-h).

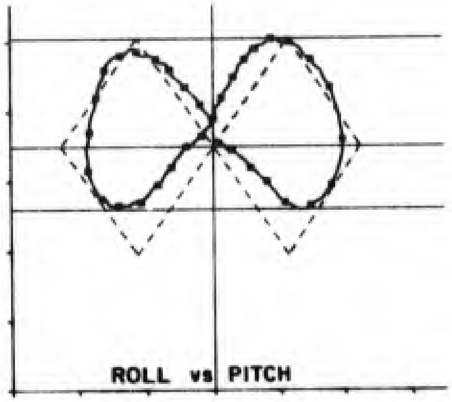
Airspeed excursions show an obvious increase in variance as skill ratings decrease (Figure 38, a-d). This is particularly evident in the second half of the maneuver from the excellent/good to the fair/unsatisfactory categories.

The rate of change of airspeed with respect to time is generally lower in the first and fourth quarters than in the second and third quarters (rates begin and end slowly with respect to the middle portions of the maneuver) (Figure 38, e-h). The widest variances occur as well in the first and fourth quarters, particularly for unsatisfactory performances.

Contrary to guidelines used by many instructors in teaching and performing the lazy 8, the value of airspeed at points of maximum positive and negative pitch does not appear to be 150 knots as judged by the PIT Instructor data. Observation of this came first from analysis of the debriefing plots and is substantiated by the mean-data presented in Figure 35 (a, b, c, and d). Following is a presentation of the first several lazy 8s flown by the PIT instructor and, where available, his recorded comments. In addition to providing a number of insights to the correct performance of the maneuver, this presentation will illustrate the errors incurred when the pilot attempted to use 150 knots as a check point; and the improvement of the performances when he apparently abandoned its use.

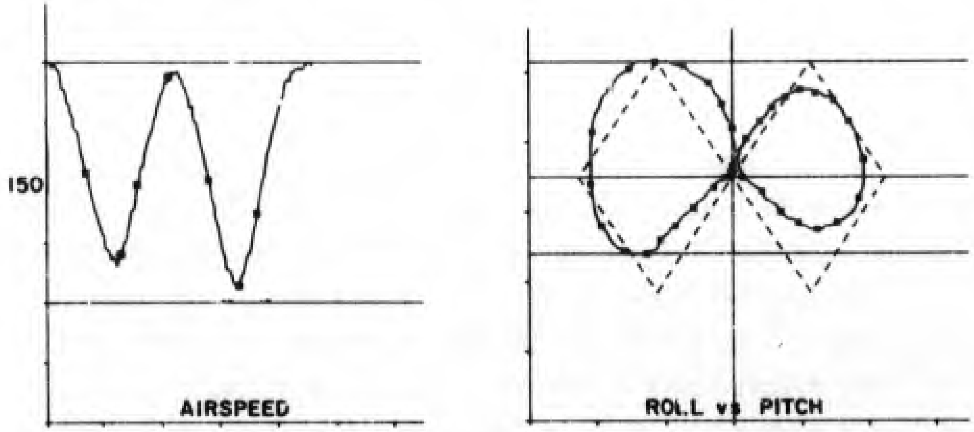
Performance 1 (11-18-69, event 4) Rating: Good





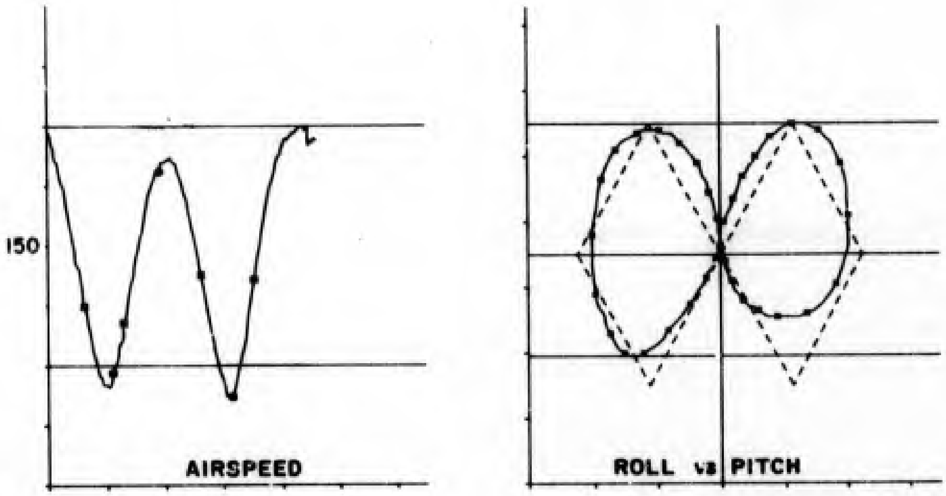
Pilot's Commentary: "As you know, the lazy 8 is a maximum performance maneuver where we will attempt to fly the airplane through a wide range of airspeeds, bank angles, and pitch attitudes. Power is 90%, our entry airspeed is 200 knots; speed brake is up. To accomplish the maneuver we will start a climbing turn very similar to a climb for a maximum performance climbing turn, planning to have our maximum pitch attitude after 45° of turn, or right about now. Airspeed should be approximately 150 knots. The nose begins to come down at this time. Bank is still increasing. Nose through the horizon after 90° of turn, down to its lowest point. You will notice that the airspeed was high during the point the nose came through the horizon, down to the nose lowest after 135° of turn. Back up to 200 knots and level flight now. Try to correct the mistake I made during the first half of that one by increasing my pitch more during the first half of this next maneuver and getting my airspeed down, planning to come through after 90° of turn. Airspeed still a little high, about 114 knots. Nose lowest after 135, back up to level flight after 180° of turn. End of maneuver. I would have graded that one about a low good or a high fair. Lets call it a good maneuver."

Performance 2 (11-18-69, event 5) Rating: Good



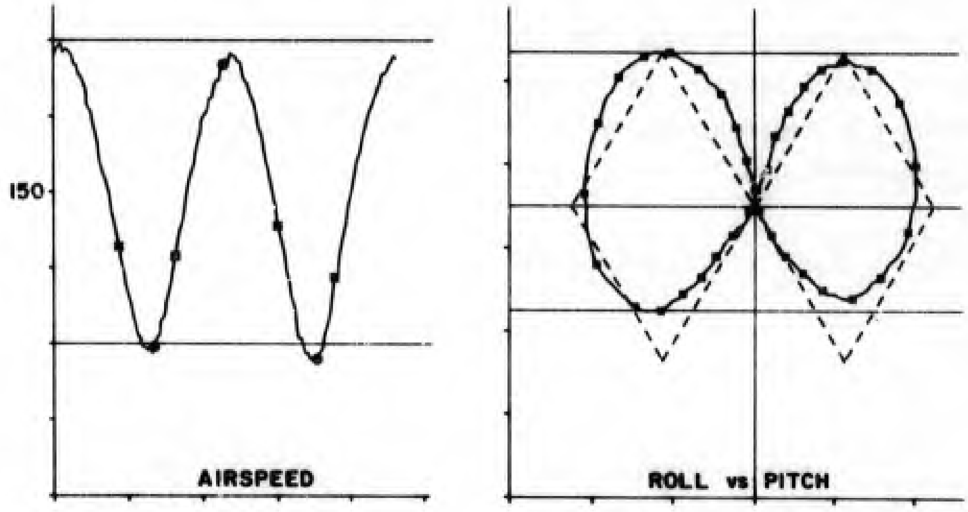
Pilot's Commentary: "Ready to start into lazy 8 number 2. Continuing the maneuver, trying to adjust my airspeed this time so that it comes down to 100 knots, and you will notice that I did not get it. We will come back to straight and level flight, 200 knots, and I will again try to get the pitch up further so that I get down to 100 knots. And I am still coming through with 112. Now the reason I am grading this good is that I have the basic nose track correct. However I am not hitting the proper parameters. This maneuver is complete and I would have graded it good."

Performance 3 (11-18-69, event 6) Rating: Good



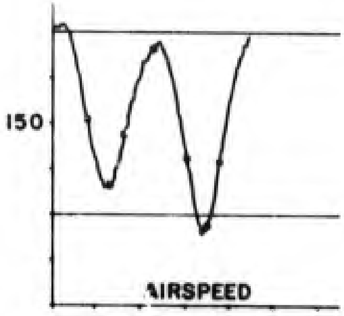
Pilot's Commentary: "Okay, I will again attempt to correct. Apparently the cooler day has given me a good deal more aircraft performance than I was expecting. I am starting the nose-up at a higher rate of change than I have been doing, getting maximum pitch after 45°. Bank continuing to increase. Nose-down through the horizon after 90° of turn, airspeed 98 knots. At its lowest after 135° of turn. I am not getting the nose-down low enough; as a result I am coming back through with a little lower airspeed on this one... 95 knots at its lowest; now let us go down a little lower as the bank decreases, planning to come back to level flight again at 200 knots and straight and level flight. End of lazy 8 number 3. I would have graded that one a high good or low excellent. Call it a good. I'd like to get just one excellent while we are out here today!"

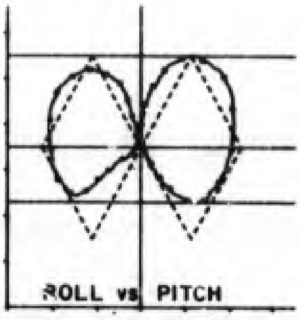
Performance 4 (11-18-69, event 7) Rating: Excellent



Pilot's Commentary: None recorded

Performance 5 (11-18-69, event 13) Rating: Good





Pilot's Commentary: "Starting our pullup...get the pitch attitude to its highest point at 45° of turn; and I'm through with high airspeed again. Try to correct it on the second half of this maneuver, nose lowest after 135 with approximately 150 knots. Again I will attempt to correct by pulling the nose up at a faster rate to begin with, airspeed at its lowest after 90° of turn, pitch at its lowest on 45°, back to straight and level after 180°. That one I would have graded good. The reason for the good is a low airspeed during the first half of the maneuver. The second half I thought was a pretty good maneuver."

(2) Simplified Combination Error Measure

Based on the foregoing observations and analysis data, a simple combination error measure was derived and computed for each performance. The measure is based on criteria for roll, pitch, and airspeed determined from the representative data. The criteria are:

M_1 = First max. positive pitch = 40°

M_2 = First min. negative pitch = -26°

M_3 = Second max. positive pitch = 40°

M_4 = Second min. negative pitch = -26°

$M_{5,6,7,8}$ = Roll at $M_{1,2,3,4}$ = 45°

$M_{9,10,11,12}$ = Airspeed at $M_{1,2,3,4}$ = 133 knots

The combined measure is

$$M = \sum_{i=1}^{12} \left| c_{M_i} - r_{M_i} \right|$$

where c_{M_i} = criterion M_i

and r_{M_i} = recorded M_i.

Figure 43 shows this computed measure for the 47 PIT instructor lazy 8s.

Note that the measure easily and clearly discriminates between excellent and fair levels of performance. Fair versus unsatisfactory is also discriminated well, the only exception being a performance that was judged to be unsatisfactory by the instructor but which was commented upon as being "maybe a low fair" by the same instructor. Similarly, other performances whose assigned ratings appear questionable by standards of the measure were found to have associated instructor comments supporting the measure's validity (Figure 43).

This measure alone accounts for 67% of the variance in instructor ratings, considering all performances. If ratings for the three performances footnoted in Figure 43 are changed as dictated by the instructor's recorded comments, the measure would account for 72% of the variance.

In light of the simplicity of the measure (sampling three variables at four discrete points in the maneuver) and the fact that absolutely no weighting was performed in its computation (straight error sum), the results are quite remarkable. It is hypothesized that use of an integrated error measure on the roll/pitch relationship and the employment of linear weighting would easily improve the measure 20 to 25%, as evaluated by its correlation with subjective ratings.

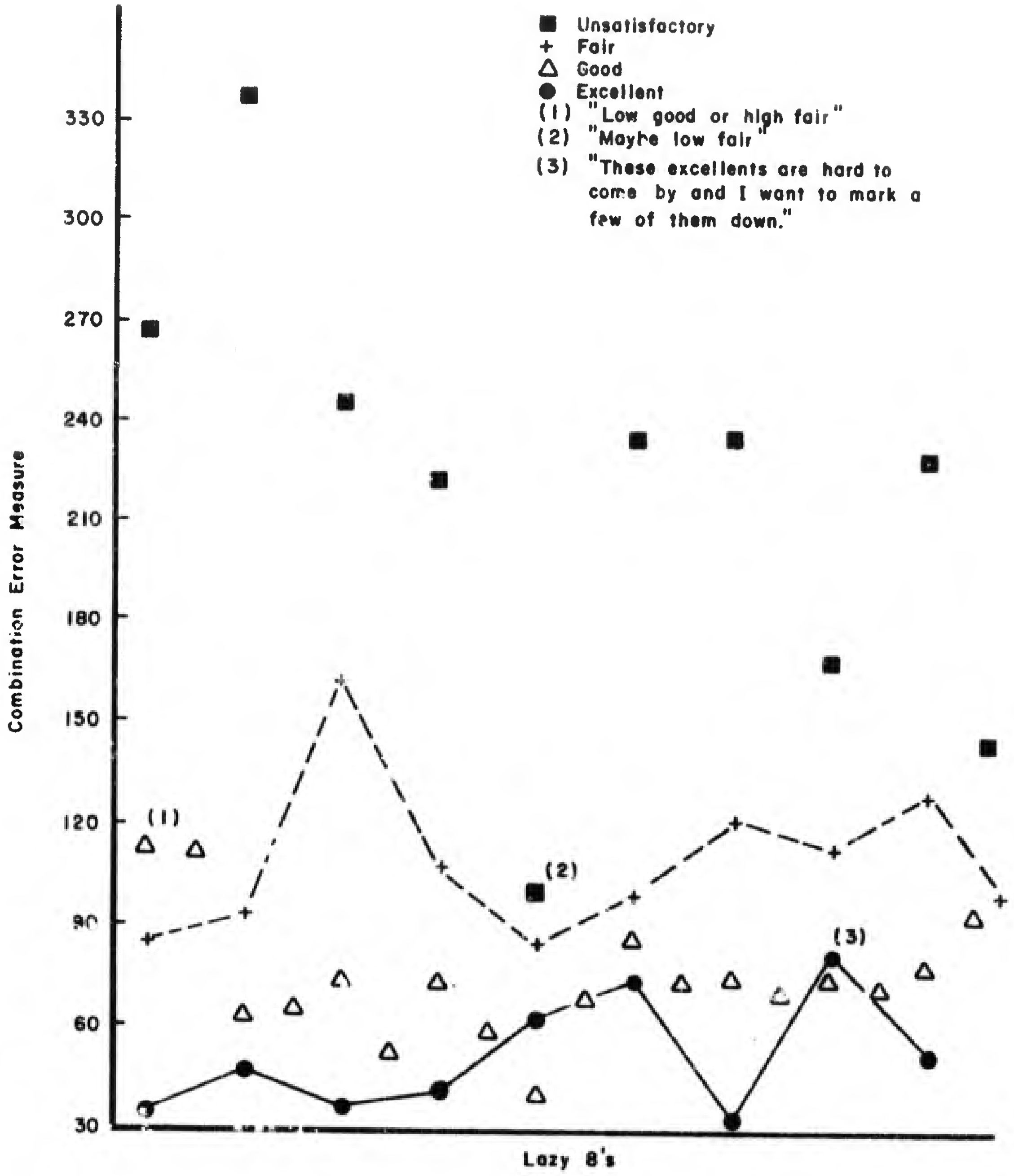


Figure 43. Combination Error Measure for 47 PIT Instructor Lazy 8 Performances

(3) Debriefing Plots

Figure 44 shows a smoothed mean roll-pitch profile for the PIT instructor excellent left performances. Also shown for comparison is an example of unsatisfactory performance as it might be overlaid and annotated in a finished debriefing plot.

b. AFHRL and ATC Instructors

Sixteen Lazy 8 performances by four different instructor pilots were analyzed. Most of these were performed during student-instruction to demonstrate proper performance of the maneuver. The performances were rated by the IP's and are distributed across the rating categories as shown in Figure 45; some performances have no rating associated with them.

With so few samples per IP, little could be gained by analysis of mean measures versus rating category or by correlations of measures with subjective ratings. It is of interest, however, to examine intra- and inter-instructor variance and technique. For this purpose, thirteen measures (numbers 1-12 and 27 in Table XVII) were selected for analysis.

Since only one sample was obtained for one of the four instructors, he was omitted from the analysis. Included, then, were three AFHRL or ATC IPs and the PIT IP, the latter's performances being chosen as all those rated excellent. Table XVIII shows the average standard deviation for each measure, taken across all 4 pilots; and the standard deviation of the average measures. The former provides some indication of intra-instructor variance; the latter provides indication of inter-instructor variance.

For most measures, the amount of variation between the average performances of the IPs is roughly equivalent to the amount of variation within a given IP. To interpret the meaning of these statements, we shall use the example of measure number 9, the airspeed sampled in the third quarter of the maneuver at the point of maximum positive pitch.

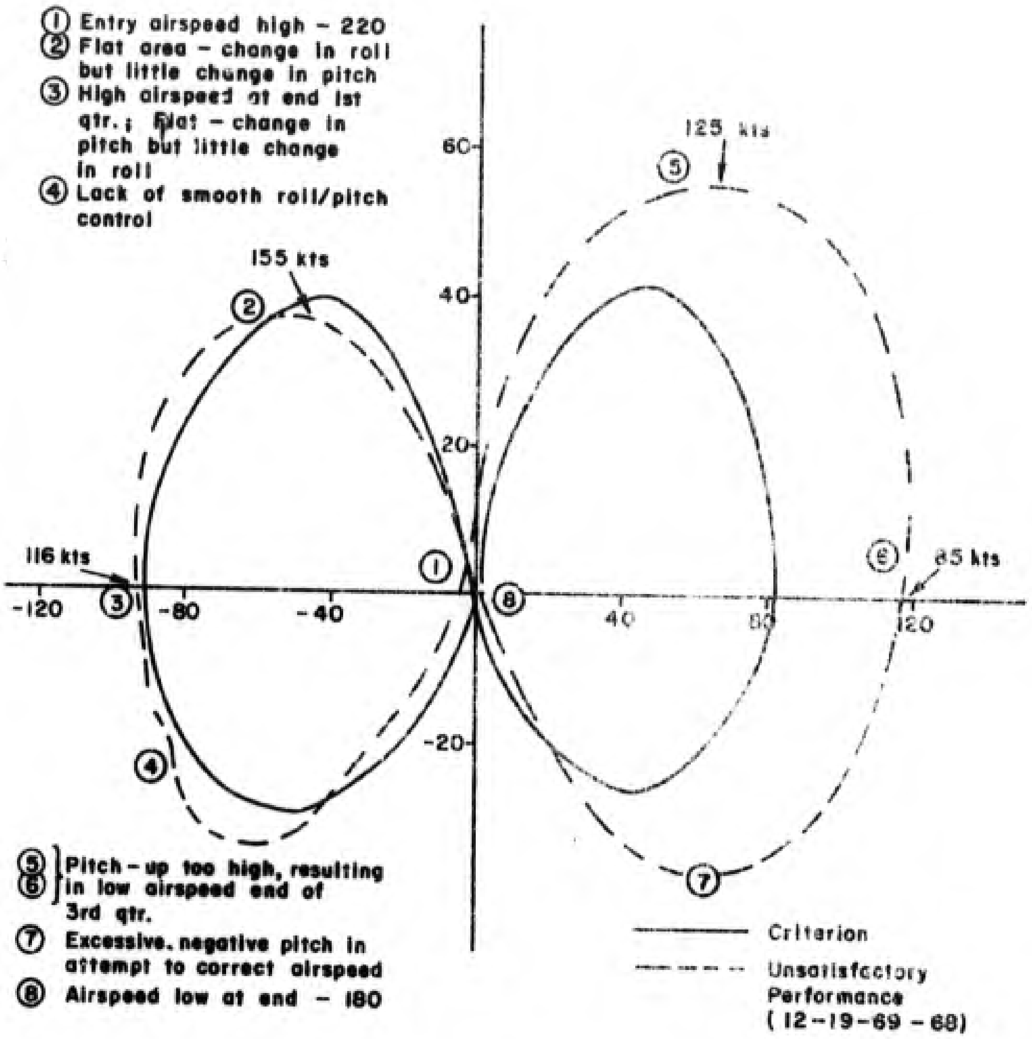


Figure 44. Sample Annotated Debriefing Plot

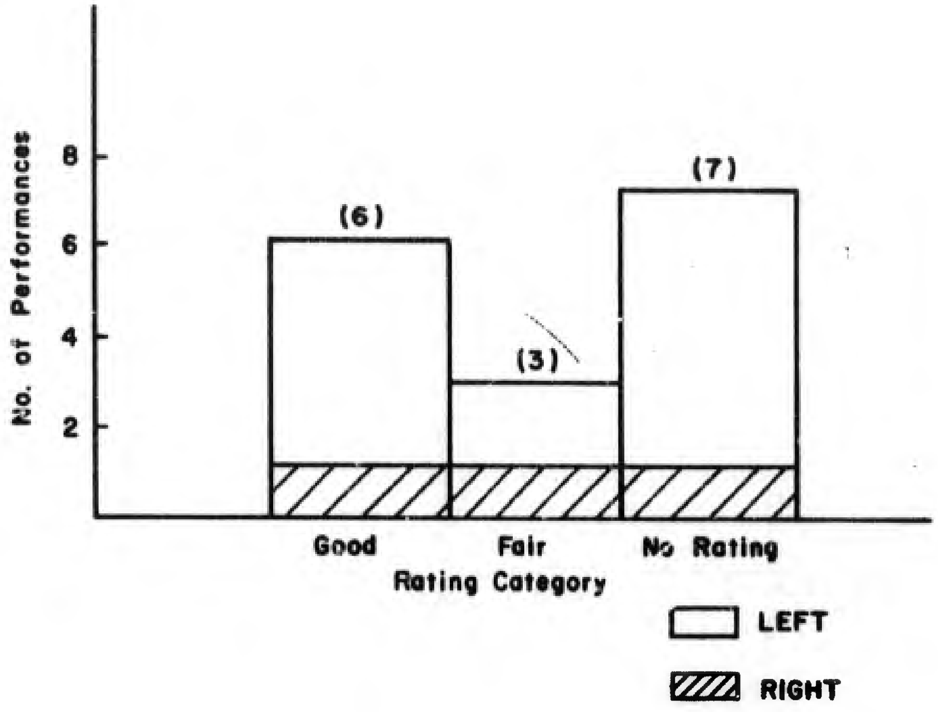


Figure 45. Distribution of Instructor Pilot Lazy 8's Across Rating Categories

TABLE XVIII

INDICANTS OF INTRA- AND INTER-INSTRUCTOR VARIANCE ON LAZY 8 PERFORMANCES

Measure	Units	Intra-Instructor* Variance Ind.	Inter-Instructor** Variance Ind.
1. 1st max. pitch	Deg	6	1
2. Roll	Deg	5	5
3. Airspeed	Kts	7	6
4. 1st min. pitch	Deg	4	5
5. Roll	Deg	5	7
6. Airspeed	Kts	10	7
7. 2nd max. pitch	Deg	4	1
8. Roll	Deg	6	5
9. Airspeed	Kts	9	9
10. 2nd min. pitch	Deg	4	6
11. Roll	Deg	5	7
12. Airspeed	Kts	8	8
13. Sum airsp. errs	Kts	10	4

* Average standard deviation for 4 IPs

** Standard deviation of averages of measures for 4 IPs

The statement implies the possibility that (1) a given IP's demonstration of the maneuver could be expected to result in an airspeed variation (on this measure) of 18 knots; and (2) if two different IPs demonstrated the maneuver, the variation could be as much as 27 knots, considering all performances of both IPs.

Measures 1 and 7, the maximum positive pitch values in the 1st and 3rd quarters, show very little inter-instructor variance. Although each IP could be expected to vary ±4 to ±6 degrees, the instructors are consistent in that their average performances would probably vary by only ±1°. Similarly, measure 13, the sum of 5 airspeed errors, shows consistency across instructors insofar as average performances are concerned.

c. Students

Forty-two performances of 16 different student pilots were analyzed, with the performances rated by the accompanying IP and distributed across rating categories as shown in Figure 46. Table XIX lists general data on the students comprising the sampling population. Also shown in Table XIX are codes representing which of two IPs flew with and rated each student.

Figures 47 to 52 illustrate plots of mean and standard deviations for the 41 measures. Correlations between measures and subjective ratings for all student performances are provided in Table XX. Debriefing plots were also generated for use in the analysis.

Roll and pitch excursions and variances increase slightly as skill ratings decrease. However, the amount of increase from fair to unsatisfactory is noticeably less than for the PIT instructor data. This could be due to different rating-standards between IPs.

Airspeed values at points of maximum pitch excursion are noticeably higher for students than for the PIT IP. Variances in the unsatisfactory performances are less.

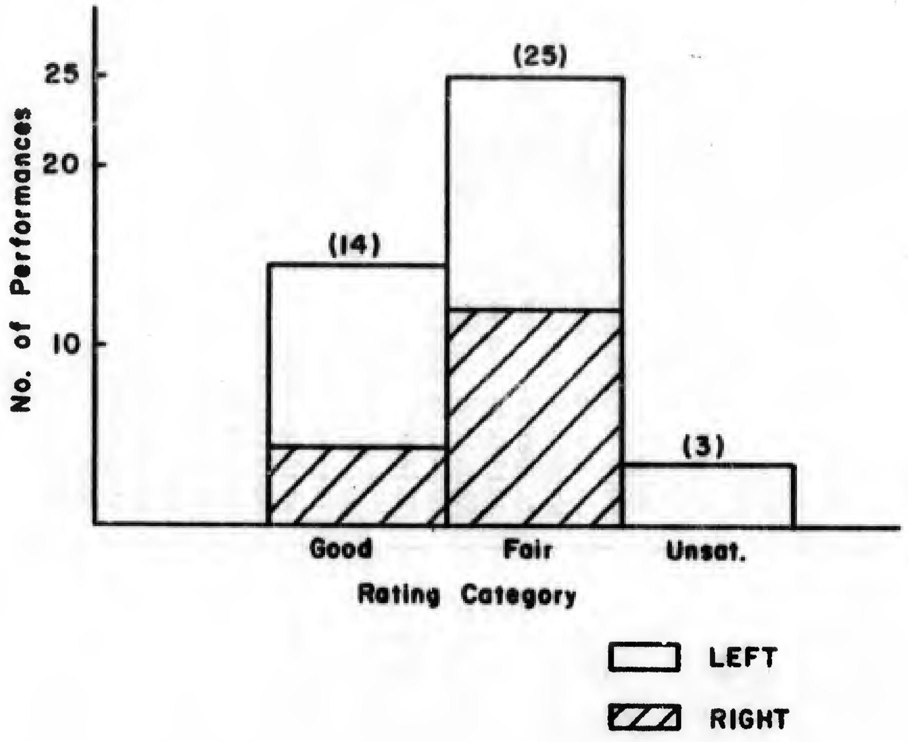


Figure 46. Distribution of Student Lazy 8's Across Rating Categories

TABLE XIX

GENERAL STUDENT DATA

Student Number	Samples*	Midphase Grade	IP's Estimate of Ability	Other Instructor Comments	IP
1	43.5 (2)	92	Average	None	1
2	47.2 (2)	--	Abv. Avg.	First time for Lazy 8s	2
3	39.0 (1)	89	Average	Flight cut short due to student complaining of severe headache	2
4	53.6 (2)	--	---	None	1
5	46.0 (2)	83	Avg. to sltly Abv.	Very smooth a/c control. Problem on midphase was procedural	2
6	47.0 (3) (2); 49.5 (2) (19); 67.7 (3)	89	Average	Washback from preceding class due to personal problems. Has good attitude and wants to fly.	2
7	49.9 (3)	86	Weaker than Avg.	Required several extra rides in pre-solo phase	2
8	52.0 (2)	87	Below Avg.	"Clanks" easily	2
9	42.2 (1)	95	Outstanding	Has previous flying experience and was controller; best I've flown with	2
10	37.7 (2)	35	Average	1st try at Lazy 8; good motivation	1
11	49.8 (2)	93	Well above avg	Will probably finish in top 5 of class	2
12	45.0 (4) (9); 52.1 (1)	89	Abv avg.	Ability not well reflected by midphase; 3 previous dual rides working on Lazy 8	2;1
13	37.6 (1)	89	low avg.	None	1
14	55.9 (4) (22); ?? (2)	73	Weak	Washback; several instructors; weak on proced. but not bad stick and rud.	2
15	52.4 (2)	88	Average	None	1
16	64.9 (1)	93	Strong	None	1

* X (Y) (Z): X = total T-37 hours prior to recorded sortie
Y = no. of Lazy 8s on this recorded sortie
Z = no. of calendar days between recorded sorties

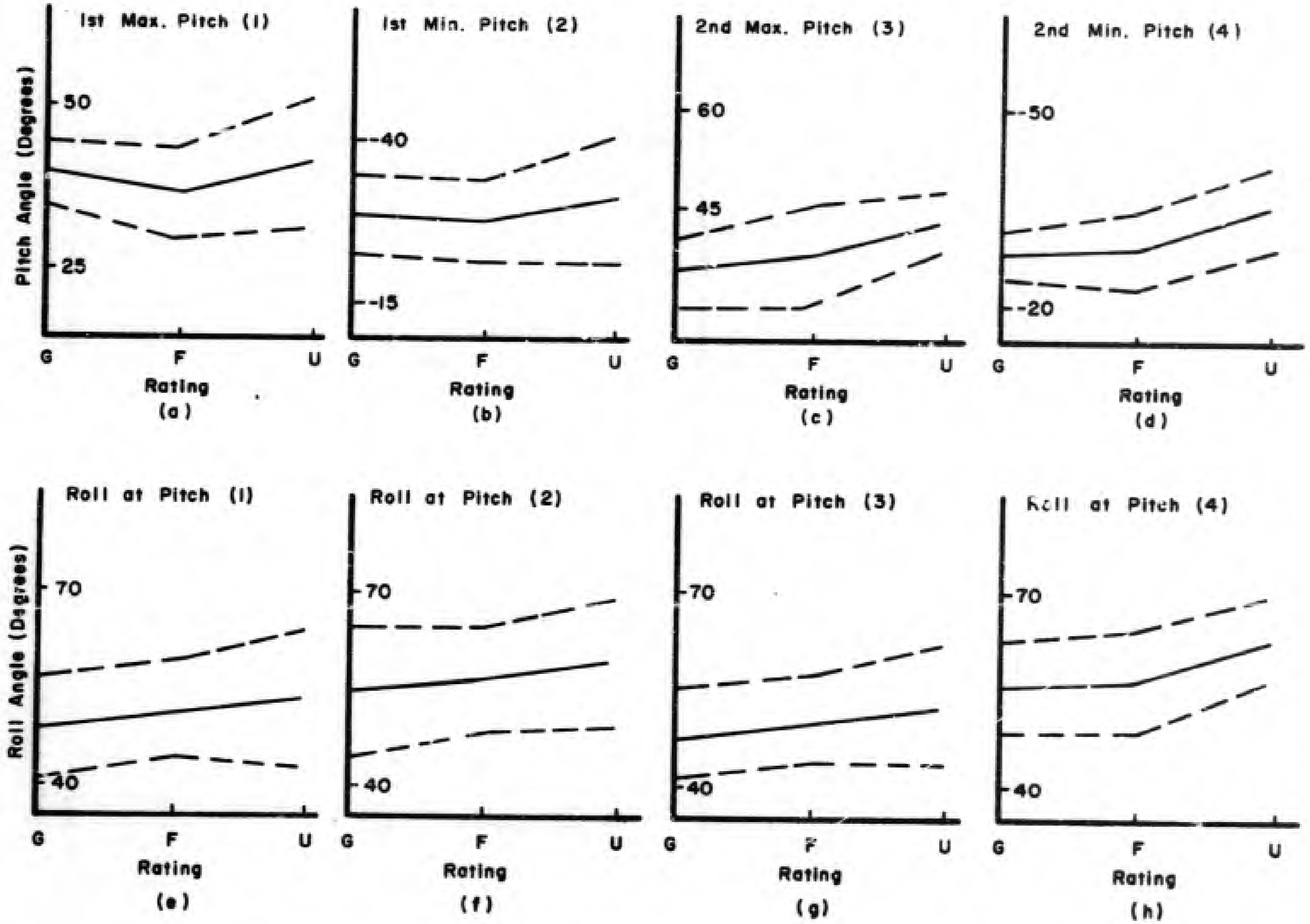


Figure 47. Pitch and Roll Measures for Student Lazy 8's [Mean ± 1σ]

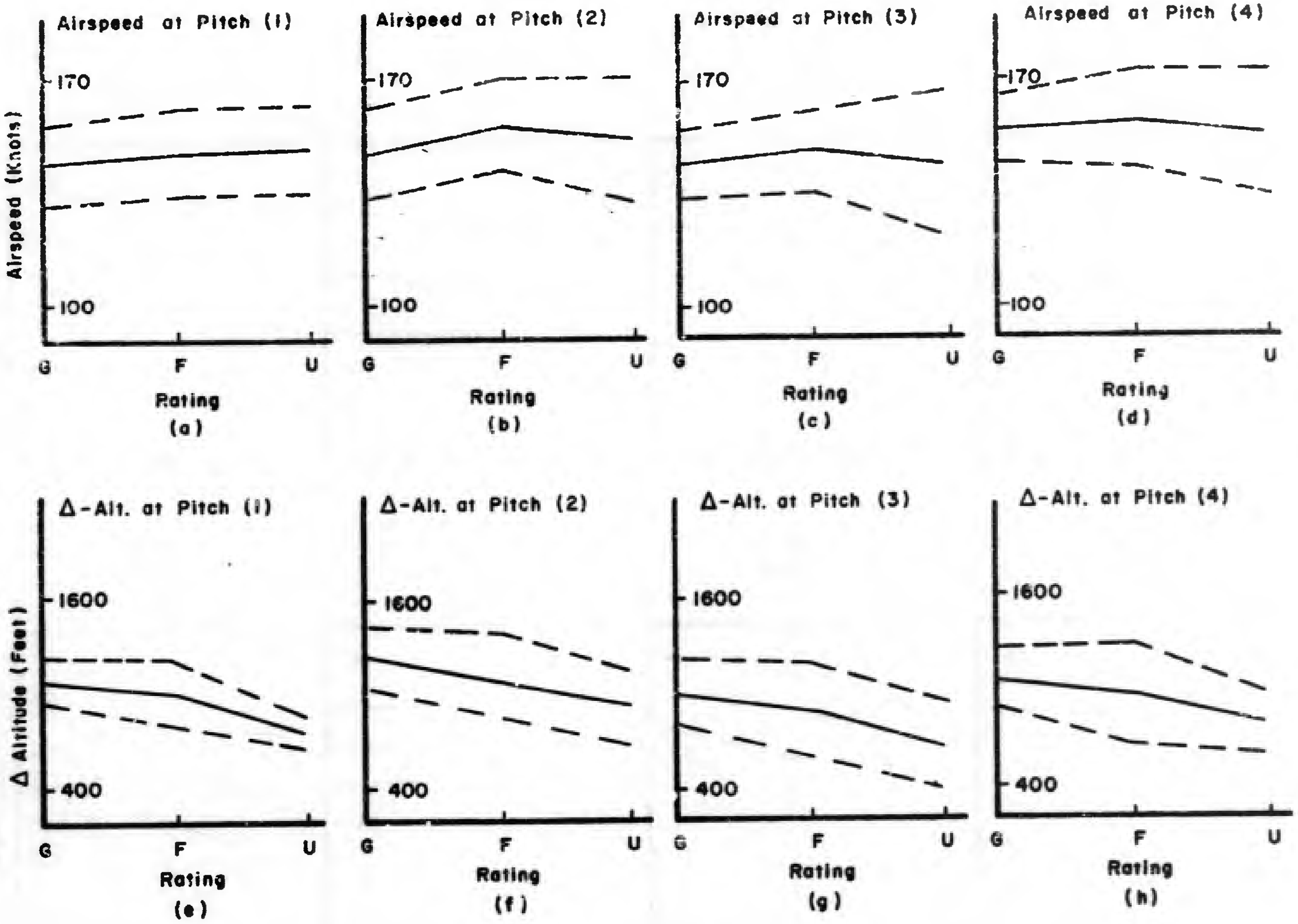


Figure 48. Airspeed and Altitude Measures for Student Lazy 8's [Mean ± 1 σ]

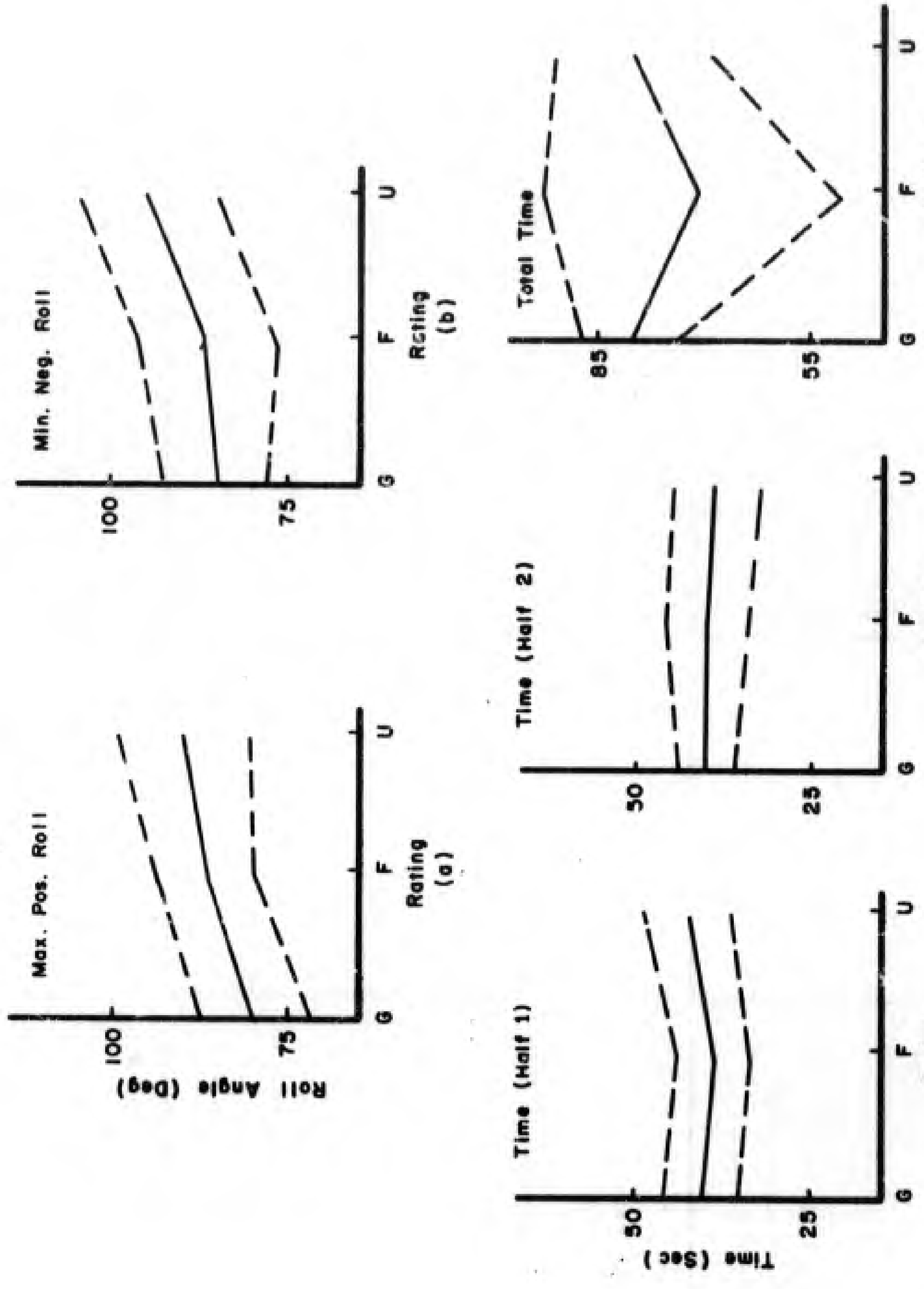


Figure 49. Roll and Time Measures for Student Lazy 8's [Mean ± 1 σ]

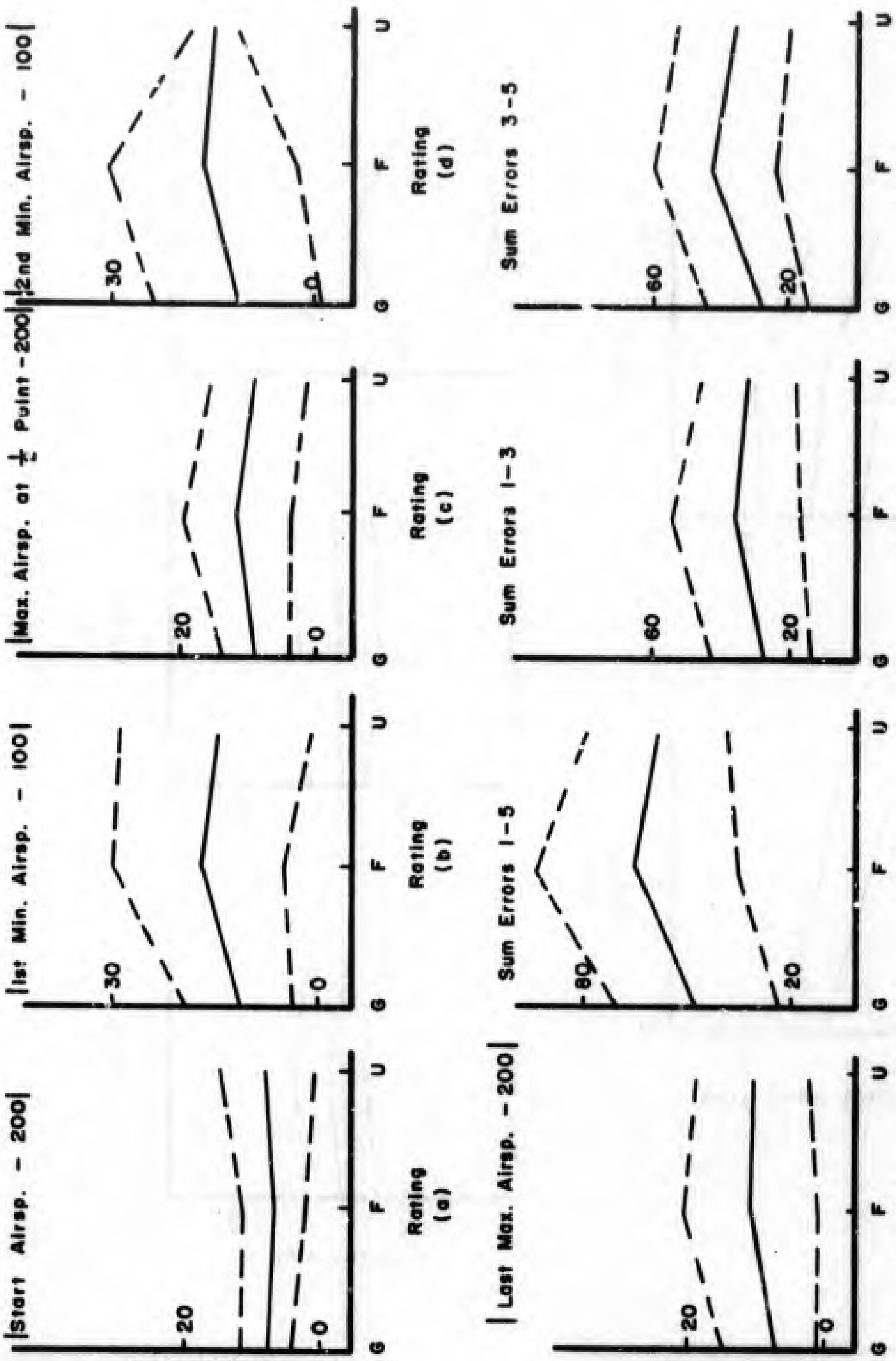


Figure 50. Airspeed Error Measures for Student Lazy 8's [Mean ± 1σ]

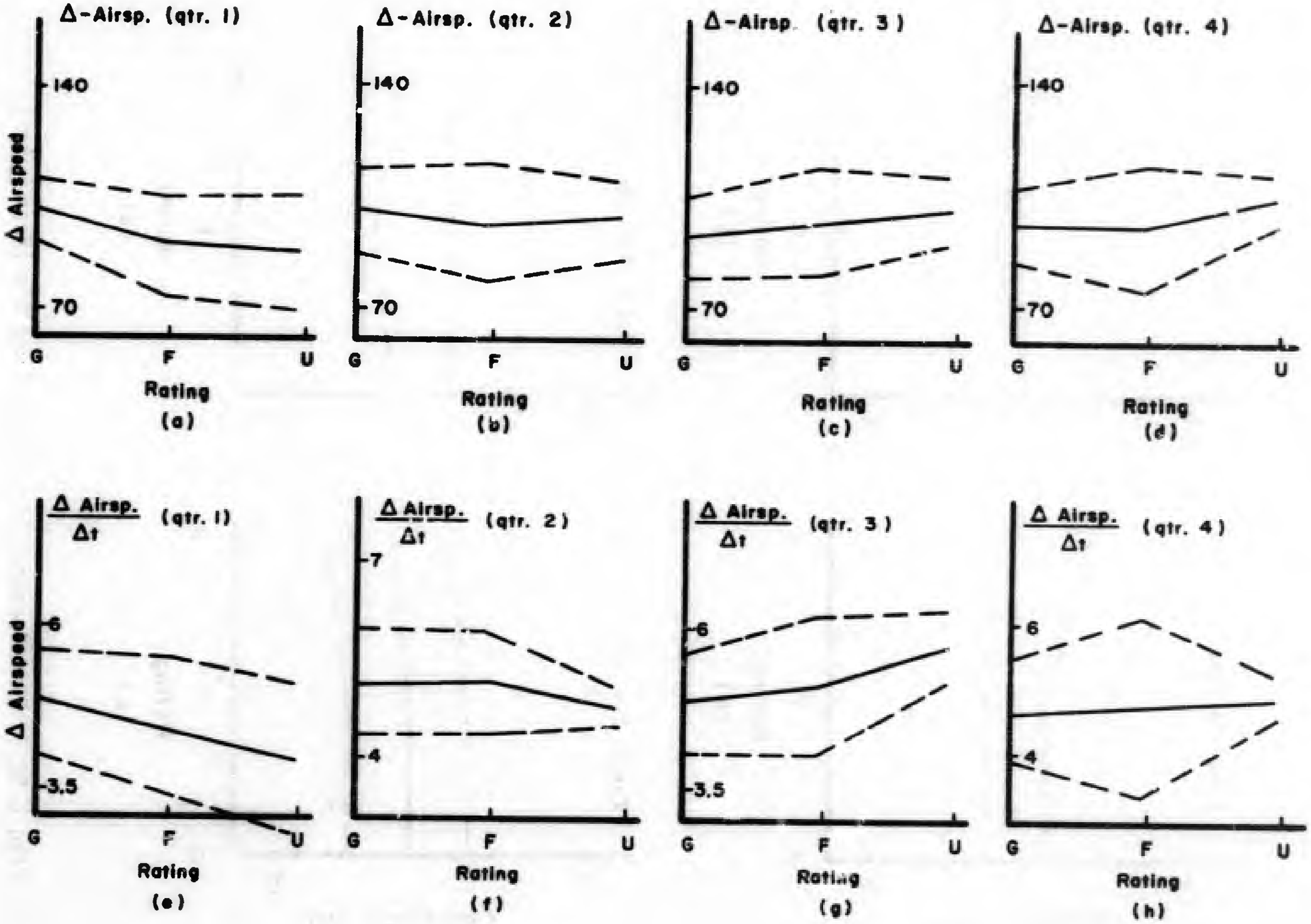


Figure 51. Airspeed Excursion and Rate Measures for Student Lazy 8's [Mean $\pm$ 1σ]

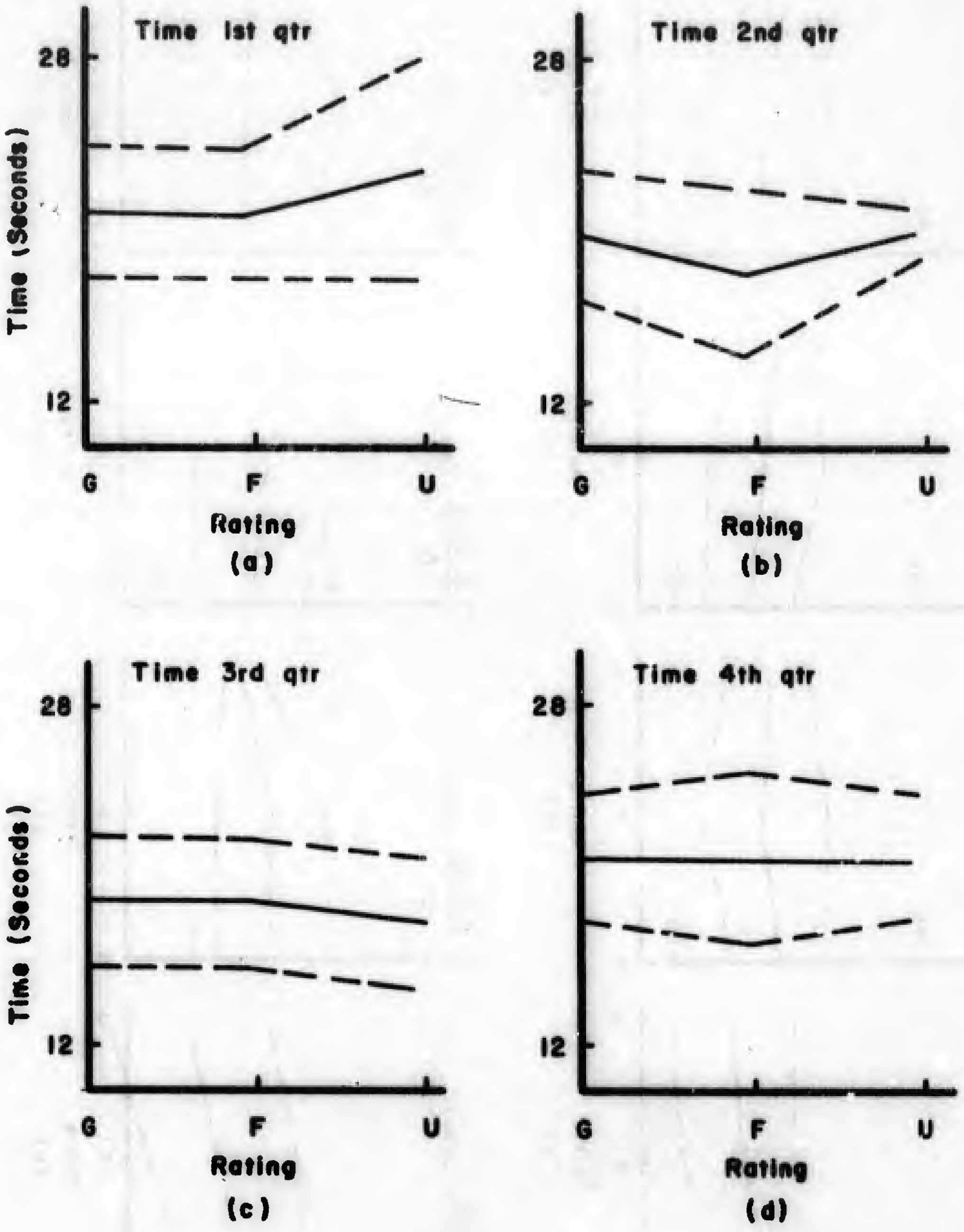


Figure 52. Time Measures for Student Lazy 8's [Mean ± 1 σ]

TABLE XX

CORRELATIONS BETWEEN MEASURES AND SUBJECTIVE RATINGS FOR STUDENT LAZY 8s

Measure Number	Correlation Coefs.		
	All	Right	Left
1. Max. 1 Pitch (1)	0.05	0.48	-0.12
2. Min. 1 Pitch (2)	0.02	0.30	-0.03
3. Max. 2 Pitch (3)	-0.28	0.02	-0.38
4. Min. 2 Pitch (4)	0.27	0.02	0.44**
5. Roll (1)	-0.21	-0.04	-0.32
6. Roll (2)	-0.17	-0.60**	-0.02
7. Roll (3)	-0.25	-0.12	-0.30
8. Roll (4)	-0.17	-0.24	-0.16
9. Airspeed (1)	-0.20	-0.44	-0.11
10. Airspeed (2)	-0.21	-0.54**	-0.08
11. Airspeed (3)	-0.07	-0.15	-0.05
12. Airspeed (4)	-0.04	-0.10	-0.02
13. Altitude (1)	0.29	0.20	0.41**
14. Altitude (2)	0.31**	0.33	0.33
15. Altitude (3)	0.27	-0.02	0.39**
16. Altitude (4)	0.26	0.12	0.32
17. Max. Roll	-0.39**	-0.45	-0.40**
18. Min. Roll	0.21	0.21	0.23
19. Time (half 1)	0.02	0.45	-0.12
20. Time (half 2)	0.07	-0.22	0.21
21. Total Time	0.13	0.20	0.10
22. Airspeed Error 1	0.03	0.01	0.04
23. Airspeed Error 2	-0.19	-0.30	-0.15
24. Airspeed Error 3	-0.16	-0.38	-0.06
25. Airspeed Error 4	-0.15	-0.11	-0.18
26. Airspeed Error 5	-0.14	0.03	0.25
27. Summary (1-5)	-0.24	-0.34	-0.20
28. Summary (1-3)	-0.19	-0.42	-0.11
29. Summary (3-5)	-0.27	-0.32	-0.25
30. Delta Airspeed (1)	0.35**	0.46	0.33
31. Delta Airspeed (2)	0.09	0.26	-0.00
32. Delta Airspeed (3)	-0.16	-0.08	-0.22
33. Delta Airspeed (4)	-0.06	0.15	-0.19
34. Airspeed Rate (1)	0.25	0.28	0.24
35. Airspeed Rate (2)	0.05	-0.07	0.11
36. Airspeed Rate (3)	-0.23	0.10	-0.44**
37. Airspeed Rate (4)	-0.06	0.09	-0.15
38. Time (1)	-0.05	0.34	-0.16
39. Time (2)	0.10	0.36	-0.11
40. Time (3)	0.10	-0.24	0.32
41. Time (4)	0.00	-0.06	0.04

* Significant to 0.01 level
** Significant to 0.05 level

Altitude excursions for students are on the order of 300 and 600 ft less (in first and second halves of maneuver, respectively) than for the PIT IP. This is probably due to the varying environmental conditions (and, therefore, aircraft performance) in which the sorties were flown. The AFHRL and ATC IP data shows altitude excursions similar to those of the students, suggesting that it is not due to differences between students and IPs as classes of subjects.

Maximum roll angles attained in the maneuver have greater variance across all skill categories for students than for the PIT IP. Similarly, the total time to perform the maneuver, while having about the same mean, has much wider variances.

Unlike the PIT case, airspeed errors appear to have no relationship to skill category for the student data (Figure 50). It is strongly suspected that this is due to a difference in rating-standards among IPs, i.e., a difference in the assumed importance of airspeed in grading the maneuver. This is substantiated later in this Section where we examine trends of measures for an individual student; it also signals clearly one of the shortcomings of using IP ratings as a guide in the development of measures.

Another major difference between the student and PIT data is the airspeed value at the points of maximum pitch excursion. Recall that the PIT IP at first was striving for 150 knots at these points and was forced to reduce this value to about 133 knots in order to accomplish the maneuver correctly. However, 150 knots appears to work satisfactorily as judged by the student data. It is suspected that differences in aircraft performance in different environmental conditions is the reason.

Correlations between measures and subjective ratings for students are, in general, insignificant. This is in direct contrast to the PIT case, where a number of significant coefficients were found. Again, this appears to be due to the IP's rating techniques for the student data, and this will be further substantiated later in this Section.

The combination error measure that discriminated performances so well for the PIT data (Figure 43) was computed for the student data. The results are shown in Figure 53. The complete lack of discrimination is evident.

d. Within-Subject Sampling as a Basis for Measurement Development

Until now, we have referenced instructor ratings as a guideline for the development of measures and for demonstrating their face-validity. This approach, as the sole approach, has serious shortcomings because it is based on the assumptions that (1) all instructors or raters apply the same standards and, for the most part at least, are consistent and reliable in their use of the (four) rating categories; and (2) the standards that are applied are valid. The authors contend that neither assumption is true.

This is not to say that the use of instructor ratings as <u>initial</u> guidelines in the development of measures is not valuable. A great deal of insight to the measurement of maneuvers can very definitely be attained by examination of subjective ratings. However, the use of subjective ratings in the development of objective measures is in itself a dichotomy, and such use must be made with caution and with the understanding that both reliable standards and rating-standardization can be expected to be lacking in the subjective system.

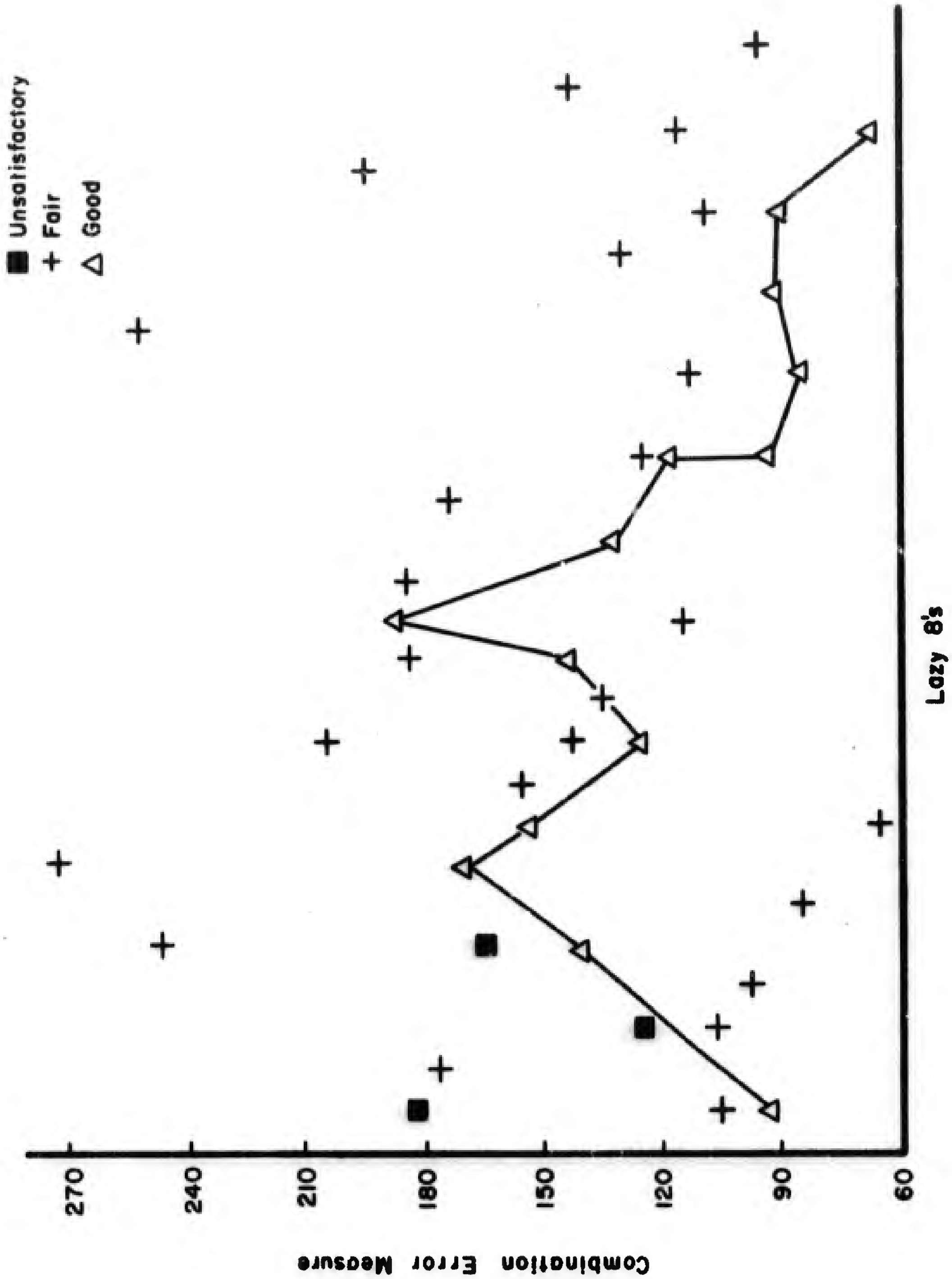


Figure 53. Combination Error Measures for 42 Student Lazy 8 Performances

Another approach is to accomplish measurement development and (equally important) to validate measures using within-subject sampling. With this approach, the major assumption is that learning occurs with time and practice of a maneuver. Individual measures that are developed should reflect all or a part of that learning through their trends from day No. 1 of instruction on a maneuver through the final day of training for each student.

In the present study, this approach was originally a part of the experimental design; however, it was impossible to apply in toto due to difficulties encountered in collecting a lot of data per student for all students sampled. It was possible, however, to attain sufficient data for one student to illustrate the approach. These results will be discussed next.

(1) Example for a Single Student

For student number 6 (Table XIX), eight performances of the lazy 8 were recorded during three different sorties. The sorties were separated by 1.5 and 17.2 flight hours and by 2 and 19 days, respectively. For reference, the performances are numbered 1 to 8, with 1-3 flown on the first sortie recorded, 4-5 on the second sortie, and 6 8 on the third sortie. (In order, the sorties were rated F, F, F, F, F, G, G, F.)

Figures 54 to 59 show each of the individual measures for the 8 performances of this student. Figure 60 shows the combination error measure for this student and for a second student (no. 14) for which 6 performances were recorded on 2 separate sorties. One measure whose trends are more obvious than others is the change in airspeed in the 4 quarters of the maneuver (Figure 58, a-d). Assuming the ATC excursion limits of 100 to 200 knots is correct, this measure should trend to 100 knots. The plots demonstrate this clearly. Also, the airspeed error measures (Figure 57) show a distinct decrease in error from early samples to later samples.

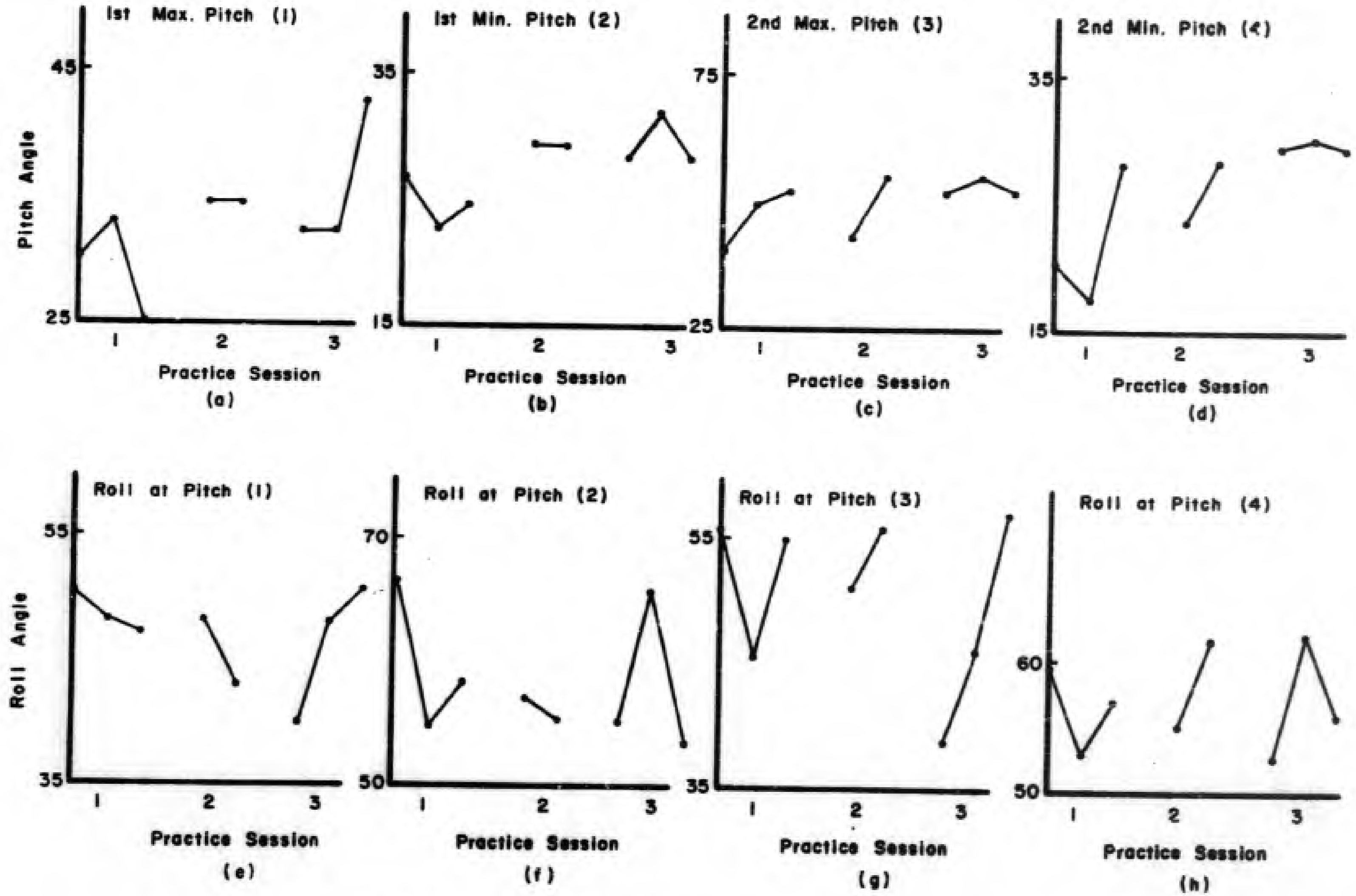


Figure 54. Pitch and Roll Measures for Single Student Performances of the Lazy 8

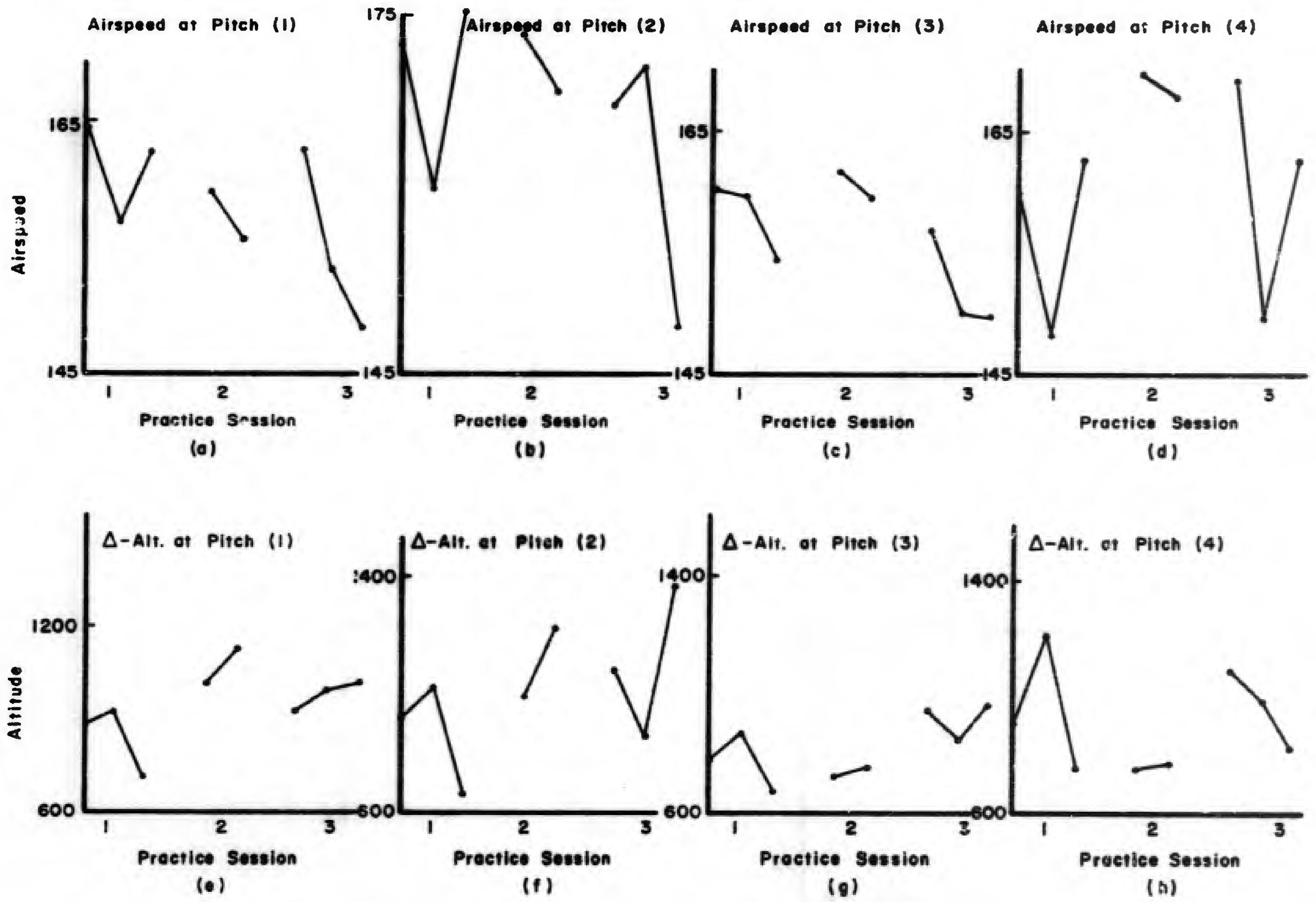


Figure 55. Airspeed and Altitude Measures for Single Student Performances of the Lazy 8

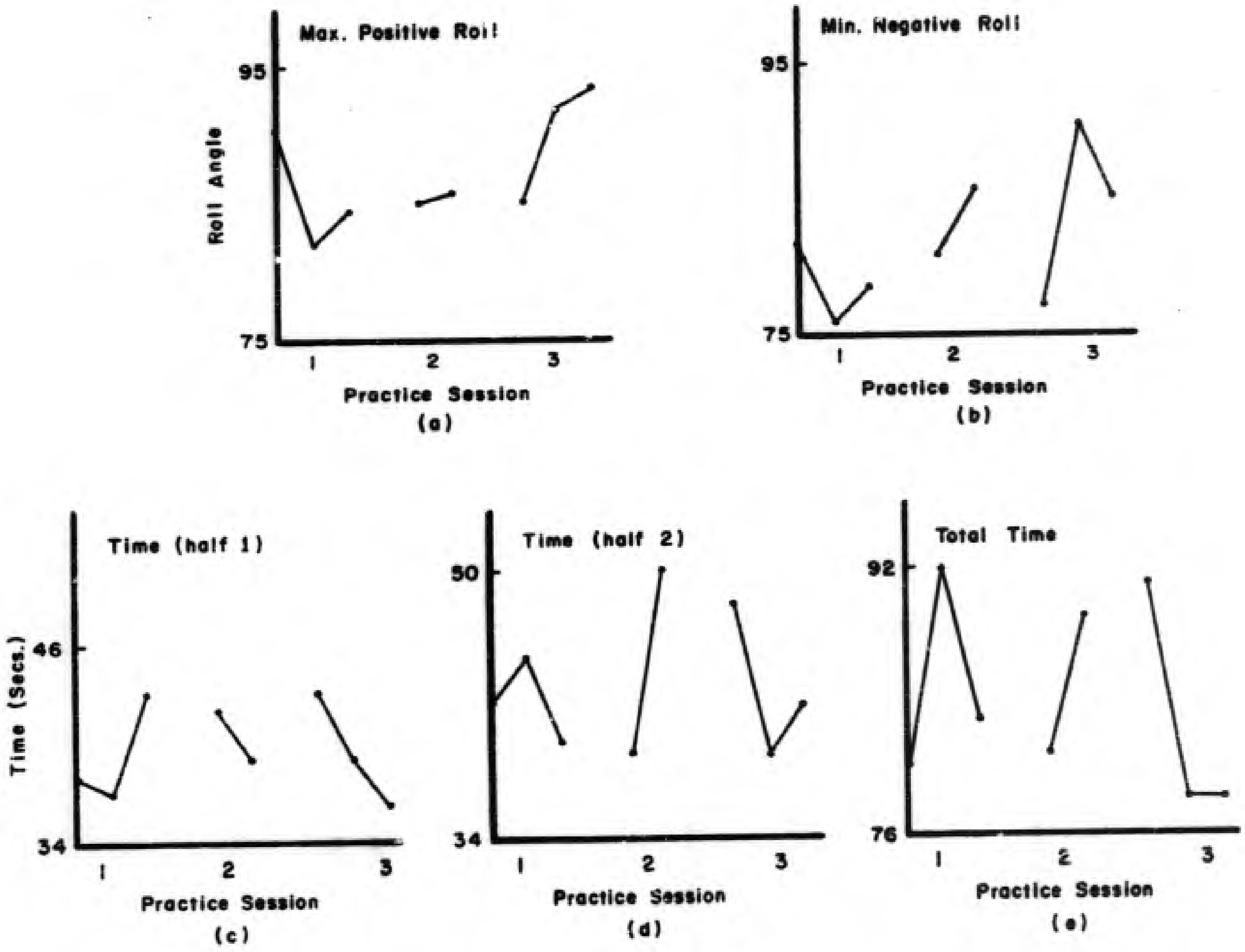


Figure 56. Roll and Time Measures for Single Student Performances of the Lazy 8

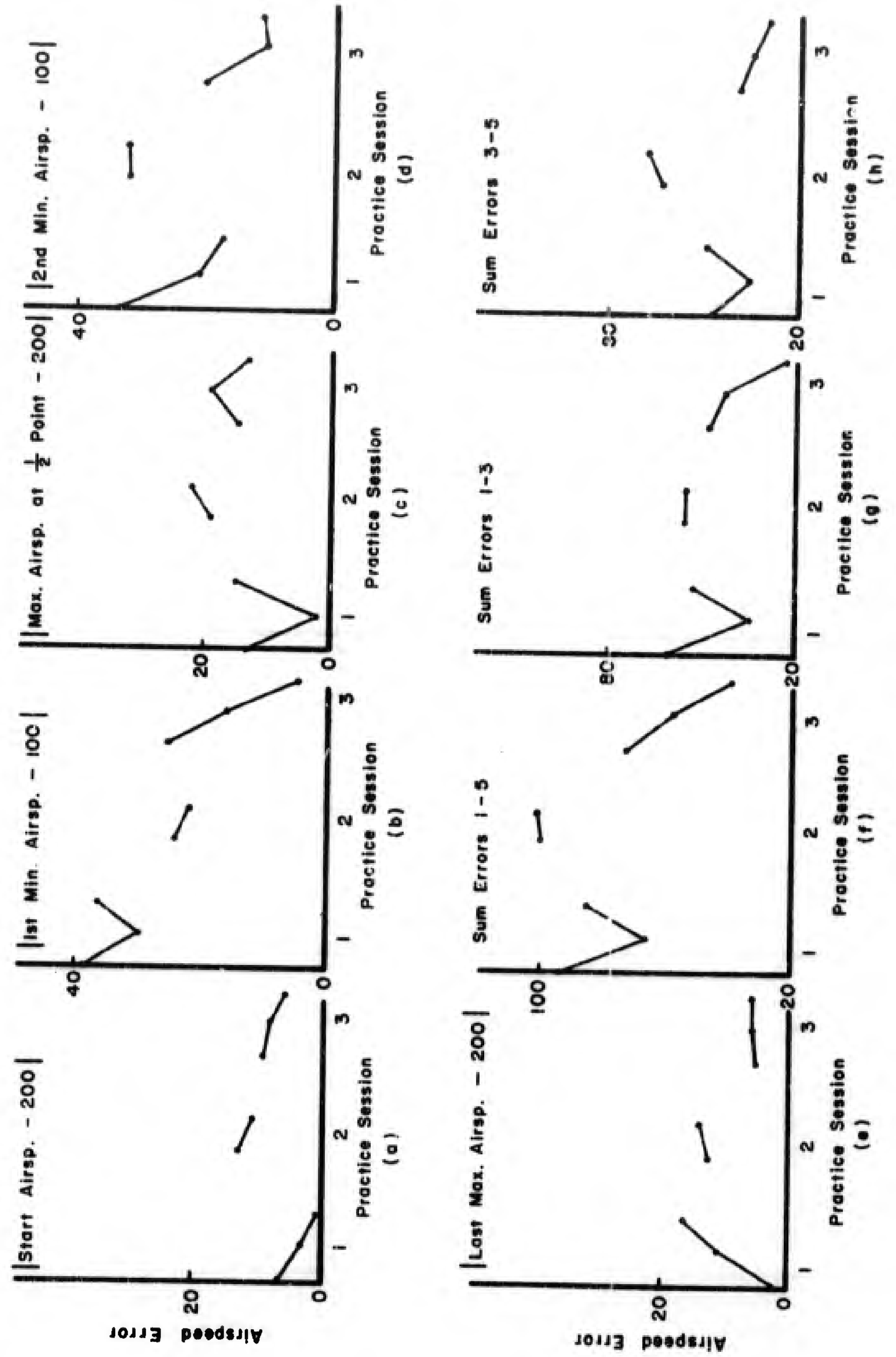


Figure 57. Airspeed Error Measures for Single Student Performances of the Lazy 8

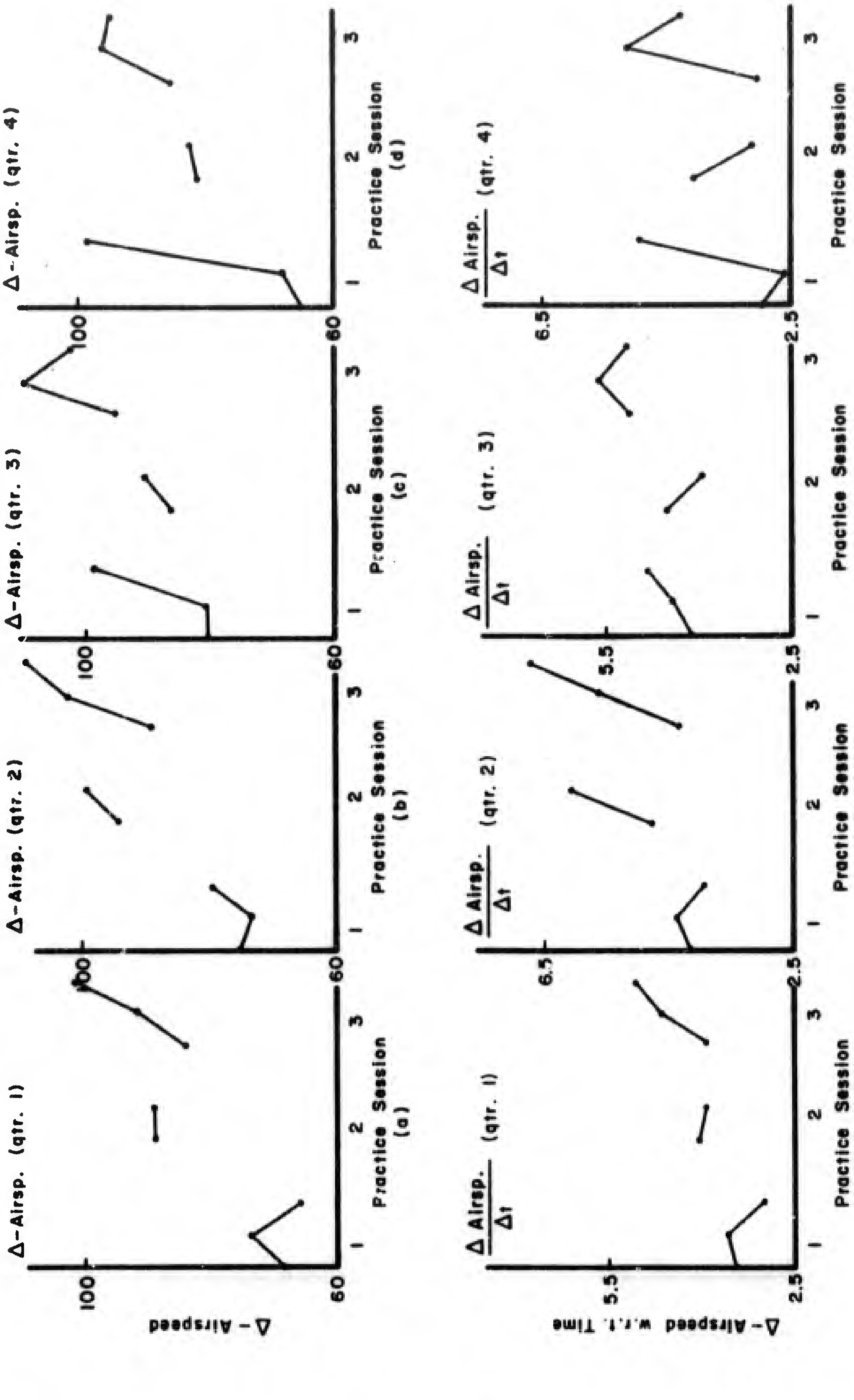


Figure 58. Airspeed Excursion and Rate Measures for Single Student Performance of the Lazy 8

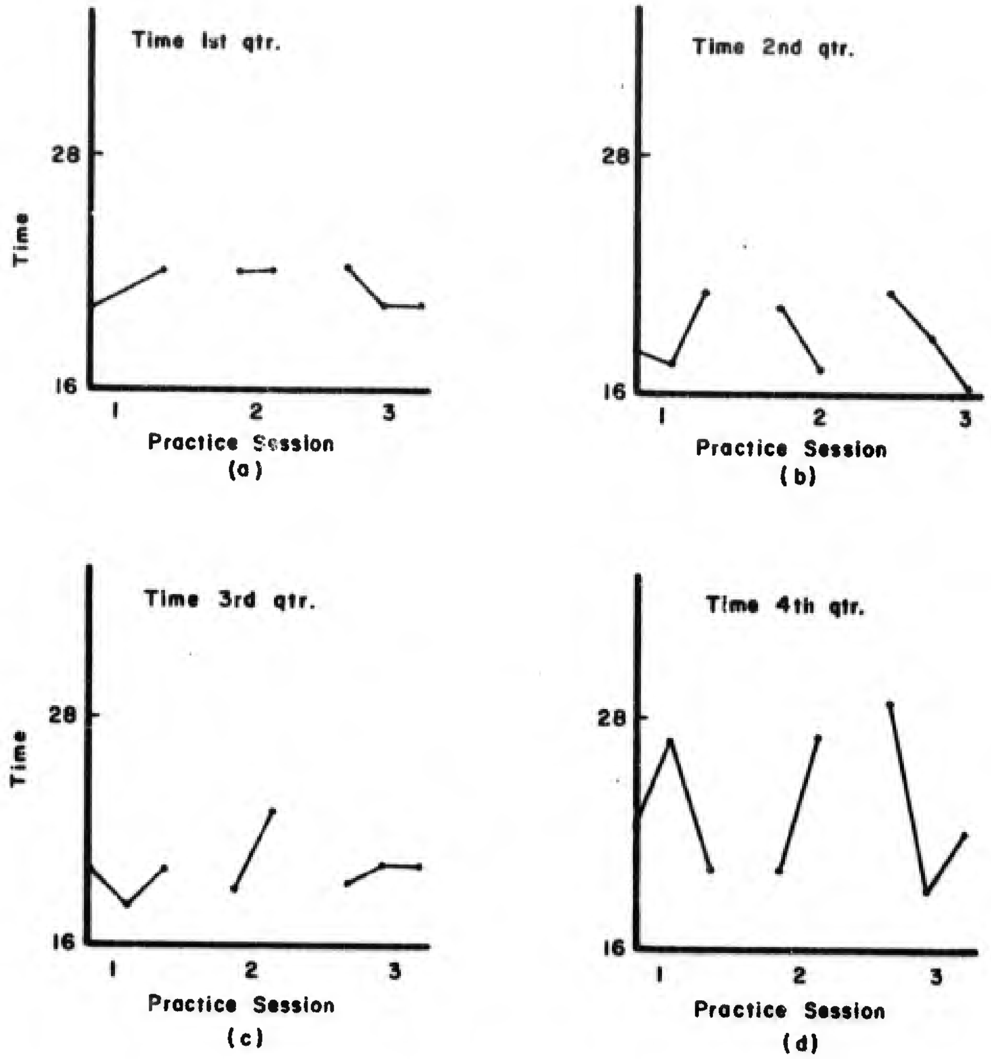


Figure 59. Time Measures for Single Student Performance of the Lazy 8

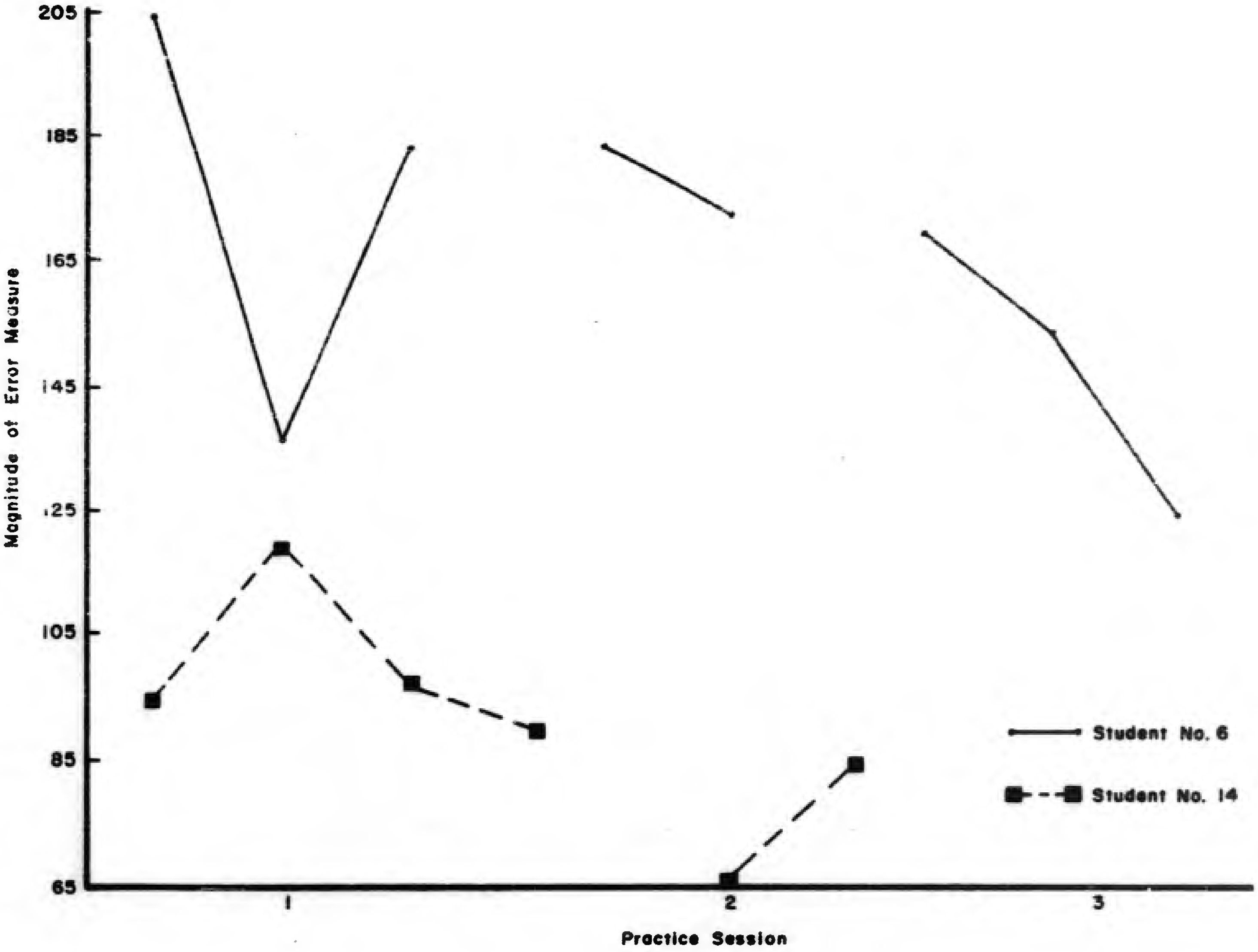


Figure 60. Combination Error Measure for Single Students' Performance of Lazy 8

Also relevant is the combination error measure of Figure 60. Although there was little if any correlation between this measure and the subjective ratings for all students (Figure 53), the trends of this measure across single student sorties show definite trends toward a decrease in error, as would be expected. On the Figure 60 plot, the measure is also shown for students numbers 6 and 14. Both students' data substantiates the validity of the measure despite its lack of correlation with subjective ratings.

e. Comparison of Instructor Rating Standards

Because of the low correlations between measures and subjective ratings for the student data (Table XX), inconsistency between the two involved IPs is suspect. To pursue this idea a little further, separate correlations for each IP were computed and are shown in Table XXI along with those for both IPs together.

The number of significant correlations (0.05 level or better) does not increase appreciably considering one IP at a time. However, some significant differences between correlations for the two IPs are noted. For IP-1, a significant positive correlation exists for the first maximum positive pitch, whereas only a small correlation (0.08) is shown for IP-2. Also, for the value of roll at the first minimum negative pitch, IP-1 shows a correlation of opposite sign and roughly equal level of significance to that of IP-2.

For altitude variations, correlations for IP-2 are consistently higher than for IP-1. At the point of first maximum positive pitch, for example, correlations were 0.66 and 0.16 for IP-2 and IP-1, respectively.

For time measures, correlations for the two IPs are generally small but of opposite signs. The most significant difference is for time to perform the second quarter of the maneuver, where the correlations are -0.62 and 0.35 for IP-2 and IP-1 respectively.

TABLE XXI

CORRELATIONS BETWEEN IP RATINGS AND MEASURES

Measure Number	IP-1 n=31	IP-2 n=11	Both IPs n=42
1. Max. 1 Pitch (1)	0.37**	0.08	0.05
2. Min. 1 Pitch (2)	-0.10	-0.27	0.02
3. Max. 2 Pitch (3)	-0.11	-0.27	-0.28
4. Min. 2 Pitch (4)	-0.09	0.37	0.27
5. Roll (1)	-0.14	-0.01	-0.21
6. Roll (2)	-0.28	0.33	-0.17
7. Roll (3)	-0.34	-0.05	-0.25
8. Roll (4)	0.00	0.08	-0.17
9. Airspeed (1)	-0.25	-0.40	-0.20
10. Airspeed (2)	-0.37**	-0.23	-0.21
11. Airspeed (3)	-0.14	-0.36	-0.07
12. Airspeed (4)	-0.06	-0.25	-0.04
13. Altitude (1)	0.16	0.66**	0.29
14. Altitude (2)	0.27	0.48	0.31**
15. Altitude (3)	0.19	0.54	0.27
16. Altitude (4)	0.16	0.60	0.26
17. Max. Roll	-0.31	-0.26	-0.39**
18. Min. Roll	0.03	-0.14	0.21
19. Time (half 1)	0.29	-0.48	0.02
20. Time (half 2)	-0.02	0.19	0.07
21. Total Time	0.27	-0.25	0.13
22. Airspeed Error 1	0.19	-0.22	0.03
23. Airspeed Error 2	-0.35	-0.27	-0.19
24. Airspeed Error 3	-0.25	-0.07	-0.16
25. Airspeed Error 4	-0.25	-0.74**	-0.15
26. Airspeed Error 5	-0.03	-0.30	-0.14
27. Summary (1-5)	-0.34	-0.44	-0.24
28. Summary (1-3)	-0.30	-0.25	-0.19
29. Summary (3-5)	-0.37**	-0.46	-0.27
30. Delta Airspeed (1)	0.48*	0.45	0.35**
31. Delta Airspeed (2)	0.24	-0.01	0.09
32. Delta Airspeed (3)	-0.01	-0.30	-0.16
33. Delta Airspeed (4)	0.16	-0.20	-0.06
34. Airspeed Rate (1)	0.38**	0.48	0.25
35. Airspeed Rate (2)	-0.06	0.63**	0.05
36. Airspeed Rate (3)	-0.03	-0.36	-0.23
37. Airspeed Rate (4)	0.14	-0.05	-0.06
38. Time (1)	0.01	-0.35	-0.05
39. Time (2)	0.35	-0.62**	0.10
40. Time (3)	0.02	0.32	0.10
41. Time (4)	-0.08	-0.04	0.00

* Significant to 0.01 level
**Significant to 0.05 level

These and other differences between the signs and magnitudes of the correlations substantiate the questionable degree of consistency between the two IPs insofar as ratings are concerned. This small sample of ratings, particularly for IP-2, cannot be expected to provide a basis for proof-positive statements regarding rating consistency, but it certainly warrants raising a question and supports the contention that IP ratings cannot be used as the sole basis for measurement development.

f. Summary and Results for Lazy 8 Measurement

Based on the foregoing analysis of lazy 8 data from three different sources (instructor of instructor-pilots, standard instructor pilots, and students), the following recommendations are made for measurement of this maneuver:

A summary error measure should be computed, using parameters of roll, pitch, and airspeed. The measure used in this study is

$$M = \sum_{i=1}^{12} |M_i - C_i|$$

where M_i and C_i are the recorded individual measures and the criteria for pitch, roll, and airspeed sampled at the four points of local pitch extremes.

An improved error measure should be computed and evaluated based on a continuous comparison between roll/pitch measures and criteria. This can be accomplished using the formula

$$M = \int_{-P}^{P}\int_{-r}^{r} |A - C| \; dr\, dp$$

where A and C are curves for actual (recorded) and criterion roll/pitch relationship, p is pitch, and r is roll.

Debriefing plots showing roll vs pitch and airspeed should be generated and annotated. On the plots, diagnostic aids should be printed in the form of individual measures and comments. Examples of such plots are shown in Appendix XVI.

Measures should be validated using repeated samples per student. Little reliance, except for initial guidance, should be placed in correlations between IP ratings and measures.

The criteria computed from the PIT IP data appear valid. However a larger sample of data is required to ascertain true validity. (This may result in slight alteration of the parameter criterion values.)

Environmental conditions (temperature and humidity) that significantly affect aircraft performance should be considered in the development of quantitative criteria.

2. BARREL ROLL

a. Student Data

Forty-eight student performances of the barrel roll were analyzed. The performances were rated by the accompanying IP and are distributed across skill categories as shown in Figure 61. Figures 62 to 67 show the plots of mean and standard deviations for the 47 measures. Correlations with subjective ratings are provided in Table XXII.

Most of the student performances (75%) were judged in the "fair" category. This of course must influence our interpretation and reliance upon data trends across skill categories as well as the correlations. So although some insights to barrel roll measurement can be determined using the existing data, tests will be necessary in future efforts using (1) a better data sample with respect to each skill category and (2) more samples per student.

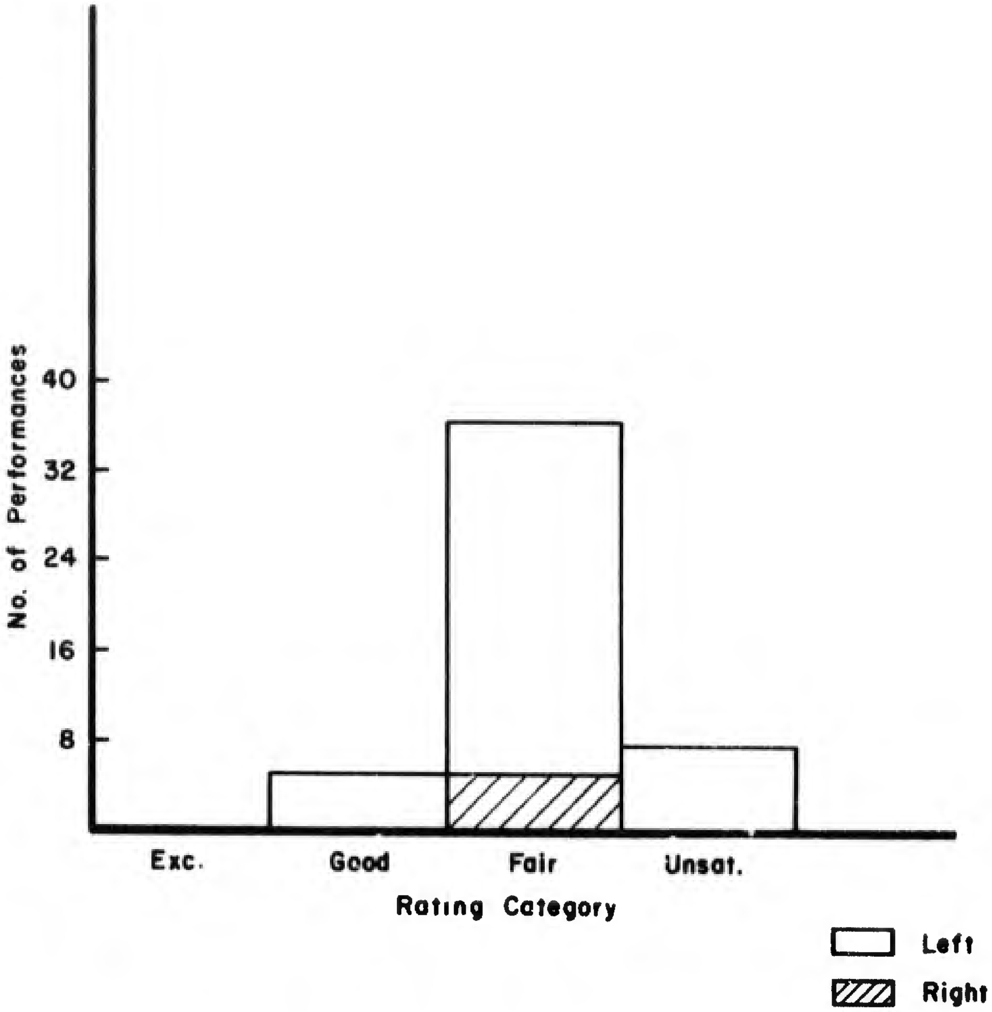


Figure 61. Distribution of Student Barrel Rolls Across Rating Categories

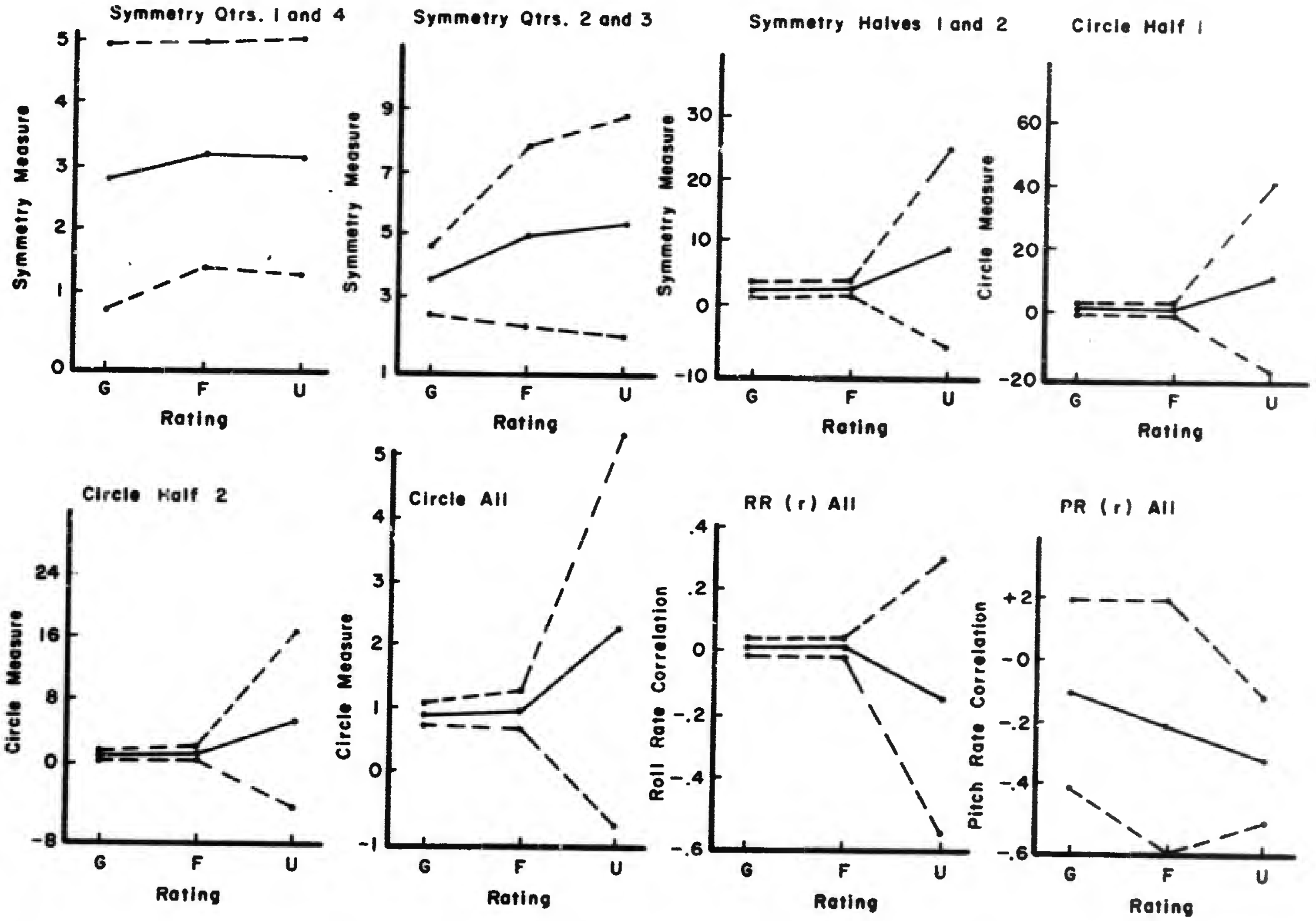


Figure 62. Symmetry, Circle, and Correlation Measures for Student Barrel Rolls

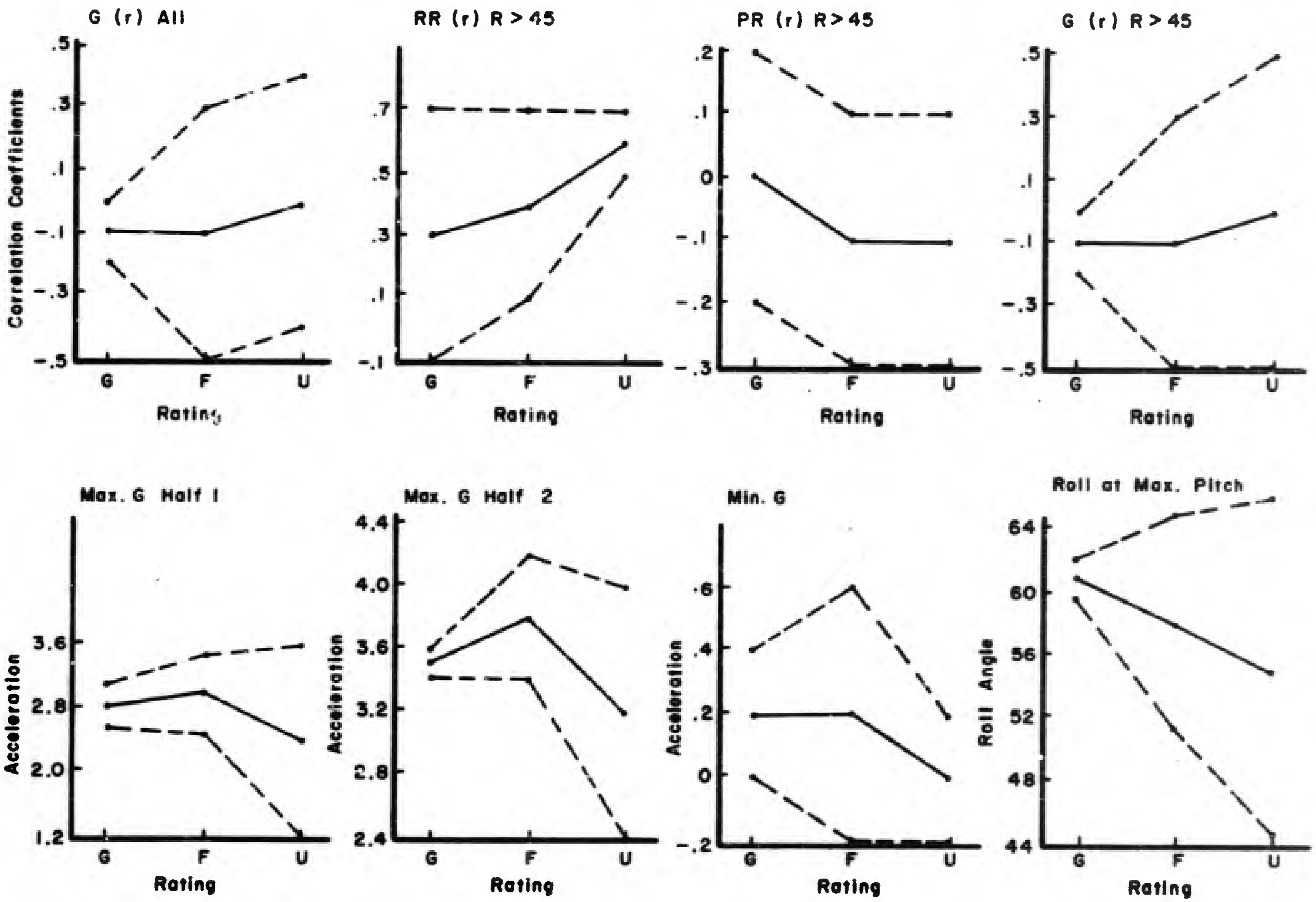


Figure 63. Correlation, G, and Roll Measures for Student Barrel Rolls

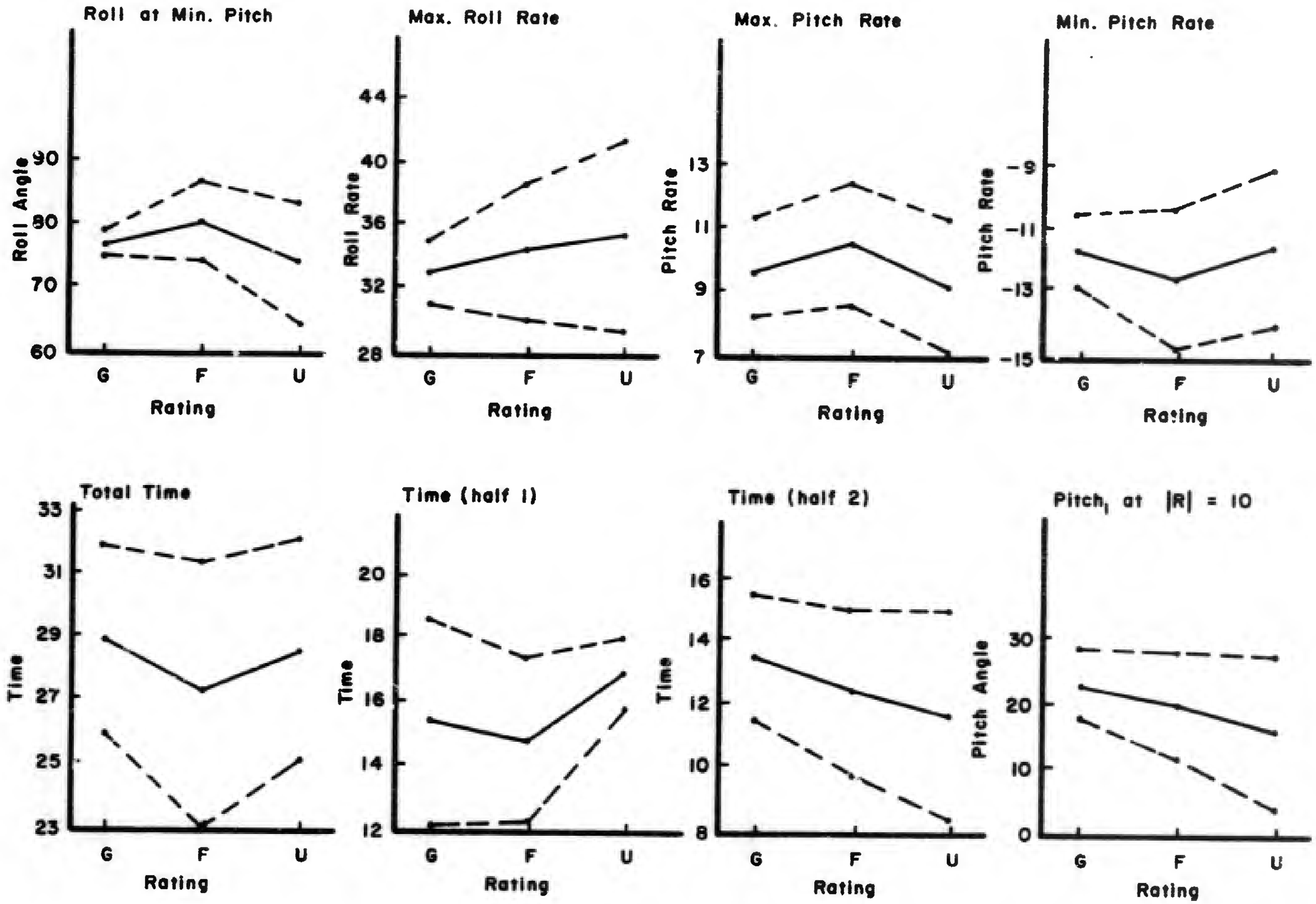


Figure 64. Argle, Rate, and Time Measures for Student Barrel Rolls

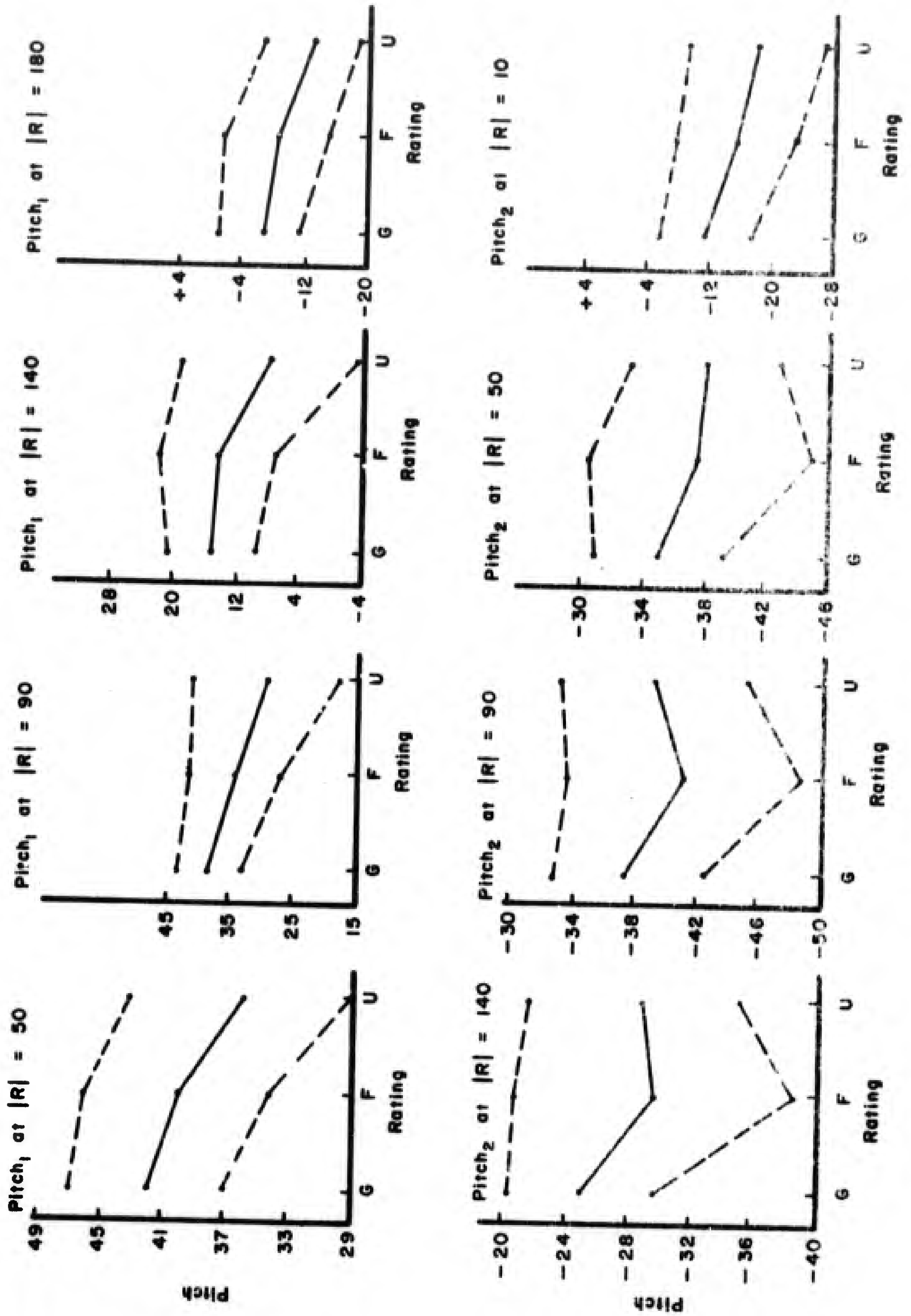


Figure 65. Pitch Angle Measures for Student Barrel Rolls

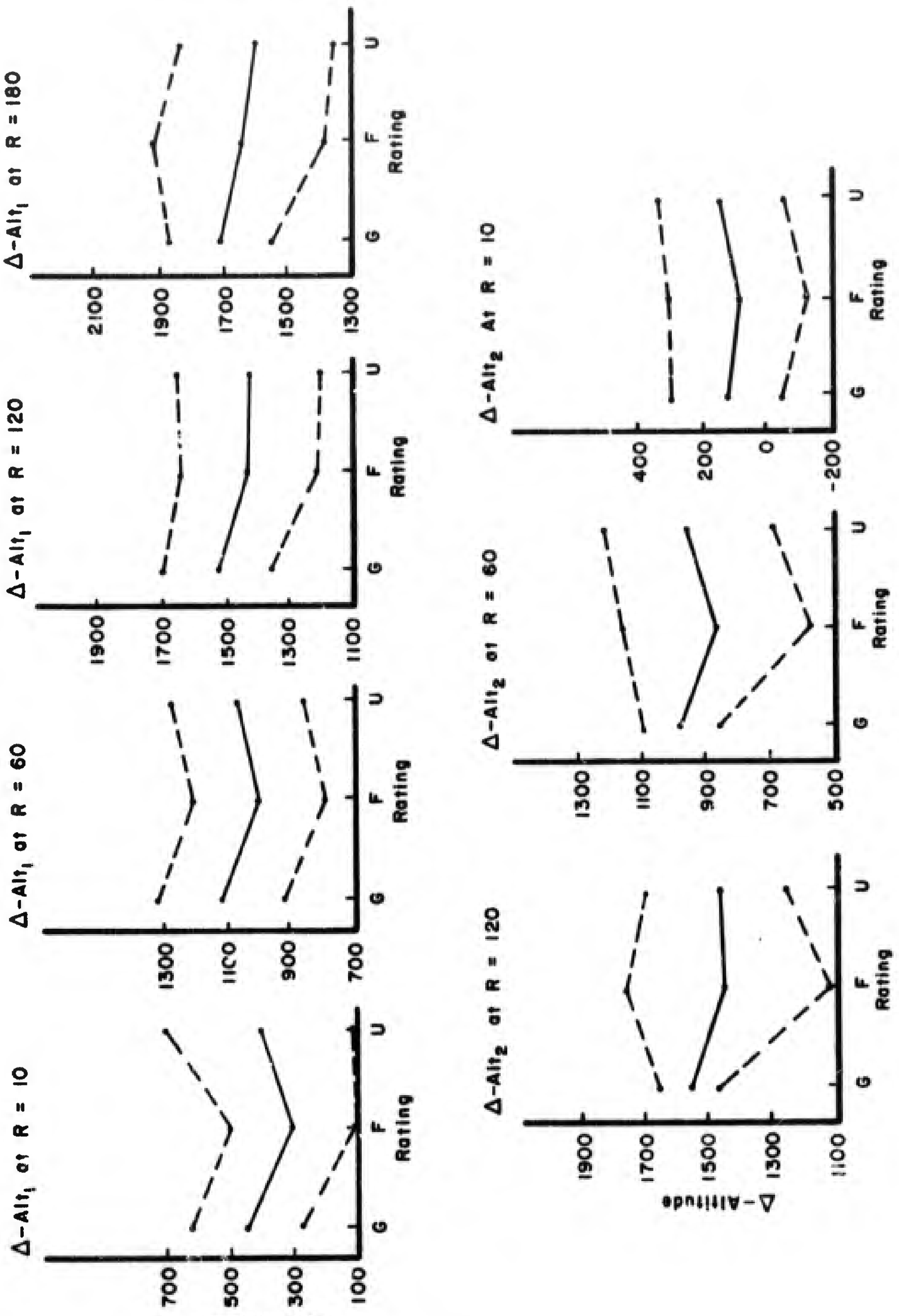


Figure 66. Altitude Excursion Measures for Student Barrel Rolls

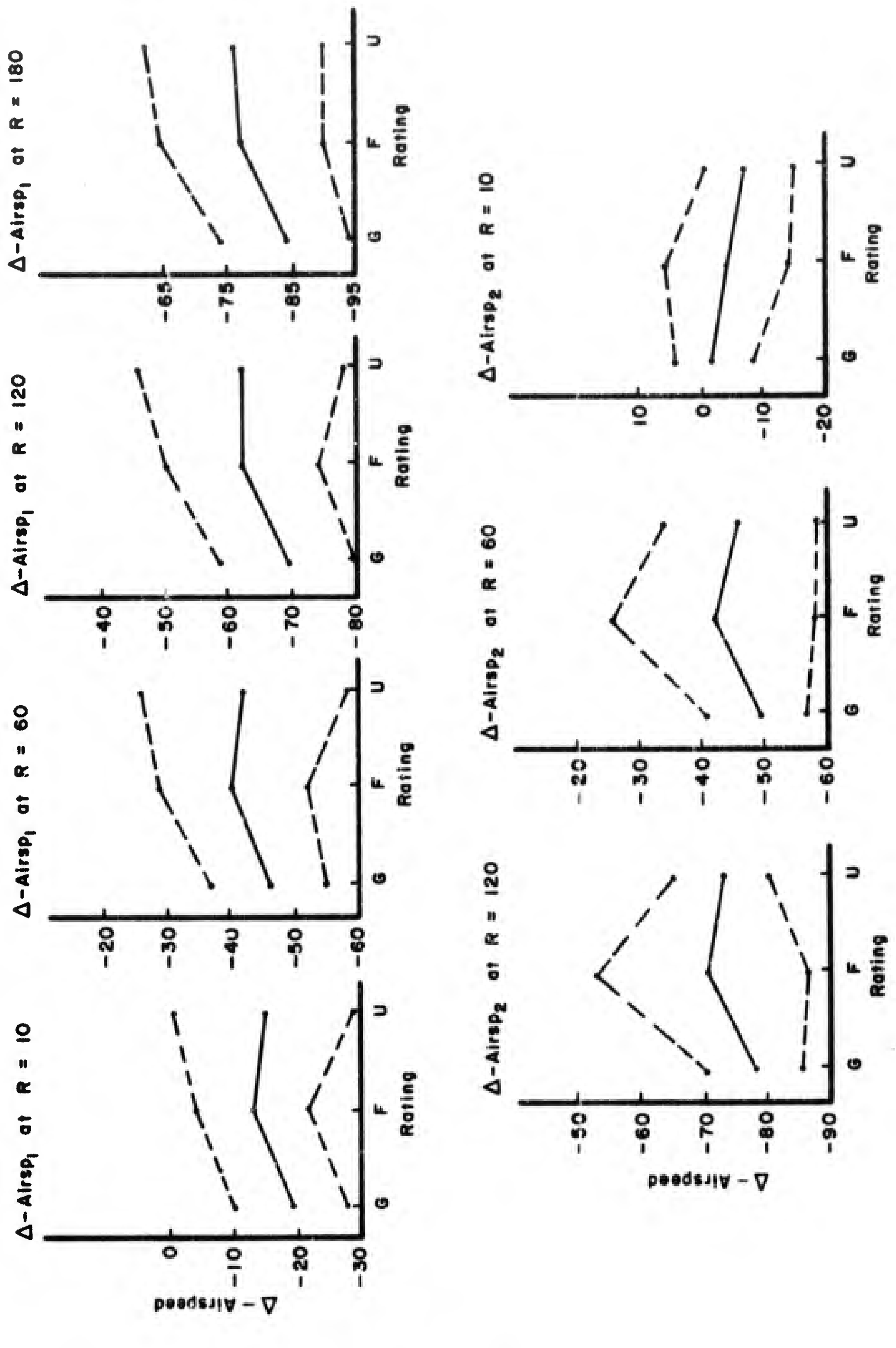


Figure 67. Airspeed Excursion Measures for Student Barrel Rolls

TABLE XXII
CORRELATIONS BETWEEN MEASURES AND SUBJECTIVE RATINGS FOR STUDENT BARREL ROLLS

Measure	Correlation Coefficients	
	All (N=48)	Left (N=43)
1. Symmetry (1-4)	-0.05	-0.05
2. Symmetry (2-3)	-0.15	-0.16
3. Symmetry (Halves)	-0.32*	-0.32*
4. Circle 1	-0.27	-0.27
5. Circle 2	-0.31*	-0.31*
6. Circle All	-0.31*	-0.31*
7. RR Correlation All	0.24	0.24
8. PR Correlation All	0.11	0.14
9. g Correlation All	-0.04	-0.06
10. RR Correlation R>45	-0.31*	-0.33*
11. PR Correlation R>45	-0.01	0.01
12. g Correlation R > 45	-0.06	-0.11
13. Max g 1	0.17	0.18
14. Max g 2	0.19	0.20
15. Min g	0.18	0.19
16. Roll Max Pitch	0.21	0.22
17. Roll Min Pitch	0.15	0.15
18. Max RR	-0.13	-0.15
19. Max PR	0.11	0.12
20. Min PR	-0.04	-0.04
21. Time (Total)	-0.01	-0.00
22. Time 1	-0.19	-0.19
23. Time 2	0.18	0.18

TABLE XXII (Concluded)
CORRELATIONS BETWEEN MEASURES AND SUBJECTIVE RATINGS FOR STUDENT BARREL ROLLS

Measure	Correlation Coefficients	
	All (N=48)	Left (N=43)
24. P (R = 10)	0.22	0.24
25. P (R = 50)	0.26	0.27
26. P (R = 90)	0.28	0.29
27. P (R = 140)	0.23	0.24
28. P (R = 180)	0.24	0.26
29. P (R = 140)	0.09	0.09
30. P (R = 90)	0.04	0.04
31. P (R = 50)	0.10	0.10
32. P (R = 10)	0.22	0.22
33. Δ- ALT (R = 10)	0.02	0.03
34. Δ- ALT (R = 60)	0.04	0.05
35. Δ- ALT (R = 120)	0.10	0.10
36. Δ- ALT (R = 180)	0.11	0.13
37. Δ- ALT (R = 120)	0.05	0.07
38. Δ- ALT (R = 60)	-0.01	0.00
39. Δ- ALT (R = 10)	-0.04	-0.04
40. Δ- ARSP (R = 10)	-0.08	-0.09
41. Δ- ARSP (R = 60)	-0.06	-0.05
42. Δ- ARSP (R = 120)	-0.13	-0.13
43. Δ- ARSP (R = 180)	-0.15	-0.17
44. Δ- ARSP (R = 120)	-0.06	-0.10
45. Δ- ARSP (R = 60)	-0.02	-0.04
46. Δ- ARSP (R = 10)	0.14	0.14

---

*Significant to 0.05 level.

There is a distinct increase in variance as skill ratings decrease in the symmetry measure on quarters 2 and 3. No significant increase is noted for quarters 1 and 4, however. This indicates that more variance in the roll/pitch relationship is exhibited in the inverted attitude, as may be expected. A distinct increase in variance is also noted for halves 1 and 2 as skill ratings vary from fair to unsatisfactory.

Circle measures, which are error measures, increase in value as well as variance as skill ratings decrease. From this data and from the debriefing plots, it is postulated that the circle measure will prove to be one of the best single indicies of performance skill.

Of the constancy measures on roll rate, pitch rate, and normal acceleration, only the roll rate measure for $|roll| > 45$ appears significant from the standpoint of significant correlations. However, the plot shows that as skill ratings decrease, the correlation increases toward 1.0, indicating less variance in roll rate itself. This is the opposite from that which was expected based on the maneuver analysis, and requires further investigation in future efforts. In addition, variance of the correlation decreases as skill ratings decrease, though one would expect an increase.

Maximum G measures show a slight increase as skill ratings vary from good to fair, but a decrease in value and increase in variance with reduction to unsatisfactory. This may indicate that max. G measures may discriminate higher-skill performances better than lower-skill ones; or that lower-skill performance patterns are typically flatter on top and dished-out on the bottom, resulting in much less normal acceleration on the average. Minimum G measures show a decrease from fair to unsatisfactory, indicating the known tendency to "get light" on top when unskilled in performance of this maneuver.

Roll at maximum pitch is approximately 60 to 62° for good performances and decreases noticeably as skill ratings decrease (with an accompanying increase in variance). This suggests a tendency (as skill degrades) to pitch-up, with relatively little roll when roll to the inverted position. This tendency can also be clearly seen in the debriefing plots and supports the validity of the circle measures, which are based on a criterion of evenly and constantly changing roll and pitch. A surprising point regarding roll at maximum pitch is that theoretically it should be 90° to maintain a constant offset angle from the reference point. However, none of the highly skilled performances, including those of instructors, exhibit this. It appears that the requirement for a constant offset angle may be an unrealistic criterion, both from the standpoint of human ability, and perhaps, aircraft performance ability.[8]

The pitch measures at various values of roll are most easily analyzed via the plot of Figure 68. The unsatisfactory performances exhibit a smaller maximum positive pitch angle and pitch reduces to zero before roll has reached 180°. All performances exhibit a linear as opposed to a smooth, curvilinear roll/pitch relationship in the second quarter of the maneuver.

Figures 69 and 70 show similar plots for altitude and airspeed excursions. Little, if any, relevant measurement information can be expected to exist in these measures.

The correlations between measures and subjective ratings (Table XXII) indicate only four significant measures. Although any number of alternative combinatory measures could be postulated, the data are insufficient to permit validation, so none were computed for the barrel roll in this study.

---

[8] Plans exist to test the realism of this criterion using a flight simulator. We attempted to test it in the aircraft, but despite specific attempts on the part of the pilots, they were unable to achieve 90° roll at maximum pitch and still complete the maneuver satisfactorily in all other respects.

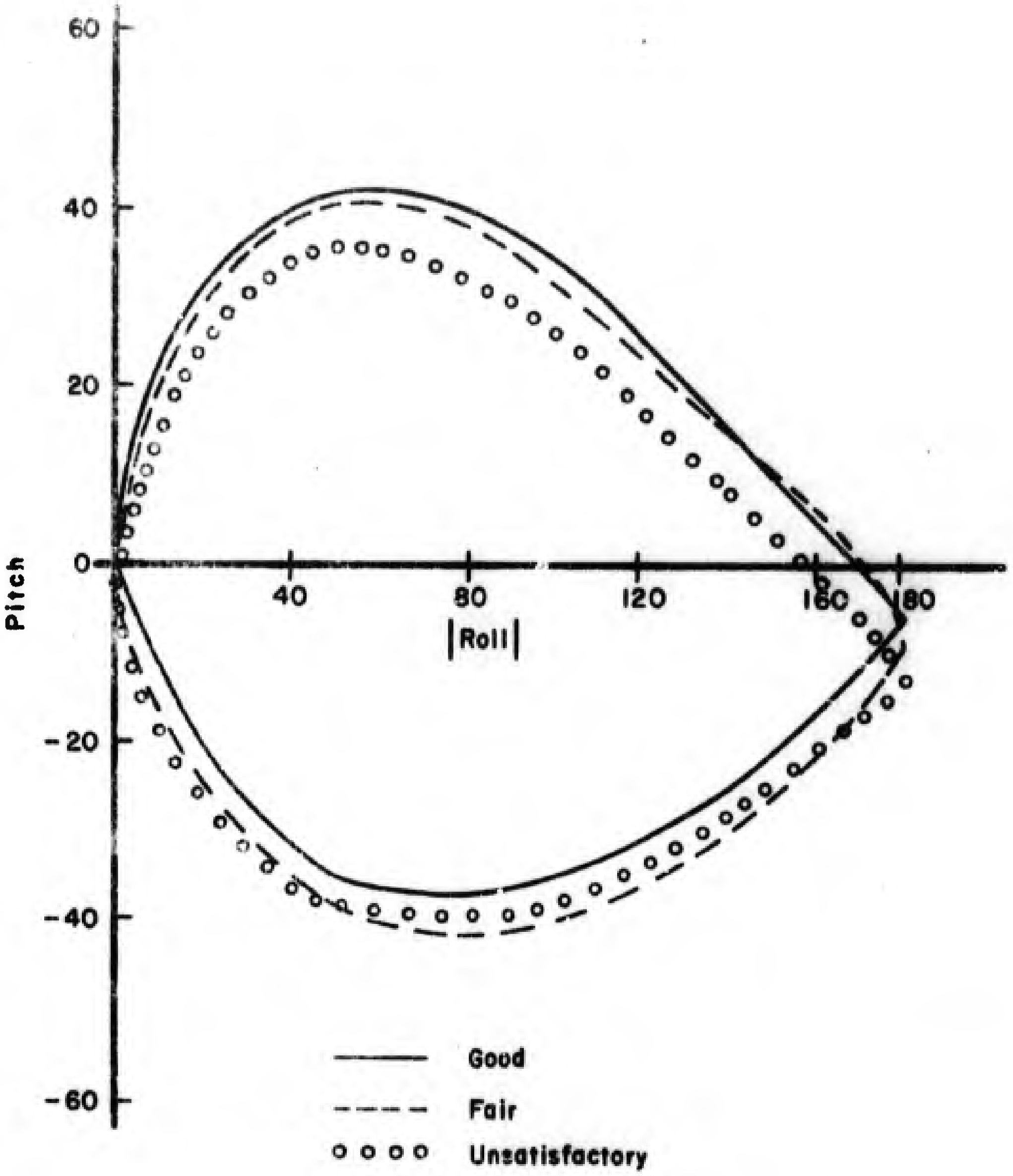


Figure 68. Average Student Barrel Roll Performances

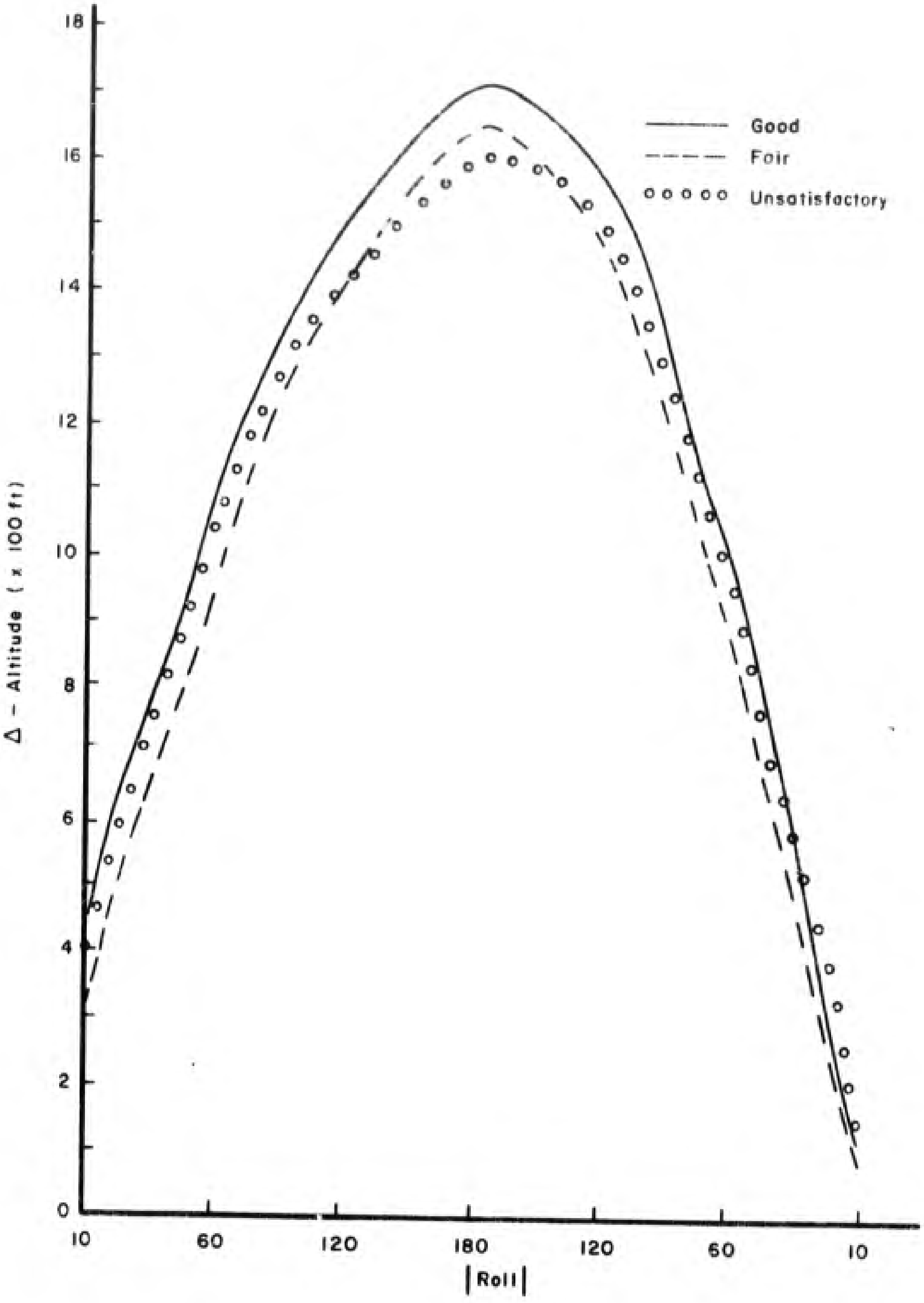


Figure 69. Average Altitude Excursions for Student Barrel Rolls

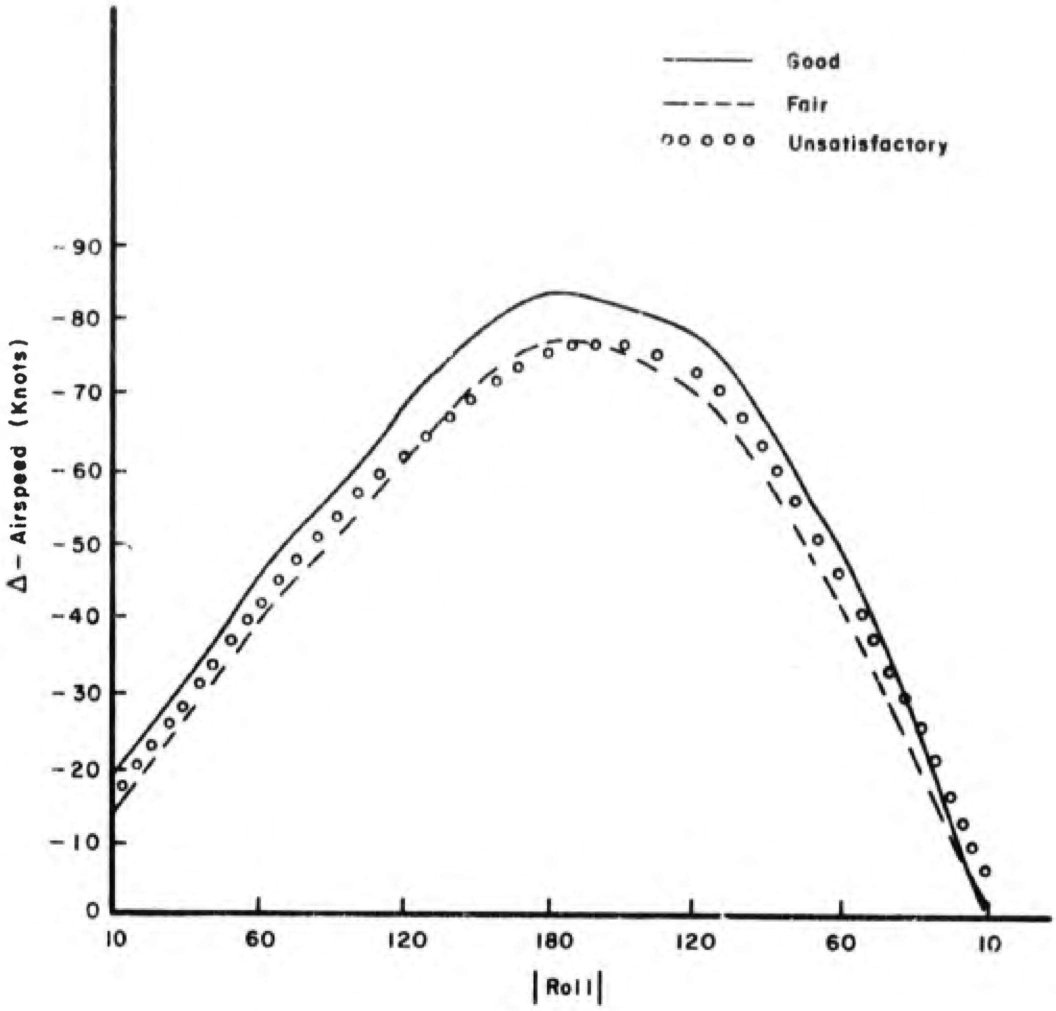


Figure 70. Average Airspeed Excursions for Student Barrel Rolls

b. PIT Instructor Data

Due to time limitations, barrel roll measures were not computed for the PIT Instructor data. However, debriefing plots were generated for 41 performances, and their analysis gives additional insights to the measurement of this maneuver. Several plots are presented in Appendix XVIII, along with the transcribed pilot comments.

It can be seen, in viewing the plots, that the roll/pitch relationship is very relevant to measurement. This supports the trends indicated in the student data. Many of the conditions described in pilots' comments are clearly demonstrated by the roll/pitch plot, e.g., dishing out on the bottom, excessive pitch without sufficient roll, "flat" portions of the maneuver, and too much initial back pressure.

c. Summary

Unfortunately, not nearly enough barrel roll data was collected to form supportable recommendations about measurement of this maneuver. The major deficit is successive samples per student needed to develop and validate measures. Based on the data collected, it is theorized that the following measures are valid and should be investigated further:

1. Roll/Pitch Circle Measures
2. Maximum and Minimum G's
3. Constancy of Roll Rate
4. Symmetry Measures

Further studies should also address the questions raised earlier regarding roll value at maximum pitch, and whether or not maintenance of a constant offset angle is a realistic criterion. Further, the authors found a distinct difference between instructors in their method of performing the barrel roll insofar as g control is concerned. Realistic criteria on g's need to be determined.

Measurement-wise, it is obvious that less was accomplished on the barrel roll than on the lazy 8. This was due primarily to lack of sufficient data; but contributing factors are (1) time limitations on the study, with more emphasis having been placed on the lazy 8, and (2) an apparent inconsistency in criteria for the barrel roll, and subsequently, a great necessity for computing standards (which has not yet been accomplished).

3. OTHER MANEUVERS: TYPICAL DATA

Some representative data were plotted for maneuvers other than the lazy 8 and barrel roll. This data will be used to support follow-on studies in this subject area. As a matter of interest and documentation, typical plots of roll, pitch, airspeed and altitude are presented for several of these other maneuvers in Figures 71 through 76.

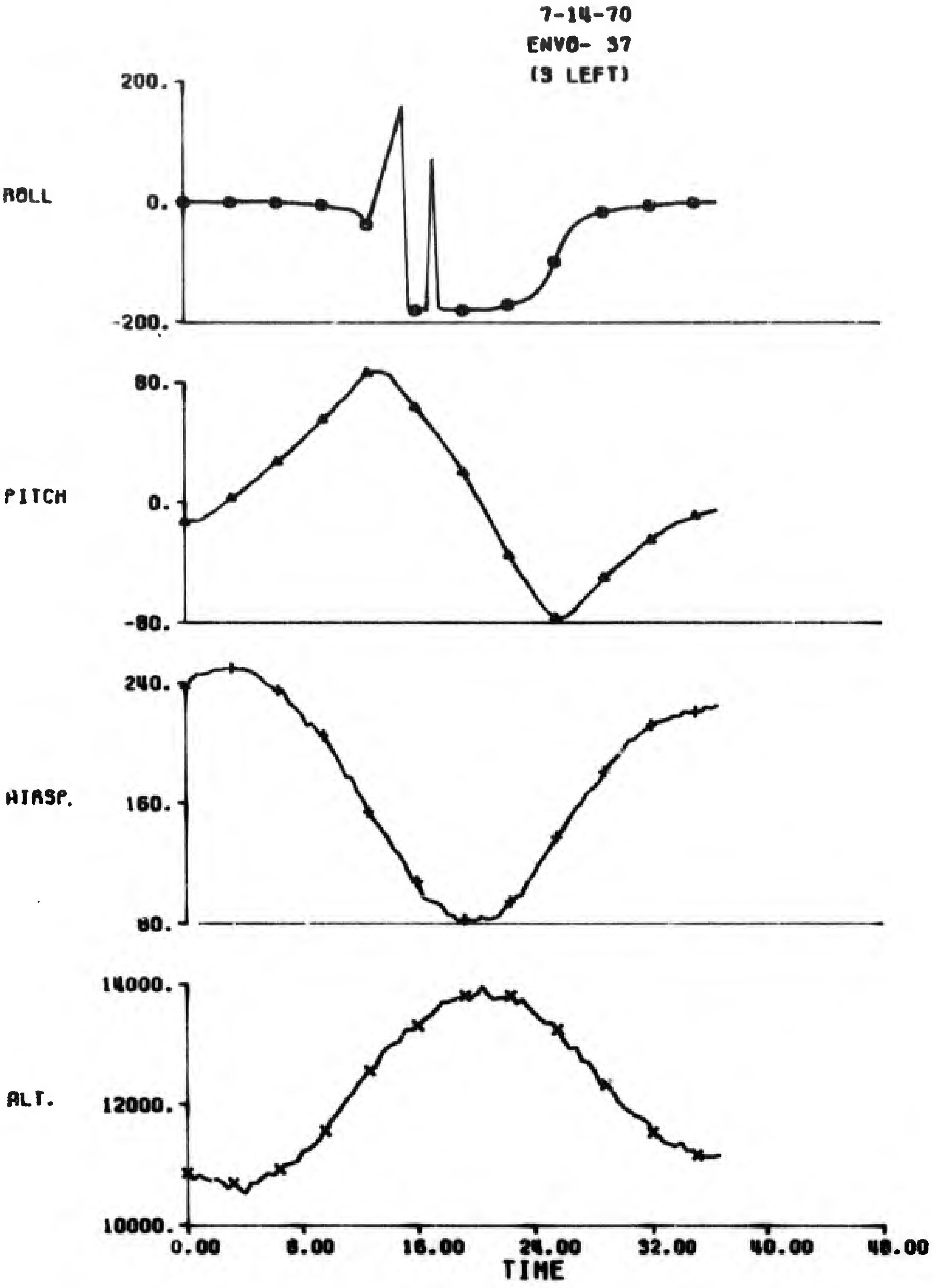


Figure 71. Loop

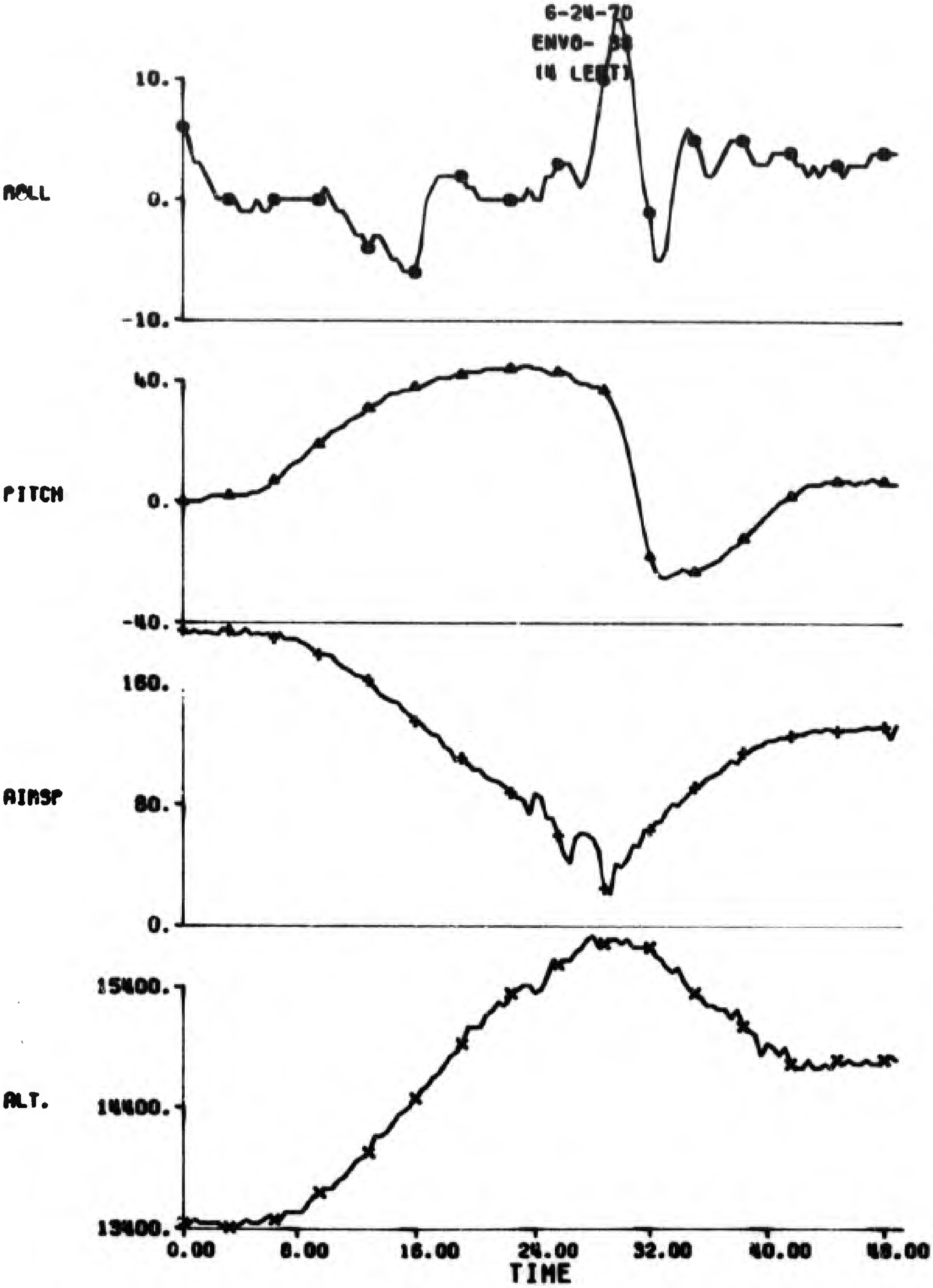


Figure 72. Stall

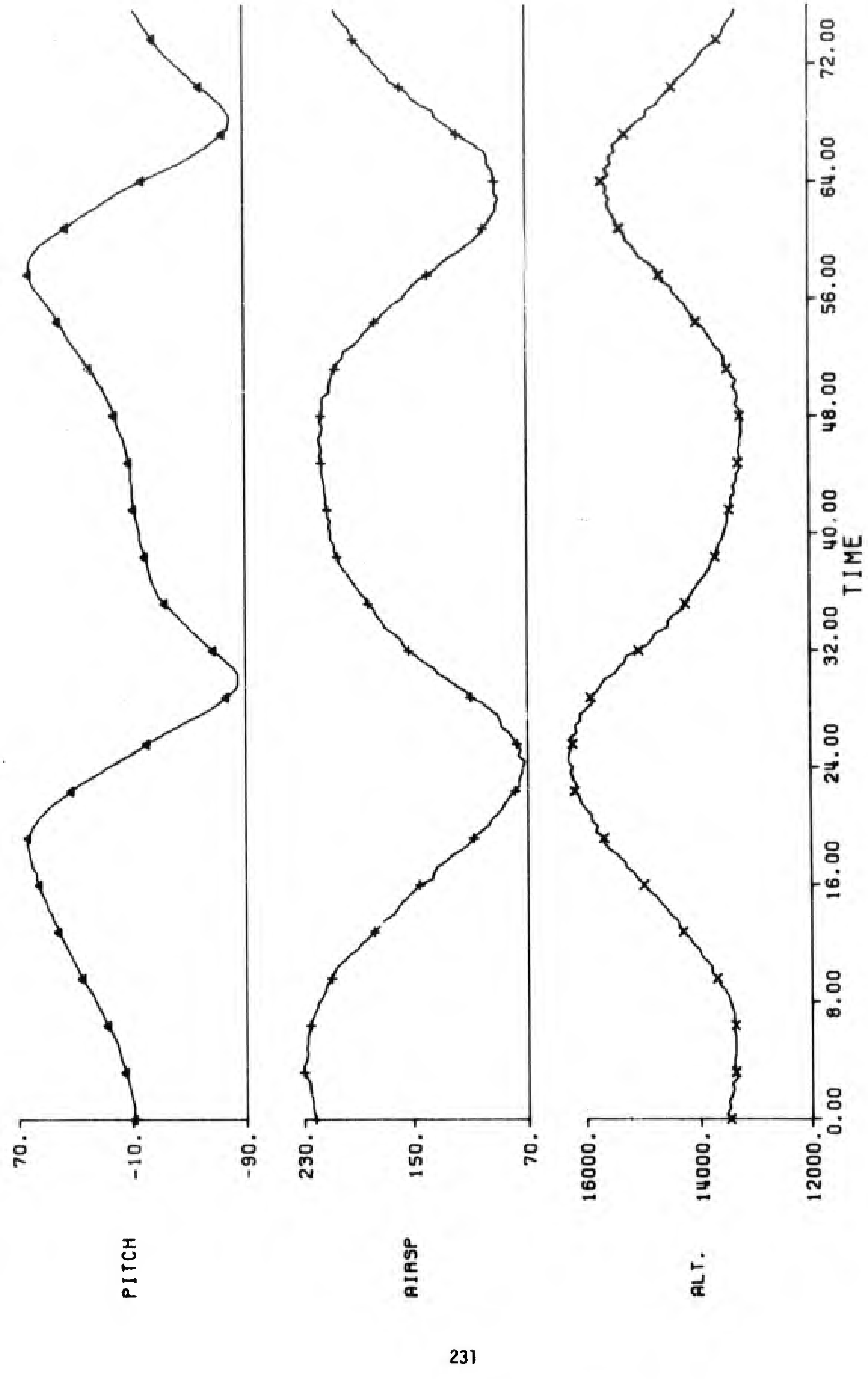


Figure 73. Cloverleaf (1/2)

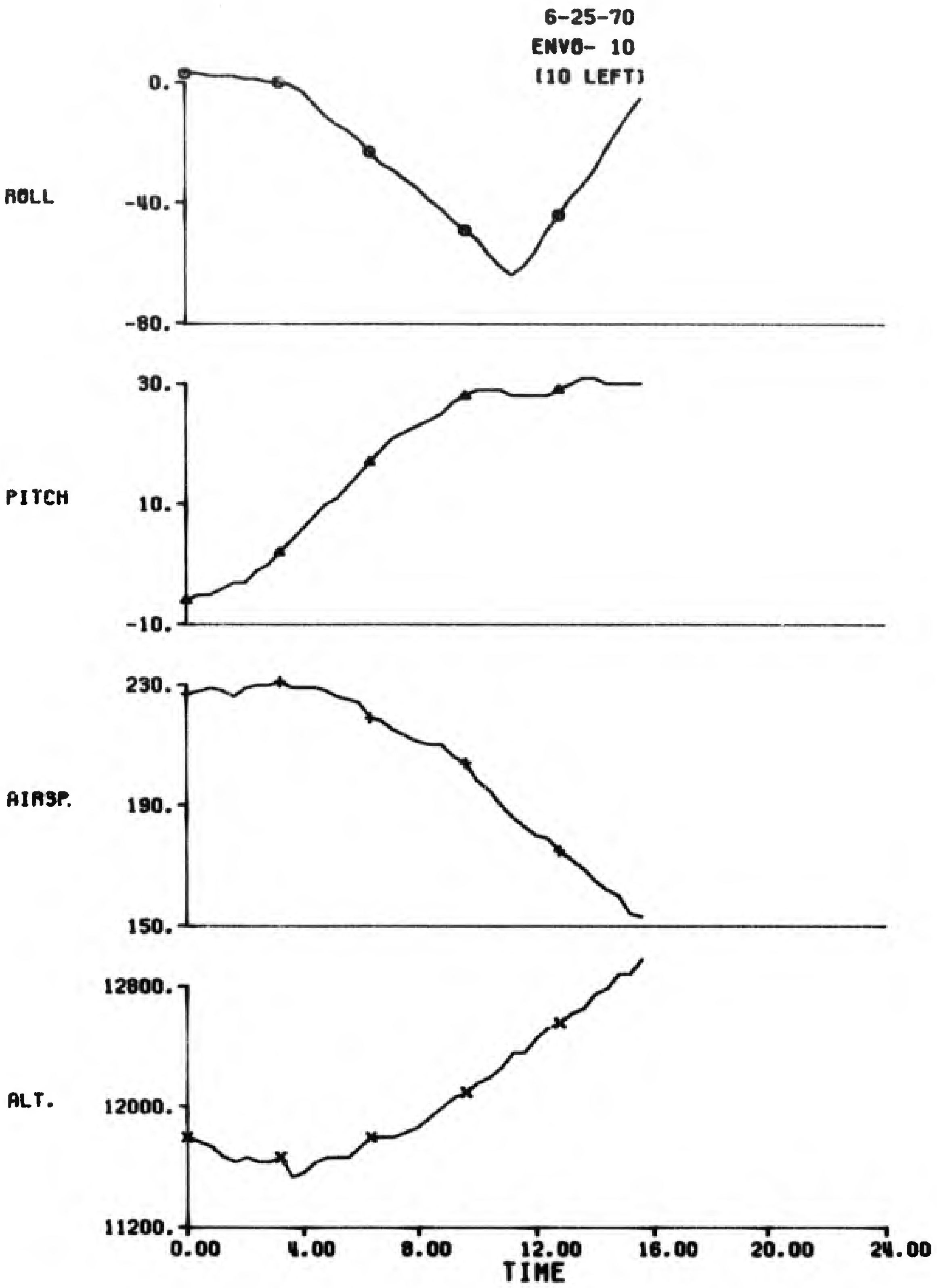


Figure 74. Maximum Performance Climbing Turn

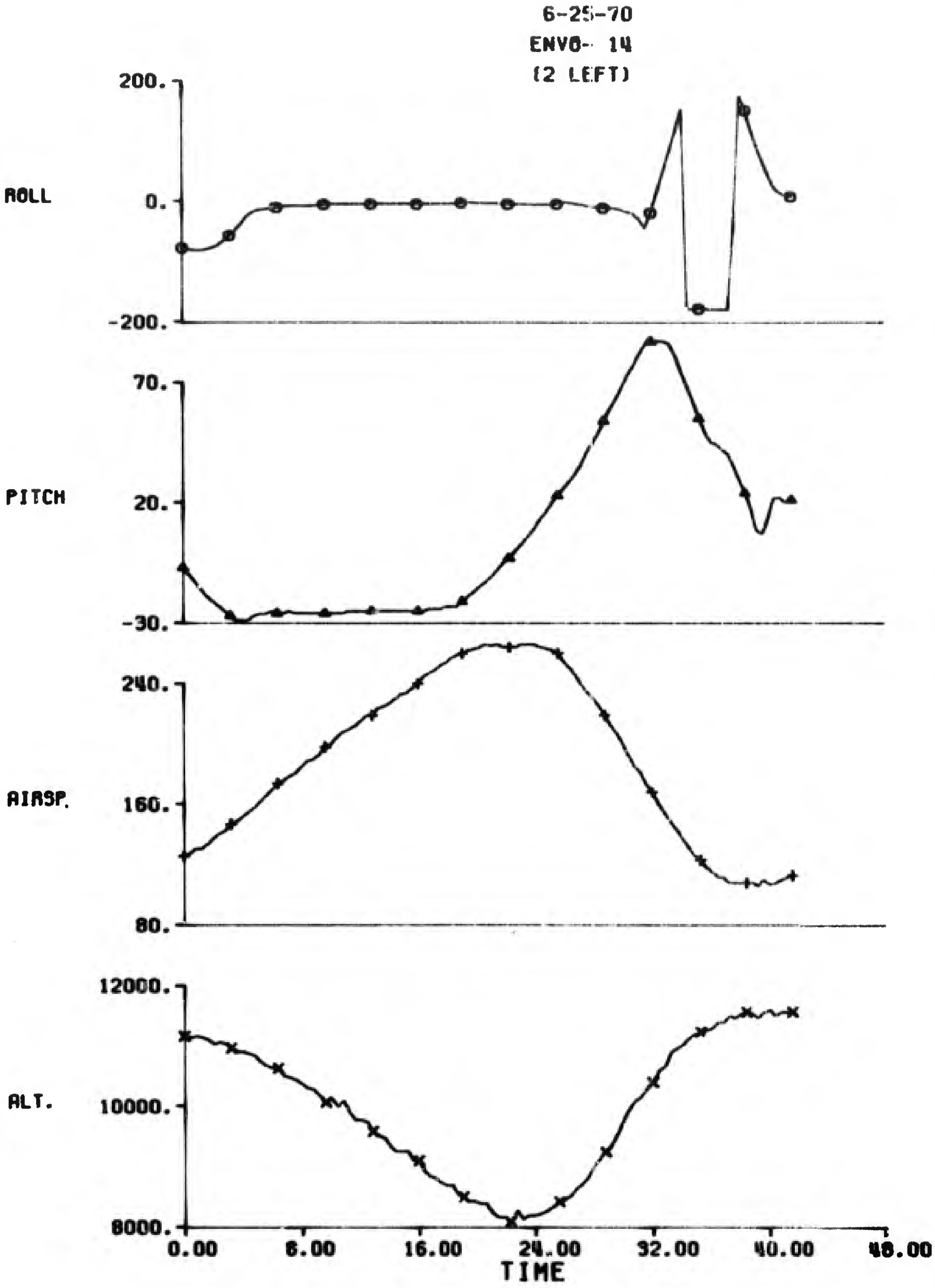


Figure 75. Immelmann

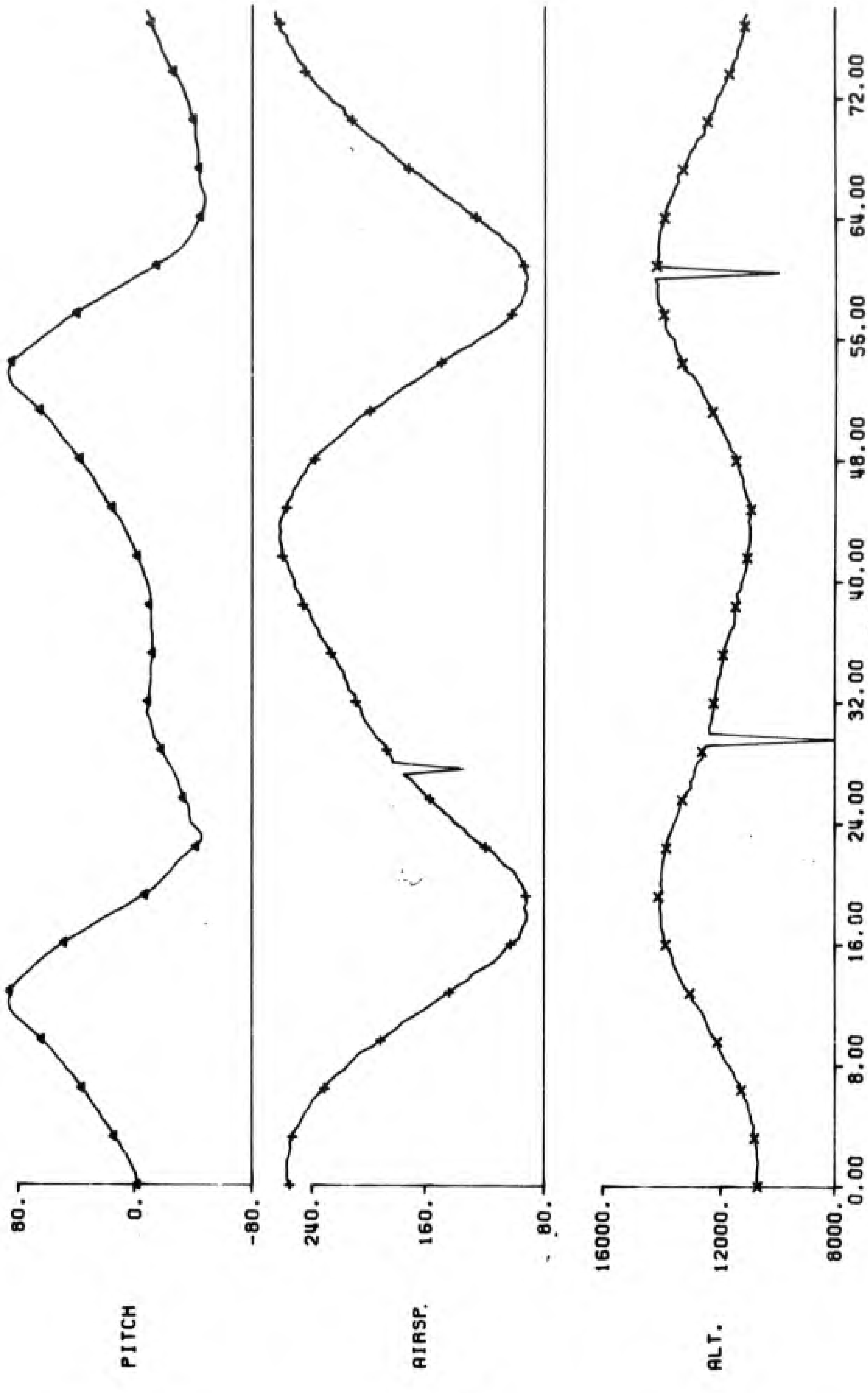


Figure 76. Cuban 8

SECTION VIII

DISCUSSION AND ADDITIONAL REMARKS

It is fortunate that at the onset of this program the authors were a little naive about the problems and difficulties that plague collectors of in-flight data. Otherwise, that which has resulted in an extremely worthwhile and timely effort may have been put off had there been more realistic original estimates of the time and level-of-effort required to complete the program. As it turned out, only 30 to 40% of the total effort (manhours) expended was actually devoted to the central issue, e.g., development of measurement techniques for two representative maneuvers; the bulk of the effort was devoted to establishing the machinery, so to speak, for data collection, reduction, calibration, and analysis. In a way, the results and benefits of the effort are therefore actually greater than originally anticipated, because in addition to accomplishing the major goals related to feasibility of quantitative measurement, (i.e., knowing what to do), the authors have compiled an impressive list of "what not to do" in the future. So in addition to providing a summary of central results, this Section will be devoted to some of the major problems encountered (and lessons learned) in accomplishing an effort of this type.

1. PROBLEMS

It is not easy to obtain good in-flight performance data and reduce it to a form suitable for analysis. Recognition of this, and provision for sufficient personnel to handle problems as they arise, is necessary to a successful conduct of related studies. In the study being reported, the limited availability of equipment and support personnel made it necessary to obtain the needed support from two different data processing installations. This complicated the already difficult job by requiring inter-installation coordination and by creating additional problems through the use of different tape units for producing and reading data. In addition, control of personnel was not possible, and several different programmers were assigned to the program over its tenure.

This required almost continual education of these new people regarding data formats and program objectives. Finally, no control existed over the utilization of data processing equipment, and turn around time from flight to calibrated data was considerably longer than it should have been for efficient operation due to higher priority programs competing for use of the equipment.

The in-flight data acquisition equipment represented no exception to "Murphy's Law," particularly because it was largely (off-the-shelf) used equipment. Partway through the program problems arose with the heading transducer that were never completely rectified despite several recalibrations. (Later, it was determined that a new transducer is required.) Other equipment malfunctions occurred from time to time, seriously delaying data collection schedules and validating the importance and necessity of establishing a rigorous periodic recalibration and preventive maintenance program for the airborne equipment. This would hopefully minimize the requirement for the unscheduled, on-call type of maintenance that upsets schedules.

Operational problems also confounded the problem. Despite planning-precautions, flight line personnel often failed to clean the recorder heads as required, and data from several sorties were lost. This occurred most often during the last several weeks of off-site data collection and was in part the reason why sufficient validation data was not successfully collected. Another operational problem regarded in-flight use of the recorder through cockpit controls. Each instructor was briefed on recorder operation, but evidently the briefings were not thorough enough. On several successive sorties, the participating IP turned the recorder off between maneuvers, and this resulted in losing some data at the end or beginning of maneuvers. It also caused "glitches" in the data at the time the recorder was turned off or on and destroyed the continuity of the time-count.

It is also important, in projecting schedules for studies like this, to consider not only anticipated aircraft maintenance downtime, but special requirements for modifications and inspections. For example, data collection was interrupted on two separate occasions for flap-hinge mods and wing spar inspections. These sound innocent enough, but in the case of this study the aircraft was bailed to Flight Test and they, therefore, accomplished the mods. Scheduling of hangar space and personnel to accomplish the work was perhaps more of a problem than it would be with a regular training aircraft in the ATC fleet.

For student data collection, the arrangement with ATC included assurance that normal schedules and curricula would not be interfered with. This made collection of large quantities of data per student per maneuver difficult.

The effort was conducted 100% in-house and necessarily attempts were made to minimize any direct costs. At the onset of the program, some surplus recorders were obtained. These proved unusable. The recorder and instrumentation gear finally installed was used equipment, not in itself bad, but necessitating some additional test and parts replacement early in the program.

The effort was largely prototype and investigatory in nature and considerable effort was expended on alternative solutions to problems as they occurred:

2. EULER ANGLES COMPUTATION

One small side-effort concerned the computation of Euler angles from recorded rates. This was investigated for three reasons: (1) It would provide an additional check on the relative accuracies with which rates and angles are recorded, (2) It would allow angles through all attitudes to be generated without necessitating all-altitude roll and pitch transducers, (3) It would provide the only good test conceivable on the accuracy of rate information. Programs were written to compute angles from rates. Results showed that recorded rate information was too noisy to produce good results and the effort was abandoned to the priority of other problems.

3. MODELING OF NORMATIVE DATA

Another side-effort concerned taking a closer look at computation of norms or standards. Although used to some extent in this study, mean-performances are not believed to be infallible representations of standards, any more than the mean is always a good representation of any data.

In studying the formal description and ATC criteria for the lazy 8 maneuver, the idea occurred that functions representing both roll and pitch versus degrees-of-turn may be easily approximated using trigonometric functions. For example roll angle increases to a maximum at turn = 90°, decreases to zero at turn = 180°; then repeats this pattern. In simplest form, we could represent this motion by a sine wave multiplied by the maximum roll angle attained in the maneuver (80 - 90°).

Pitch behaves similarly but has an amplitude equal to the largest pitch angle attained in the maneuver and a frequency equal to twice that of the roll function.

An harmonic analysis of a function is a truncated Fourier Series approximation to the function defined at discrete, equidistant points over a finite interval. The function approximation is of the form

$$F(x) = a_0 + \sum_{n=1}^{k} \left[a_n \operatorname{Cos}(nx) + b_n \operatorname{Sin}(nx) \right].$$

In addition to providing a model of performances, the function's coefficients (a_i and b_i) could provide useful measures. For instance, in order for all a_i coefficients to be zero, two characteristics must be present in the data: (1) perfect symmetry and (2) zero pitch at 0 and 90° turn points. The farther from zero the a_i are, the farther the data are from having the above two characteristics.

A program was written to accept as inputs the number of performances to be harmonically analyzed, the number of harmonics to be used in the model, and the recorded data. It then printed out the derived Fourier coefficients and the data generated by stepping the model from 0 to 180 turn by increments of 5°. Results indicate that this is an extremely promising approach to modeling the data, resulting in much more realistic and useful standards than can be represented by the mean.

4. DEBRIEFING PLOTS ANALYSIS

A respectable amount of time was devoted to conceptual analysis of the debriefing plots. After becoming familiar with the plots and learning to read them, forty of the plots were shuffled and attempts were then made by the authors to judge from the plots alone whether each performance was E, G, F, or U. Out of 40 performances, only 8 were classified incorrectly. This was an insignificant test, done as much out of idle curiosity as for any other reason, and not exactly uncontaminated in design. However, it convinces the authors that a properly indoctrinated instructor could evaluate performances using debriefing plots alone and do the job at least as well and much more diagnostically than he can on-site (in-flight).

Further experimentation was done in this area by devising plastic overlays for the plots on which were sketched standard profiles $\pm 1\sigma$. This is helpful in interpreting the performances and diagnosing errors. The approach of using overlays instead of plotting the performances against standards would be useful in analyzing the data and debriefing the student based on his deviation from norms as well as his deviation from standard criteria.

5. MEASUREMENT APPROACH

In this effort, the approach to the development of performance measures was "analytic" in that it involved and required considerable desk-analysis of both the criteria (ATC) and the recorded data. Maneuver analyses were performed, measures were postulated, results were examined, a new set of measures was postulated based on the initial results, and finally, these measures were applied to a broad spectrum of student and instructor performances. Analysis of the final results included investigating correlations between the measures and subjective ratings and then, to a more limited extent, examining the trends of measures across individual student performance.

The result of this effort was that a good set of prototype measures for the lazy 8 was developed, and a similar set for the barrel roll. Unfortunately, the measures for the barrel role were less defensible tnan were those for the lazy 8, because of insufficient data. The validation of these measures was somewhat hampered by such factors as lack of IP performance standardization, questionable "text book" criteria for the two maneuvers, lack of IP rating standardization, and the necessity of using within-subject sampling as a basis for both the development and validation of measures.

The approach itself was time-consuming to apply due to the need for continual interaction with large quantities of data. It is a workable approach given proper manpower support and it enjoys an affinity with logical human performance aspects of the maneuvers that is perhaps lacking in other more highly automated approaches. It lacks the desirable characteristics of requiring less effort to pursue the second time than the first, because for each maneuver examined, new and different problems arise and each must be treated individually.

It is appropriate at this point, to remark that throughout the duration of this program, another entirely different approach to developing measurement methods was pursued using some of the same data. The alternate approach lies at the opposite end of the spectrum from this analytic approach with respect to automation and global applicability. To pursue the alternate approach, certain functions of the data had to be determined and computed. Identification of these functions was enhanced through results, as they unfolded, from the analytic approach. Thus the two approaches were largely conducted in a complementary fashion, even though the results from each are reported independently. References 3 and 5 document the alternate approach.

After having applied this "analytic" approach and, concurrently, a more automated approach (which is based on adaptive modeling), the concensus is that neither suffices independently – at least now. The analytic approach, although workable, is simply too time-consuming to be effective in, say, developing measures for an entire training curriculum. Also, it suffers from a standardization standpoint in that one is never really sure he is finished when using it. This is in turn due to a fundamental weakness of the approach in that the types of measures it addresses represent only a subset of all possible measures. (Conversely, the alternate approach, References 3 and 5, addresses an extremely broad spectrum of measures.)

The analytic approach has several noteworthy merits, the main one of which is the in-depth understanding one must obtain of the maneuver and related performance techniques, and subsequently the application of logic and judgment to the problem that would be possible only through the utmost in programming sophistication on an automated basis.

The point to be made is that the analytic approach is too "manual" to be efficient on a large scale application and does not address all types of measures. More automated approaches take the labor out of the job, are widely applicable, and address a broad spectrum of measures, but they require an element of human judgment to be practical. A blend of the two types of approaches appears ideal.

6. MEASUREMENT RESULTS

For the lazy 8, measurement can be accomplished using roll, pitch, and airspeed. This was demonstrated in this study through the development of a simple error measure, with criteria consisting of values for the variables computed from skilled pilot's data. An improvement on this error measure is believed possible through application of continuous rather than discrete error computations as discussed in Section VII.

The time and scope of this effort did not permit further pursuit of this idea, however.

The above statements are made without the essential justification that good validation, beyond the content validity that existed, would provide. When accomplished, validation should include the previously discussed tests based on within-subject sampling. Concurrent validation using instructor ratings, if conducted, should be pursued as a necessary (not sufficient) test, and then only with the cautions previously identified.

The barrel roll measures could not be developed to the extent they were for the lazy 8 due to lack of sufficient data. From the information examined, however, it appears that roll, pitch, normal acceleration, and roll-rate will provide the necessary data base. Roll and pitch are not relevant as single-variable measures; rather, it is their relationship that forms the essential measure. The nature of a criterion relationship could not be well defined; according to published criteria, it appears to be circular, but the actual data of skilled pilots does not support the validity or realism of this criterion. To a greater extent than in the lazy 8, standards must be determined for this maneuver. Roll rate measures should reflect the constancy of this value after the maneuver is underway. Measures on g's should reflect maximum excursions, but here again criteria are lacking, and little standardization among IPs was found.

From a diagnostic standpoint, the debriefing charts would form an appropriate media for conveying both measures and diagnostic comments to the instructor or student. This would provide the necessary information on not just how well the student performed, but why and where he performed poorly.

It is compelling to bring out one final idea relating to measurement. This idea is not original with the authors, and it was not pursued in this study, but it was so obvious in this study and is so central to any final measurement design that this discussion would be incomplete without mentioning it. The idea is that measurement of individual performances of a maneuver cannot effectively be considered independently, even if one is only concerned with one performance at the time. Rather, the distribution of measures on successive trials, and if one desires, the subsequent probability of successful performance based on that distribution is the important consideration. Therefore, measures themselves should ultimately be expressed in terms of the resulting distribution. This automatically takes into account both the measure(s) achieved and inter-performance variance, both of which are considered relevant to pilot evaluation.

APPENDICES

Preceding page blank

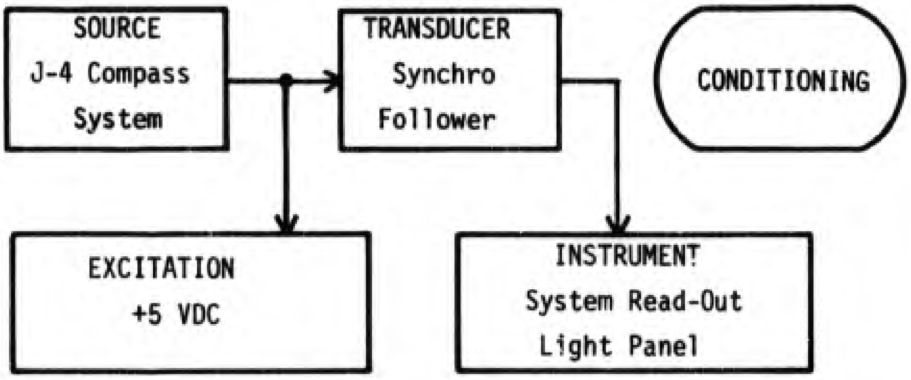
APPENDIX I

CALIBRATION DATA AND CALIBRATION BLOCK DIAGRAMS FOR RECORDED FLIGHT DATA

Parameter: Heading Units: Degrees

Parameter Input	Transducer Output		Parameter Input	Transducer Output
360	0		170	2.730
350	0.128		160	2.879
340	0.281		150	3.017
330	0.404		140	3.155
320	0.563		130	3.324
310	0.701		120	3.468
300	0.840		110	3.616
290	0.988		100	3.744
280	1.137		90	3.913
270	1.280		80	4.001
260	1.424		70	4.170
250	1.567		60	4.246
240	1.711		50	4.282
230	1.864		40	4.308
220	2.003		30	4.334
210	2.151		20	4.359
200	2.305			
190	2.448			
180	2.581			

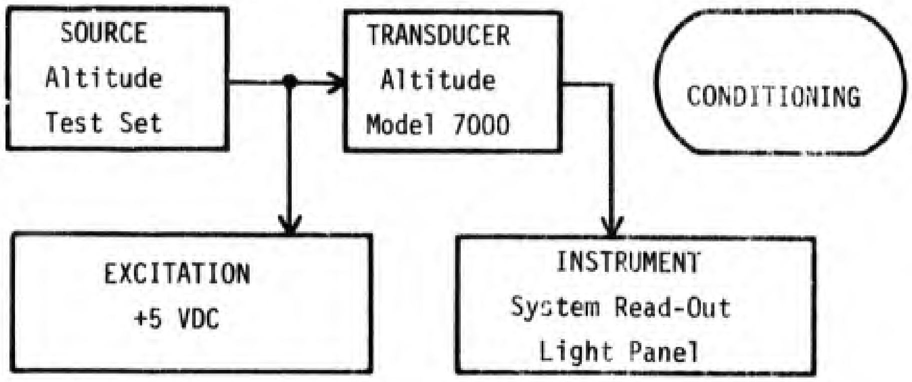
Calibration Block Diagram



Parameter: Altitude Units: Feet (X1000)

Parameter Input	Transducer Output		Parameter Input	Transducer Output
0.89	0.133			
1.0	0.163			
1.5	0.225			
2.0	0.292			
2.5	0.379			
3.0	0.450			
4.0	0.647			
6.0	0.896			
8.0	1.206			
10.0	1.480			
12.0	1.787			
14.0	2.100			
16.0	2.397			
18.0	2.689			
20.0	3.002			
22.0	3.309			
24.0	3.596			
26.0	3.908			

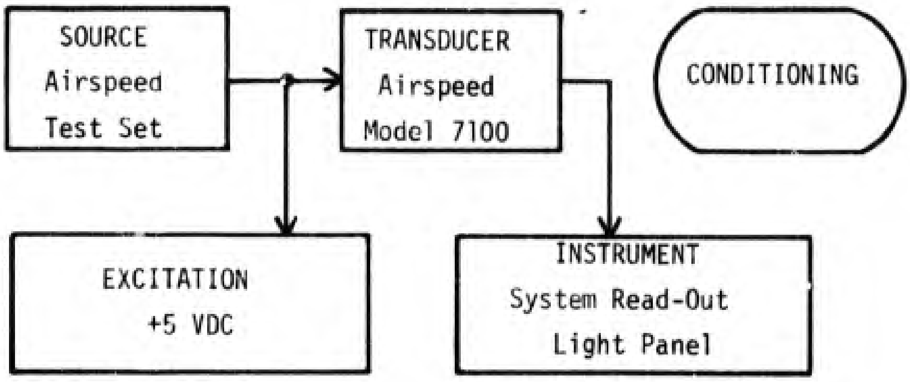
Calibration Block Diagram



Parameter: Airspeed Units: Knots

Parameter Input	Transducer Output		Parameter Input	Transducer Output
0	0.491			
60	0.7836			
70	0.9065			
80	1.091			
90	1.152			
100	1.310			
120	1.585			
140	1.864			
160	2.165			
180	2.438			
200	2.723			
220	3.006			
240	3.267			
260	3.529			
280	3.790			
300	4.025			

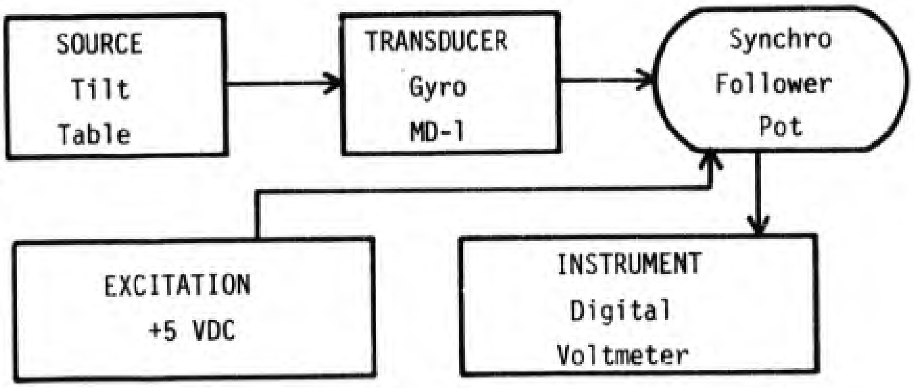
Calibration Block Diagram



Parameter: Pitch Angle   Units: Degrees

Parameter Input	Transducer Output		Parameter Input	Transducer Output
70	3.50			
60	3.36			
50	3.22			
40	3.08			
30	2.94			
20	2.79			
10	2.65			
0	2.50			
-10	2.36			
-20	2.21			
-30	2.07			
-40	1.93			
-50	1.77			
-60	1.63			
-70	1.49			

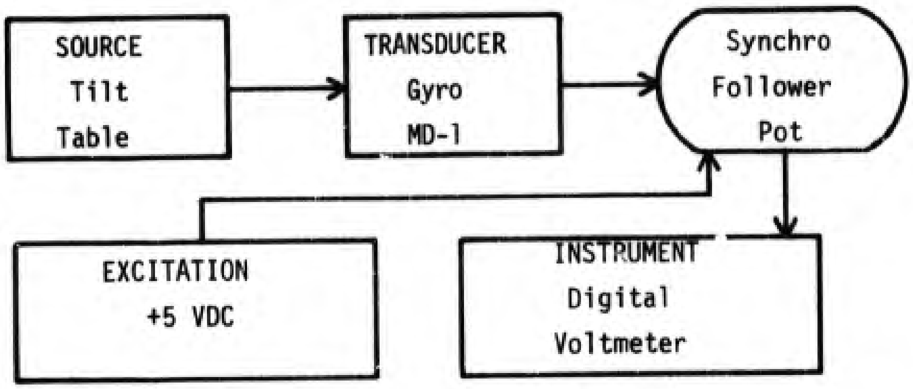
Calibration Block Diagram



Parameter: Roll Angle Units: Degrees

Parameter Input	Transducer Output		Parameter Input	Transducer Output
180	5.00		- 10	2.36
120	4.27		- 20	2.21
110	4.12		- 30	2.07
100	3.98		- 40	1.93
90	3.83		- 50	1.77
80	3.68		- 60	1.63
70	3.53		- 70	1.48
60	3.39		- 80	1.34
50	3.25		- 90	1.19
40	3.10		-100	1.05
30	2.95		-110	0.91
20	2.79		-120	0.84
10	2.65		-180	0
0	2.50			

Calibration Block Diagram

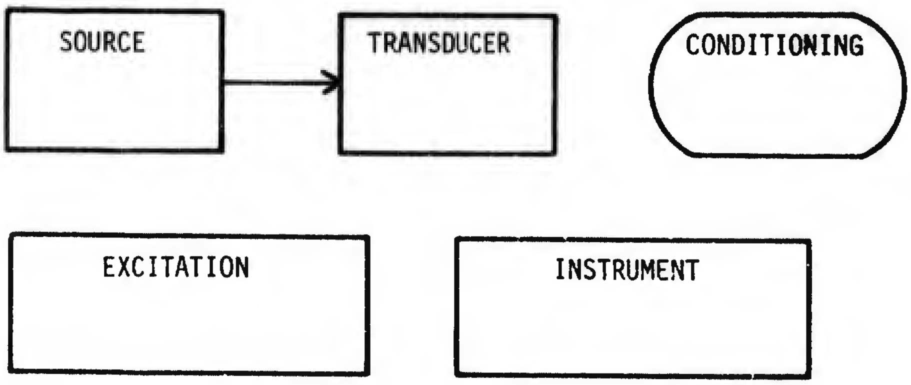


Parameter: Acceleration

Units: g's

Parameter Input	Transducer Output		Parameter Input	Transducer Output
-7	-4.9			
+7	+4.9			

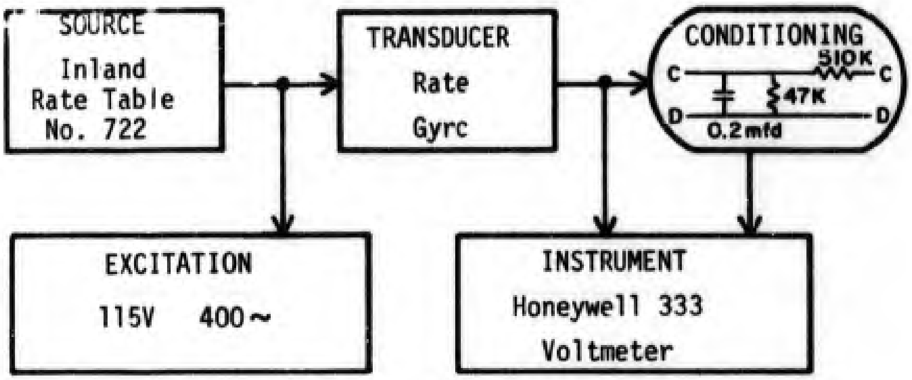
Calibration Block Diagram



Parameter: Pitch Rate Units: Degrees/Second

Parameter Input	Transducer Output		Parameter Input	Transducer Output
90	4.98		-10	-0.53
80	4.47		-20	-1.08
70	3.92		-30	-1.635
60	3.36		-40	-2.21
50	2.79		-50	-2.77
40	2.23		-60	-3.34
30	1.66		-70	-3.90
20	1.095		-80	-4.45
10	0.545		-90	-4.99
0	0			

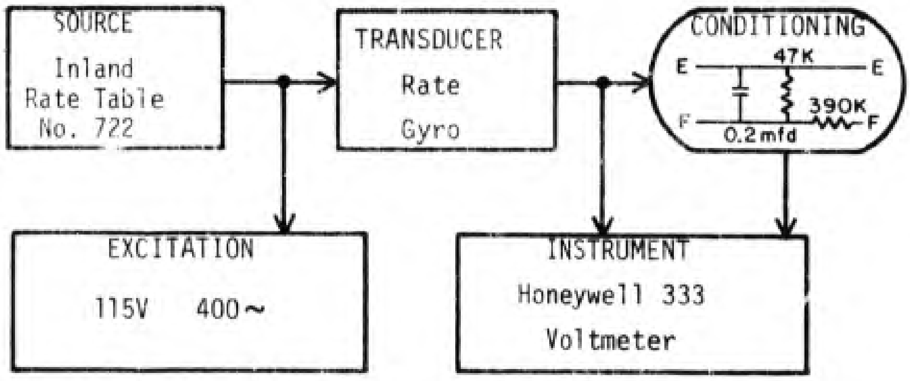
Calibration Block Diagram



Parameter: Roll Rate Units: Degrees/Second

Parameter Input	Transducer Output		Parameter Input	Transducer Output
180	4.66		- 20	0.495
160	4.13		- 40	-1.0
140	3.595		- 60	-1.5
120	3.07		- 80	-2.03
100	2.545		-100	-2.545
80	2.03		-120	-3.03
60	1.51		-140	-3.60
40	1.0		-160	-4.125
20	0.49		-180	-4.65
0	0			

Calibration Block Diagram

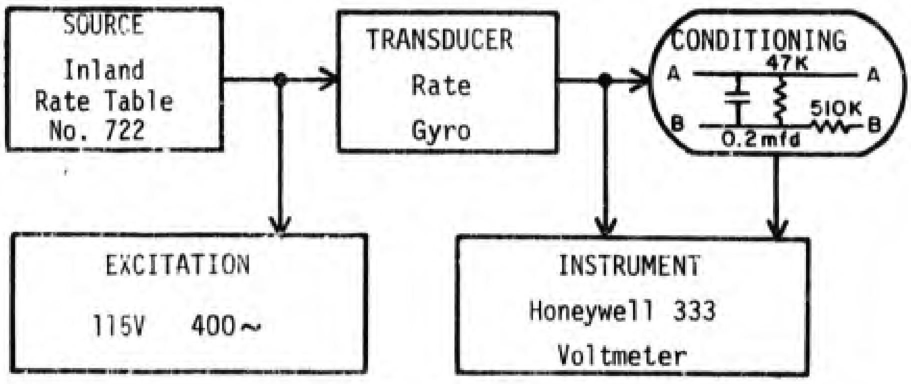


Parameter: Yaw Rate

Units: Degrees/Second

Parameter Input	Transducer Output		Parameter Input	Transducer Output
70	4.75			
60	4.135			
50	3.501			
40	2.84			
30	2.14			
20	1.425			
10	.705			
0	0			
-10	-0.73			
-20	-1.45			
-30	-2.165			
-40	-2.87			
-50	-3.54			
-60	-4.17			
-70	-4.78			

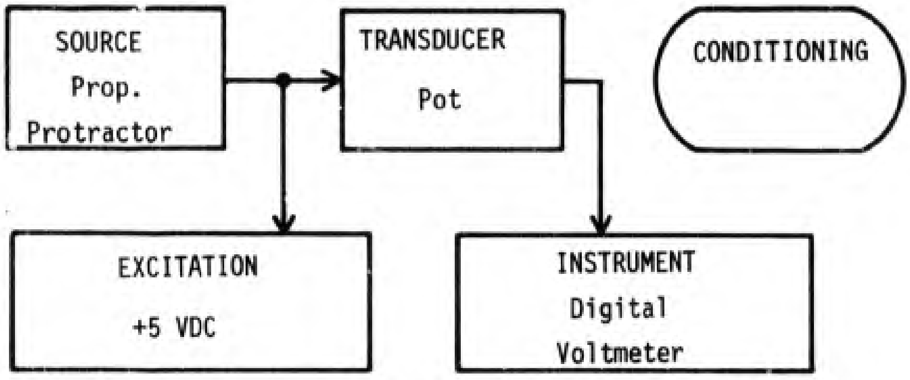
Calibration Block Diagram



Parameter: Longitudinal Stick Position Units: Degrees

Parameter Input	Transducer Output		Parameter Input	Transducer Output
-14.9	0.16			
-10.	0.60			
- 8.	0.78			
- 6.	1.00			
- 4.	1.24			
- 2.	1.45			
0	1.66			
2.	1.88			
4.	2.14			
6.	2.36			
8.	2.59			
10.	2.84			
12.	3.09			
14.	3.32			
16.	3.57			
18.	3.83			
20.	4.10			
22.	4.34			
24.9	4.74			

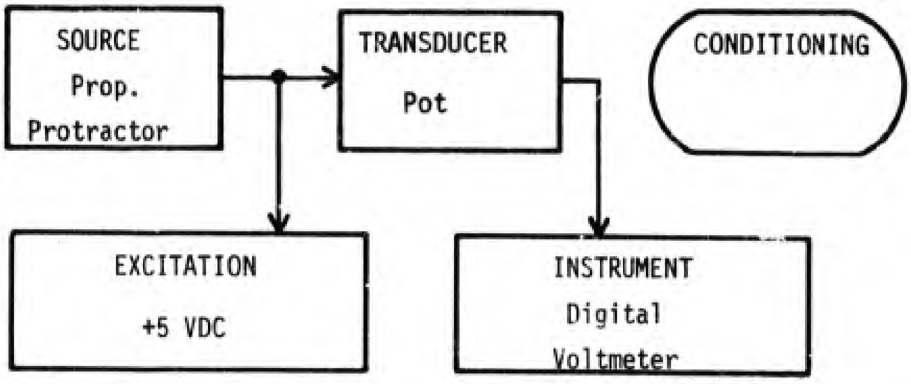
Calibration Block Diagram



Parameter: Lateral Stick Position Units: Degrees

Parameter Input	Transducer Output		Parameter Input	Transducer Output
15	0.27			
14	0.45			
12	0.81			
10	1.11			
8	1.43			
6	1.69			
4	1.94			
2	2.24			
0	2.48			
- 2	2.75			
- 4	3.00			
- 6	3.28			
- 8	3.61			
-10	3.89			
-12	4.23			
-14	4.59			
-16	5.00			

Calibration Block Diagram

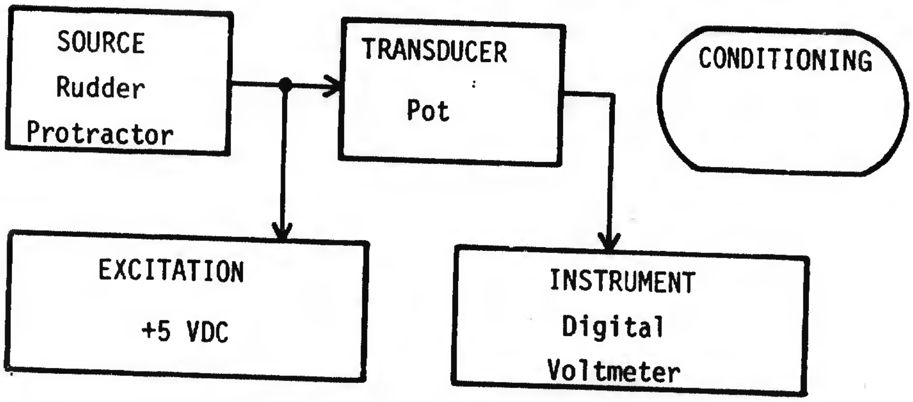


Parameter: Rudder Position

Units: Degrees

Parameter Input	Transducer Output		Parameter Input	Transducer Output
24	0.07		- 2	2.80
22	0.4		- 4	3.00
18	0.8		- 6	3.20
14	1.18		- 8	3.40
10	1.57		-10	3.60
8	1.78		-14	4.00
6	2.00		-18	4.40
4	2.17		-22	4.80
2	2.40		-24	5.00
0	2.54			

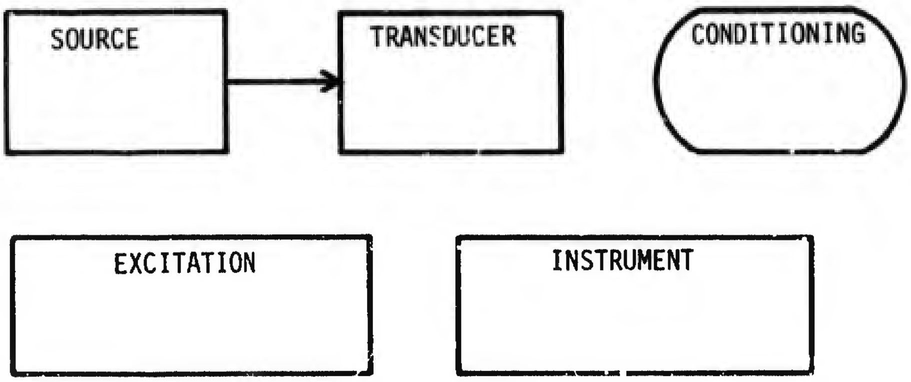
Calibration Block Diagram



Parameter: Engine RPM Units: Percent

Parameter Input	Transducer Output		Parameter Input	Transducer Output
14.28	0.7			
28.57	1.4	L		
42.85	2.11	E		
57.14	2.82	F		
71.42	3.55	T		
85.71	4.28			
100.	5.00			
14.28	0.56			
28.57	1.12	R		
42.85	1.69	I		
57.14	2.27	G		
71.42	2.88	H		
85.71	3.45	T		
100.	4.00			

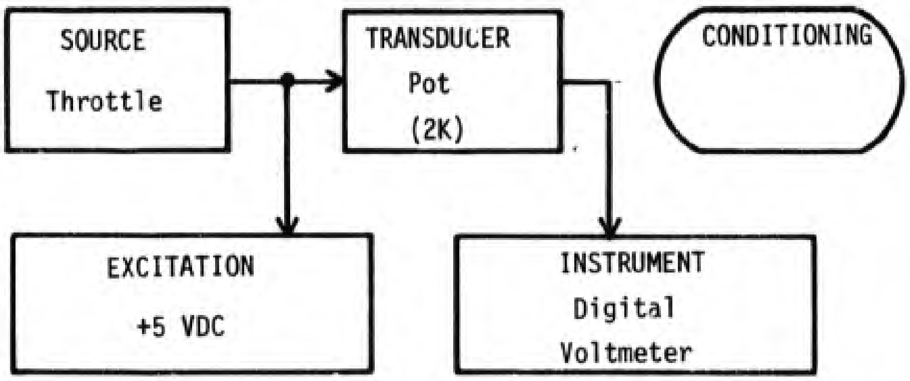
Calibration Block Diagram



Parameter: Throttle Position Units: Degrees

Parameter Input	Transducer Output		Parameter Input	Transducer Output
0	0.23			
16	1.72	L		
32	2.76	E		
48	3.72	F		
64	4.64	T		
0	0.39	R		
16	1.82	I		
32	2.87	G		
48	3.85	H		
64	4.61	T		

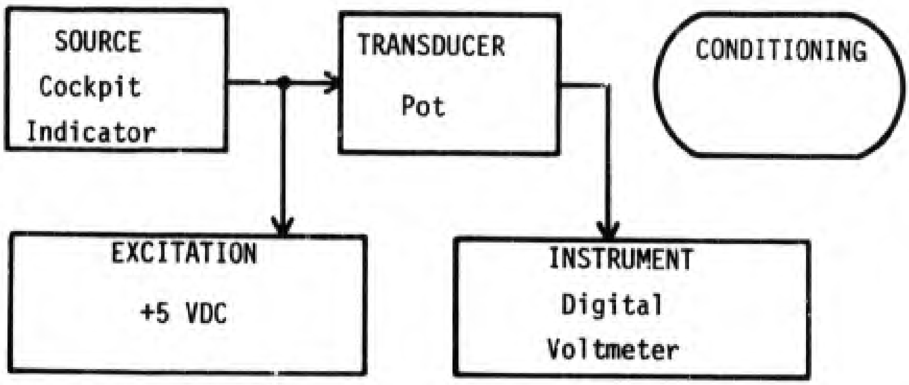
Calibration Block Diagram



Parameter: Flap Position Units: Percent

Parameter Input	Transducer Output		Parameter Input	Transducer Output
0	4.36			
20	3.76			
40	2.85			
60	1.90			
80	1.00			
100	0.11			

Calibration Block Diagram



APPENDIX II

ILLUSTRATION OF INITIAL PRINT-OUT FORMAT

Note: Three pages of computer print out were required to represent approximately 50 seconds of data.

Page 1

Time	Airspeed	Altitude	Vertical Velocity	Pitch (Actual)	Pitch (Computed)	Pitch Rate	Stick Pos. (Long.)	Stick Rate (Long.)	Elevator Tab Up	Elevator Tab Down	Normal Acceleration
968.00	191.68	1590.50	-----	1.37	-----	1.63	1.75	-11.15	0.	0.	1.33
969.00	189.90	1661.24	-----	0.34	-----	1.63	1.57	14.86	0.	0.	1.31
970.00	188.56	1661.24	-----	1.37	-----	1.07	1.12	-13.38	0.	0.	0.97
.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.

NOTE: Page 1 was formatted to represent variables that are primarily relevant to movement of the aircraft vertically and/or about the aircraft y-axis.

Page 2

Time	Heading	Turn Rate	Roll (Actual)	Roll (Computed)	Roll Rate	Stick Pos. (Lateral)	Stick Rate (Lateral)	Lateral Acceleration	Yaw (Computed)	Yaw Rate	Rudder	Rudder Rate
968.00	328.91	----	-52.07	----	-2.21	0.51	1.22	----	----	4.32	1.84	0
969.00	323.61	----	-48.61	----	-1.25	0.88	0	----	----	4.63	1.79	-1.59
970.00	320.78	----	-41.88	----	-7.97	2.01	6.48	----	----	0.79	1.88	8.75
.	.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.	.

NOTE: Page 2 was formatted to represent variables that are primarily relevant to movement of the aircraft horizontally and/or about the aircraft Y or Z axes.

Page 3

Time	Throttle (Left)	RPM (Left)	Throttle (Right)	RPM (Right)	Speed Brake	Flaps	Landing Gear	Thrust Attenuator	Event Number	Time Cycle	Record
968.00	21.86	76.66	16.20	78.09	1.00	0.57	1.00	0.	65.00	2450.10	2042.00
969.00	21.86	76.15	16.20	77.83	1.00	0.49	1.00	0.	65.00	2451.10	2043.00
970.00	21.86	75.96	16.06	76.03	1.00	0.49	1.00	0.	65.00	2452.10	2044.00
·	·	·	·	·	·	·	·	·	·	·	·
·	·	·	·	·	·	·	·	·	·	·	·
·	·	·	·	·	·	·	·	·	·	·	·

NOTE: Page 3 was formatted to represent variables that pertain to engine settings, discrete pilot actions and aircraft configuration, and record-keeping data.

APPENDIX III

SOFTWARE FOR DATA CALIBRATION AND INITIAL PRINT-OUT

```
$JOB           0,5,5000         69-026,GUTHRIE, ROOM 209   BLOCK
$SETUP A(1)    X1895,X1856,-9  UNIT 14  22 OCT 70  FLIGHT 2-8
$IBJOB GUTHRE  MAP
$IBFTC T37DAT  M94,XR7,NODECK
C    $SETUP A(1)  READ THE RAW DATA (36 BIT WORDS WRITTEN AT 556 DENSITY
C      IN NON DCS BLOCKING) FROM TAPE X1895 AND SKIP AS MANY AS 9
C      REDUNDANT RECORDS.   ACCOMPLISH DCS BLOCKING AND WRITE OUT THE RAW
C      DATA AT DENSITY 800 ON TAPE X1856 AND REWIND.
       DIMENSION A(410)
       INTEGER RECORD
C    READ AND COUNT THE RECORDS WRITTEN ON TAPE X1856.
       RECORD=0
C    THE SYMBOLICS FOR SIO. (CALL READ) AND UNITS ARE IN THE MAIN DECK
 1     CALL READ (14,A,K,N)
       RECORD=RECORD+1
       IF (MOD(RECORD,100).NE.0) GO TO 4
       PRINT 5,RECORD
 5     FORMAT (8H RECORD=,I6)
 4     N=N+1
       GO TO (1,2,3),N
C    CALL FXEM   GIVES AN ERROR TRACE AND RETURNS CONTROL TO THE SYSTEM
C      SYMBOLICS NOT INCLUDED
 3     CALL FXEM
 2     RECORD=RECORD-1
       PRINT 5,RECORD
       STOP
       END
$IBLDR SIO.               25 SEP 67                                          SIO.0000
$TEXT  SIO.                                                                  SIO.0001
*N '*,*7(*7(*7-0 '75 74 ' '549   7 '74074875974956976 5 976776 4M7'6 7 'SIO.0002
*N97P**7X$7V*X-)6 E $76'4 2' $7'     , 7-  76776 74(5M'447' (44'' U5M'76'SIO.0003
*N8()**7V*7V*7 4 2' X' '' ''6 '69G 05 Y5 (G7 757'69) 07695 Y)7 75'7'0   SIO.0004
*N96(((X(*X(*7 7E(0  G7Z76 5 774 4 99M'5 7' (4 79M'5 7-  76776 447' )4M'SIO.0005
*N7G)(*7(*7X*7 76 G6)76'4 2' )' '' ''6 '69G 05 )G7 757'69) 0) 07695 Y)7 SIO.0006
*N'RX)*7**7X*7 75'7'-   0  5 7-  76776 76'4 2' '' X7494M776 0677577'0 5 SIO.0007
*N'NX(*7(*7(*7 -6,5 7-  7'++  5597' 0  559449' X   74-02X83'     25690  SIO.0008
*T'**(*77              *)P  9  8                                         SIO.0009
$CDICT SIO.                                                              SIO.0010
*N XZ*84  1'*)P84 *)P U'(PP S'*(P U'**( X'(*)-6 P*)-  ()*-  (*P-  ((*-  SIO.0011
*19Z'((**-  ()G-                                                         SIO.0012
$DKEND SIO.                                                              SIO.0013
$IBLDR UNITS              18 SEP 69                                      UNITS000
$FILE  UNITS    'UNIT14',A(1),INPUT,BIN,BLK=410                          UNITS001
$FILE  UNITS    'UNIT15',A(2),INOUT,BIN,BLK=1080                         UNITS002
$FILE  UNITS    'UNIT16',A(3),INOUT,BIN,BLK=1080                         UNITS003
$FILE  UNITS    'UNIT17',A(4),OUTPUT,BIN,BLK=1080                        UNITS004
$FILE  UNITS    'UNIT18',A(5),OUTPUT,BIN,BLK=1080                        UNITS005
$FDICT UNITS                                                             UNITS006
*J (('42'   *(7PPPPPP72P   *('PPPPPP72P   *('PPPPPP72P   *('PPPPPP      UNITS007
*49P7PP2P   *(6PPPPPP                                                    UNITS008


$TEXT  UNITS                                                             UNITS009
*T =*7*XG        I  H  I  G  )                                           UNITS010
$CDICT UNITS                                                             UNITS011
*V *($ 4  1'*(P 4 X.'   X.'  9X.'  8X.'  9X.(  7                         UNITS012
$DKEND UNITS                                                             UNITS013
'      END OF FILE CARD
```

```
$JOB            0,5,5000         69-026 GUTHRIE ROOM 209 START
$SFTUP A(1)     X1856,NORING  UNIT 14   15 OCT 70  FLIGHT 2-5
$SFTUP A(2)     X1914  UNIT 15
$SFTUP A(3)     TAPE              UNIT 16
$IBFTC T37DAT   M94,XR7,NODECK
C  EACH FOOT OF MAGNETIC TAPE AT 800 DENSITY WILL HOLD 1300 36BIT
C    FLOATING POINT WORDS INCLUDING DCS BLOCKING. 1700 RECORDS REQUIRE
C    1805 FEET OF TAPE.  1700*((12*25)+(120*9))/1300
C    THE WORD RECORD WHEN USED IN REFERENCE TO UNITS 15 AND 16 MEANS
C    ((A240(I,J),I=1,120),J=1,S) PLUS ((A24(I,J),I=1,12),J=1,25)=1380 WDS
C    $SFTUP A(1)  X1856  DCS BLOCKED RAW DATA
C    $SFTUP A(2)  X1914  TAPE TO CONTAIN THE FIRST 1700 RECORDS OF
C      CALIBRATED DATA
C    $SETUP A(3)  TAPE  IF THERE ARE MORE THAN 1700 RECORDS AN ADDITIONAL
C      TAPE IS REQUIRED ON UNIT 16
      DIMENSION A(410),M(100),WORDS(100),TAPES(2)                       MAIN00
      COMMON /A1/ N12,N120,RECORD,IUNIT,N,TAPE,INP(100),JCOL(100),      MAIN01
     1XARRAY(51,18),YARRAY(51,18),JCAL(100),I24,I240                    MAIN02
      COMMON /A2/ J1,A24(24,25),A240(240,9),CYCLE,SET
      INTEGER RECORD,SET                                                MAIN04
      NAMELIST /NAM1/ ITAPE,IP,IPD                                      MAIN05
      READ (5,1) TAPE                                                   MAIN06
C    TAPE   THE REEL NUMBER TO BE MOUNTED ON A(1)  UNIT 14
 1    FORMAT (A6)                                                       MAIN07
      READ (5,NAM1)                                                     MAIN08
      J1516=15                                                          MAIN09
      SET=0                                                             MAIN10
      CYCLE=0.0                                                         MAIN11
      RECORD=0                                                          MAIN12
      J1=0                                                              MAIN13
      IUNIT=14                                                          MAIN14
C  READ AND WRITE INTEGER CONTROL VECTORS
C    JCOL(100) CONTAINS THE COLUMN NUMBER (J) OF XARRAY(NP,J) AND  YARRAYMAIN15
C    (NP,J)                                                             MAIN16
      READ (5,2) (JCOL(I),I=1,100)                                      MAIN17
 2    FORMAT (20I4)                                                     MAIN18
C    INP(100) CONTAINS THE NUMBER OF POINTS (NP) OF XARRAY(NP,J) AND    MAIN19
C    YARRAY(NP,J)                                                       MAIN20
      READ (5,2) (INP(I),I=1,100)                                       MAIN21
C    JCAL(100) CONTAINS THE COLUMN NUMBER OF THE CALIBRATED DATA TO BE  MAIN22
C    STORED IN A240(I,J) AND A24(I,J-6)                                 MAIN23
      READ (5,2) (JCAL(I),I=1,100)                                      MAIN24
      WRITE (6,97) (JCOL(I),I=1,100)                                    MAIN25
 97   FORMAT (12H0JCOL VECTOR/1X/(1X,20I6))                             MAIN26
      WRITE (6,98) (INP(I),I=1,100)                                     MAIN27
 98   FORMAT (11H0INP VECTOR/1X/(1X,20I6))                              MAIN28
      WRITE (6,99) (JCAL(I),I=1,100)                                    MAIN29
 99   FORMAT (12H0JCAL VECTOR/1X/(1X,20I6))                             MAIN30
C  FEAD AND WRITE THE CALIBRATION DATA
      DO 3 J=1,18                                                       MAIN31
```

```
      READ (5,4) LABELX,LABELY,NP                                       MAIN32
 4    FORMAT (A6,5X,A6,5X,I2)                                           MAIN33
      READ (5,5) (XARRAY(I,J),I=1,NP)                                   MAIN34
      READ (5,5) (YARRAY(I,J),I=1,NP)                                   MAIN35
 5    FORMAT (10F8.3)                                                   MAIN36
      WRITE (6,49) LABELX,LABELY,NP                                     MAIN37
 49   FORMAT (1H0,A6,5X,A6,5X,I2)                                       MAIN38
      WRITE (6,50) (XARRAY(I,J),I=1,NP)                                 MAIN39
      WRITE (6,50) (YARRAY(I,J),I=1,NP)                                 MAIN40
 50   FORMAT (1H0,10F12.3/(1X,10F12.3))                                 MAIN41
 3    CONTINUE                                                          MAIN42
      PRINT 13,J1516                                                    MAIN43
 13   FORMAT (6H UNIT=,I4)                                              MAIN44
      N12=0                                                             MAIN45
      N120=0                                                            MAIN46
      CALL CYCLES (A,M,WORDS)                                           MAIN47
      N12=12                                                            MAIN48
      N120=120                                                          MAIN49
 9    CALL CYCLES (A,M,WORDS)                                           MAIN50
C  DIFFERENTIATE VERTICAL VELOCITY=A24(I,21),TURN RATE=A24(I,22),STICK
C   RATE LONGITUDINAL=A240(I,7),STICK RATE LATERAL=A240(I,8),RUDDER RATE
C    =A240(I,9)
      DO 6 I=1,12                                                       MAIN51
      A24(I,21)=DIFF (A24,24,25,I,6,0.1)                                MAIN52
 6    A24(I,22)=DIFF (A24,24,25,I,7,0.1)                                MAIN53
      DO 7 I=1,120                                                      MAIN54
      A240(I,7)=DIFF (A240,240,9,I,3,0.01)                              MAIN55
      A240(I,8)=DIFF (A240,240,9,I,4,0.01)                              MAIN56
 7    A240(I,9)=DIFF (A240,240,9,I,5,0.01)                              MAIN57
      IF (RECORD.GT.2) GO TO 48                                         MAIN58
      A24(1,20)=A240(1,2)                                               MAIN59
      A24(1,23)=0.0                                                     MAIN60
      A24(1,24)=A240(1,1)                                               MAIN61
C  INTEGRATE ROLL=A24(I,20),YAW=A24(I,23),PITCH=A24(I,24)
 48   DO 8 I=2,13                                                       MAIN62
      A24(I,20)=A24(I-1,20)+0.05*(A24(I,2)+A24(I-1,2))                  MAIN63
      A24(I,23)=A24(I-1,23)+0.05*(A24(I,8)+A24(I-1,8))                  MAIN64
      A24(I,24)=A24(I-1,24)+0.05*(A24(I,17)+A24(I-1,17))                MAIN65
 8    CONTINUE                                                          MAIN66
C  WHEN LAPE.NE.0 WRITE OUT CALIBRATED DATA ON UNIT 15 (J1516=15) OR ON
C  UNIT 16 (J1516=16)
      IF (LAPE.EQ.0) GO TO 10                                           MAIN67
      WRITE (J1516) ((A240(I,J),I=1,120),J=1,9)                         MAIN68
      WRITE (J1516) ((A24(I,J),I=1,12),J=1,25)                          MAIN69
 10   CALL SELECT (IP,IPD)                                              MAIN70
C   SUBROUTINE SELECT SETS N=2 WHEN AN END OF FILE IS ENCOUNTERED
      GO TO (21,22),N                                                   MAIN71
C   SHIFT THE CURRENT CYCLE OF CALIBRATED DATA TO THE PREVIOUS CYCLE


C     STORAGE AREA SO AS TO ALLOW THE DIFFERENTION AND INTEGRATION
C     TO BE CONTINUOUS
 21   DO 15 I=13,24                                                     MAIN72
      DO 15 J=1,25                                                      MAIN73
 15   A24(I-12,J)=A24(I,J)                                              MAIN74
      DO 16 I=121,240                                                   MAIN75
      DO 16 J=1,9                                                       MAIN76
 16   A240(I-120,J)=A240(I,J)                                           MAIN77
      IF (RECORD-1701) 9,11,12                                          MAIN78
 11   J1516=16                                                          MAIN79
      PRINT 13,J1516                                                    MAIN80
      GO TO 9                                                           MAIN81
 12   IF (RECORD-3401) 9,22,22                                          MAIN82
 22   CALL PRINT                                                        MAIN83
      STOP                                                              MAIN84
      END                                                               MAIN85
```

```
$IBFTC CYCLEX  M94,XR7,DECK
      SUBROUTINE CYCLES (A,M,WORDS
C  SUBROUTINE CYCLES EXTRACTS,CALIBRATES AND STORES FOR [illegible] MAJOR [illegible] OF
C   OF 100 WORDS
      DIMENSION A(410),M(100),WORDS(100)
      COMMON /A1/ N12,N120,RECORD,IUNIT,N, [illegible]E,INP(100), [illegible] ,
     1XARRAY(51,18),YARRAY(51,18),JCAL(100),I24,I2[illegible]
      COMMON /A2/ J1,A24(24,25),A240(240,[illegible]),CYCLE, [illegible]
      INTEGER RECORD,SET
      RECORD=RECORD+1
C  CALL READ (IUNIT,A,K,N) THIS SUBROUTINE PERMITS [illegible] CALLS FROM
C   FORTRAN IV TO IOCS AND ALLOWS THE CALLING PROGRAM [illegible]
C   CONTROL IF AN END OF FILE OR PERMANENT REDUNDANCY IS ENCOUNTERED
      CALL READ (IUNIT,A,K,N)
C  WRITE OUT THE FIRST FOUR RAW DATA BINARY RECORDS.
      IF (RECORD.LT.5) WRITE (6,10) (A(I),I=1,410)
 10   FORMAT (9H1A MATRIX/1X/(1X,8O16))
      N=N+1
C     K=NO. WORDS IN RECORD A.  GOOD READ (N=1).  END OF FILE (N=2),
C     PERMANENT REDUNDANCY (N=3)
      GO TO (1,2,3),N
 1    IF (K.EQ.410) GO TO 7
      WRITE (6,4) K,RECORD,TAPE,N
 4    FORMAT (12H0THERE ARE  ,I5,3X,17HWORDS IN RECORD  ,I5,3X,5H[illegible] TAPE
     1  ,A6,3X,2HN=,I5)
      CALL EXEM
 2    WRITE (6,5) TAPE,RECORD,N
 5    FORMAT (33H0END OF FILE ENCOUNTERED ON TAPE ,A6,11H  IN RECORD,I6,
     13X,2HN=,I5)
      DO 17 I=13,24
      DO 17 J=1,25
 17   A24(I,J)=0.0
      DO 18 I=121,240
      DO 18 J=1,9
 18   A240(I,J)=0.0
      RETURN
 3    WRITE (6,6) TAPE,RECORD,N
 6    FORMAT (42H0PERMANENT REDUNDANCY ENCOUNTERED ON TAPE ,A6,
     113H  IN RECORD  ,I6,3X,2HN=,I5)
      CALL PRINT
      CALL EXEM
 7    I24=N12
      I240=N120
C  DO 12 MAJOR CYCLES WITHIN ONE 410 (36 BIT) WORD RECORD.EACH CYCLE HAS
C   100 (12 BIT) DATA WORDS
      DO 9 I=2,376,34
      CYCLE=CYCLE+1.0
      I24=I24+1


      DO 8 J=1,100
 8    M(J)=0
C  CALL A MAP CODED SUBROUTINE TO EXTRACT THE NECESSARY 12 BIT DATA
C   WORDS AND CONVERT THE TIME WORDS TO SECONDS
      CALL XTRACT (A(I),M(2))
C  CONVERT THE 12 BIT INTEGER WORDS (STORED ONE PER 36 BIT WORD) TO REAL
C   FLOATING POINT WORDS AND PERFORM THE NECESSARY CALIBRATION
      CALL CALBRT (M,WORDS)
      CALL STORE (WORDS)
 9    CONTINUE
      RETURN
      END
```

```
$IBFTC STORES  M94,XR7,DECK
       SUBROUTINE STORE (WORDS)
       COMMON /A1/ N12,N120,RECORD,IUNIT,N,TAPE,INP(100),JCOL(100),
      1XARRAY(51,18),YARRAY(51.18),JCAL(100),I24,I240
       COMMON /A2/ J1,A24(24,25),A240(240,9),CYCLE,SET
       INTEGER SET
       DIMENSION WORDS(100)
       DO 1 L=1,100
       J=JCAL(L)
       IF (J.EQ.0) GO TO 1
       IF (J.GT.6) GO TO 2
       IF (J.EQ.1) I240=I240+1
       A240(I240,J)=WORDS(L)
       GO TO 1
 2     A24(I24,J-6)=WORDS(L)
 1     CONTINUE
       A24(I24,25)=CYCLE/10.0
       RETURN
       END
```

```
$IBFTC SELECX  DECK,M94,XR7
      SUBROUTINE SELECT (I,ID)
C  FROM THE CALIBRATED DATA STORED IN A24 AND A240 SELECT THE SERIES IP,
C    IP+IPD.IP+2IPD+...TO BE PRINTED
      COMMON /A1/ N12,N120,RECORD,IUNIT,N,TAPE,INP(100),JCOL(100),
     1XARRAY(51,18),YARRAY(51,18),JCAL(100),I24,I240
      COMMON /A2/ J1,A24(24,25),A240(240,9),CYCLE,SET
      COMMON /A3/ PAGE1(50,12),PAGE2(50,13),PAGE3(50,12)
      INTEGER RECORD,SET
 1    IF (I.LE.12) GO TO 2
      I=I-12
      RETURN
 2    J=10*I-9
      J1=J1+1
      PAGE1(J1, 1)=A24(I,19)
      PAGE1(J1, 2)=A240(J,6)
      PAGE1(J1, 3)=A24(I,6)
      PAGE1(J1, 4)=A24(I,21)
      PAGE1(J1, 5)=A240(J,1)
      PAGE1(J1, 6)=A24(I,24)
      PAGE1(J1, 7)=A24(I,17)
      PAGE1(J1, 8)=A240(J,3)
      PAGE1(J1, 9)=A240(J,7)
      PAGE1(J1,10)=A24(I,4)
      PAGE1(J1,11)=A24(I,5)
      PAGE1(J1,12)=A24(I,9)
      PAGE2(J1, 1)=A24(I,19)
      PAGE2(J1, 2)=A24(I,7)
      PAGE2(J1, 3)=A24(I,22)
      PAGE2(J1, 4)=A240(J,2)
      PAGE2(J1, 5)=A24(I,20)
      PAGE2(J1, 6)=A24(I,2)
      PAGE2(J1, 7)=A240(J,4)
      PAGE2(J1, 8)=A240(J,8)
      PAGE2(J1, 9)=A24(I,3)
      PAGE2(J1,10)=A24(I,23)
      PAGE2(J1,11)=A24(I,8)
      PAGE2(J1,12)=A240(J,5)
      PAGE2(J1,13)=A240(J,9)
      PAGE3(J1, 1)=A24(I,19)
      PAGE3(J1, 2)=A24(I,13)
      PAGE3(J1, 3)=A24(I,15)
      PAGE3(J1, 4)=A24(I,14)
      PAGE3(J1, 5)=A24(I,16)
      PAGE3(J1, 6)=A24(I,11)
      PAGE3(J1, 7)=A24(I,10)
      PAGE3(J1, 8)=A24(I,12)
      PAGE3(J1, 9)=A24(I,1)
      PAGE3(J1,10)=A24(I,18)
      PAGE3(J1,11)=A24(I,25)


      PAGE3(J1,12)=RECORD-1
      IF (J1.LT.50) GO TO 35
      CALL PRINT
 35   I=I+ID
      GO TO 1
      END
```

```
$IBFTC PRINTS  DECK,M94,XR7
      SUBROUTINE PRINT
      COMMON /A2/ J1,A24(24,25),A240(240,9),CYCLE,SET
      COMMON /A3/ PAGE1(50,12),PAGE2(50,13),PAGE3(50,12)
      INTEGER SET
      IF (J1.EQ.0) RETURN
      SET=SET+1
 14   WRITE (6,31) SET
 31   FORMAT (13H1PAGE 1   SET,I5/
     C                    5X,4HTIME,10H  AIRSPEED,11H   ALTITUDE,10H  VERT
     1ICAL,5X,5HPITCH,7X,5HPITCH,4X,5HPITCH,12H  STICK POS.,13H   STICK
     2RATE,11H   ELEVATOR,11H   ELEVATOR,8X,6HNORMAL/32X,8HVELOCITY,10H
     3 (ACTUAL),12H  (COMPUTED),5X,4HRATE,5X,7H(LONG.),6X,7H(LONG.),5X,6
     4HTAB UP,11H   TAB DOWN,14H  ACCELERATION/1X)
      WRITE (6,41) ((PAGE1(IR,IC),FLAG1(IR,IC),IC=1,12),IR=1,J1)
 41   FORMAT (1X,F7.2,A1,F9.2,A1,F10.2,A1,F9.2,A1,F9.2,A1,F11.2,A1,F8.2,
     1A1,F11.2,A1,F12.2,A1,F10.0,A1,F10.0,A1,F13.2,A1)
      WRITE (6,32) SET
 32   FORMAT (13H1PAGE 2   SET,I5/
     C                    4X,4HTIME,9H  HEADING,4X,4HTURN,6X,4HROLL,8X,4HR
     1OLL,5X,4HROLL,12H  STICK POS.,12H  STICK RATE,7X,7HLATERAL,9X,3HYA
     2W,6X,3HYAW,8H  RUDDER,9H   RUDDER/21X,4HRATE,10H  (ACTUAL),12H  (C
     3OMPUTED),5X,4HRATE,12H   (LATERAL),12H   (LATERAL),14H  ACCELERATI
     4ON,12H  (COMPUTED),5X,4HRATE,13X,4HRATE/1X)
      WRITE (6,42) ((PAGE2(IR,IC),FLAG2(IR,IC),IC=1,13),IR=1,J1)
 42   FORMAT (1X,F7.2,A1,F7.2,A1,F7.2,A1,F9.2,A1,F11.2,A1,F8.2,A1,F11.2,
     1A1,F11.2,A1,F13.2,A1,F11.2,A1,F8.2,A1,F7.2,A1,F8.2,A1)
      WRITE (6,33) SET
 33   FORMAT (13H1PAGE 3   SET,I5/
     C                    5X,4HTIME,11H   THROTTLE,7X,3HRPM,11H   THROTTLE
     1,7X,3HRPM,8H   SPEED,5X,5HFLAPS,10H   LANDING,7X,6HTHRUST,9X,
     25HEVENT,9X,4HTIME,7X,6HRECORD/14X,6H(LEFT),4X,6H(LEFT),4X,7H(RIGHT
     3),10H   (RIGHT),8H   BRAKE,16X,4HGEAR,13H   ATTENUATOR,8X,6HNUMBER
     4,8X,5HCYCLE/1X)
      WRITE (6,43) ((PAGE3(IR,IC),FLAG3(IR,IC),IC=1,12),IR=1,J1)
 43   FORMAT (1X,F7.2,A1,F10.2,A1,F9.2,A1,F10.2,A1,F9.2,A1,F7.0,A1,F9.2,
     1A1,F9.0,A1,F12.0,A1,F13.0,A1,F12.1,A1,F12.0,A1)
      J1=0
      RETURN
      END
```

```
$IBMAP XTRATC  DECK
XTRACT SAVE    (1,2,4)
       CLA     3,4
       STA     N1
       STA     N3
       STA     N6
       STA     N10
       CLA     4,4
       STA     N2
       STA     N4
       STA     N7
       STA     N8
       STA     N12
 N1    LDQ     **
       RQL     25
       PXA     ,0
       LLS     10
       CHS
 N2    STO     **
       AXT     -1,2
       AXT     -1,1
 N3    LDQ     **,1
       AXT     3,4
 N5    RQL     1
       PXA     ,0
       LLS     10
       CHS
 N4    STO     **,2
       RQL     1
       TXI     *+1,2,-1
       TIX     N5,4,1
       TXI     *+1,1,-1
       TXH     N3,1,-32
 N6    LDQ     **,1
       RQL     1
       PXA     ,0
       LLS     10
       CHS
 N7    STO     **,2
       RQL     1
       TXI     *+1,2,-1
       RQL     1
       PXA     ,0
       LLS     10
       CHS
 N8    STO     **,2
       PXA     ,0
       AXT     0,4
```

```
        RQL     1
N9      RQL     1
        TQP     *+2
        ADD     SEC1,4
        TXI     *+1,4,-1
        TXH     N9,4,-11
        TXI     *+1,1,-1
N10     LDQ     **,1
        AXT     0,4
        RQL     1
N11     RQL     1
        TQP     *+2
        ADD     SEC2,4
        TXI     *+1,4,-1
        TXH     N11,4,-10
        TXI     *+1,2,-1
N12     STO     **,2
        RETURN  XTRACT
SEC1    DEC     240
        DEC     72000
        DEC     36000
        DEC     28800
        DEC     14400
        DEC     7200
        DEC     3600
        DEC     2400
        DEC     1200
        DEC     600
        DEC     480
SEC2    DEC     120
        DEC     60
        DEC     40
        DEC     20
        DEC     10
        DEC     8
        DEC     4
        DEC     2
        DEC     1
        END
```

```
$IBMAP SIO.    DECK        SEPT           DOWDELL                       SIO. 000
       TTL  SIMPLIFIED IOCS SUBROUTINE                                  SIOCS002
* SIMPLIFIED INPUT-OUTPUT CONTROL SYSTEM - 21 SEPTEMBER
* THIS SUBROUTINE PERMITS DIRECT CALL FROM                              SIOCS005
* FORTRAN IV TO IOCS ROUTINES(OPEN,READ,WRITE,CLOSE)                    SIOCS006
*                                                                       SIOCS007
* THE VARIOUS CALLING SEQUENCES ARE-                                    SIOCS008
*    CALL CLOSE(N,M)                                                    SIOCS009
*        N=LOGICAL TAPE                                                 SIOCS010
*        M=(0=NO REWIND, NO EOF ON OUTPUT)                              SIOCS011
*         =(1=REWIND, WRITE EOF ON OUTPUT)                              SIOCS012
*         =(2=NO REWIND, WRITE EOF ON OUTPUT)                           SIOCS013
*         =(3=REWIND, UNLOAD, WRITE EOF ON OUTPUT)                      SIOCS014
*   MODIFIED SIO.  TO RETURN THE WORD COUNT IN K
*    CALL READ(N,A,K,J)                                                 SIOCS015
*        N=LOGICAL TAPE                                                 SIOCS016
*        A=LOCATION OF DATA AREA FOR READ                               SIOCS017
*        K=NUMBER OF WORDS TO BE READ                                   SIOCS018
*        J=STATUS SWITCH(0=GOOD READ),(1=END OF FILE),(2=PERM REDUN)    SIOCS019
*    CALL WRITE(N,A,K)                                                  SIOCS020
*        N=LOGICAL TAPE                                                 SIOCS021
*        A=LOCATION OF AREA FOR WRITE                                   SIOCS022
*        K=NUMBER OF WORDS TO BE WRITTEN                                SIOCS023
*    CALL BKSFIL(N,M)                                                   SIOCS024
*       N=LOGICAL TAPE                                                  SIOCS025
*       M=NO. OF FILES                                                  SIOCS026
       SPACE   2                                                        SIOCS027
 READ  CONTRL  READX,READY
 WRITE CONTRL  WRITX,WRITY
CLOSE  CONTRL  CLOSX,CLOSY
BKSFIL CONTRL BKSFX,BKSFY
       SPACE   2                                                        SIOCS032
       REM     SAVE AND EXIT FOR ALL ROUTINES
SAVE   SAVEN   (2,4),I                                                  SIOCS034
       SXA     LK.DR,4                                                  SIOCS035
       TRA     1,1                                                      SIOCS036
EXIT   AXT     **,1              EXIT ROUTINE                           SIOCS037
       RETURN  SAVE                                                     SIOCS038
       SPACE   2                                                        SIOCS039
       REM     CLOSE SUBROUTINE                                         SIOCS040
CLOSX  SXA     EXIT,1
       TSX     SAVE,1            SAVE ROUTINE                           SIOCS042
       CLA*    4,4               SET REWIND OPTION                      SIOCS043
       PAC     0,1                                                      SIOCS044
       LDQ     PREFIX            ROTATE PREFIX CONSTANT                 SIOCS045
       RQL     0,1               TO FORM DESIRED PREFIX                 SIOCS046
       SLQ     CLOSE1+1          PZE,MZE PTW,MON                        SIOCS047
       TSX     FVIO,1            FIND LOC(FCB)                          SIOCS048
```

```
         CLA    E.              STORE LOC(FCB)                        SIOCS049
         STA    CLOSE1+1                                              SIOCS050
CLOSE1   TSX    .CLOSE,4        CALL TO IOCS                          SIOCS051
         PZE    **                                                    SIOCS052
         TRA    EXIT            RETURN                                SIOCS053
CLOSY    BSS    0
         SPACE  2                                                     SIOCS054
         REM    READ SUBROUTINE                                       SIOCS055
READX    SXA    EXIT,1
         TSX    SAVE,1          SAVE ROUTINE                          SIOCS057
         SXA    READ2,4                                               SIOCS058
         CLA    4,4             FIND READ ADDRESS                     SIOCS059
         STA    READ1+3                                               SIOCS060
         CLA    5,4
         STA    QQ
         STZ*   6,4             ZERO ERROR SWITCH                     SIOCS064
         TSX    FVIO,1          FIND LOC(FCB)                         SIOCS065
         CLA    E.                                                    SIOCS066
         STA    READ1+1                                               SIOCS067
         STA    OPN+1                                                 SIOCS068
         STA    CLS+1                                                 SIOCS069
         PAC    0,1                                                   SIOCS070
         LDI    1,1             FCB WORD 2                            SIOCS071
         LFT    003000          WAS PREVIOUS USE INPUT                SIOCS072
         TRA    *+2             NO, MUST RESET                        SIOCS073
         TRA    READ5           YES, GO CHECK OPEN                    SIOCS074
         LFT    040000          IS FILE CLOSED                        SIOCS075
         TSX    CLS,2           NO, CLOSE IT                          SIOCS076
         LDI    1,1                                                   SIOCS077
         RIL    003000          SET TO INPUT (00)                     SIOCS078
         STI    1,1                                                   SIOCS079
         TRA    *+2                                                   SIOCS080
READ5    LNT    040000          IS FILE OPEN                          SIOCS081
         TSX    OPN,2                                                 SIOCS082
READ1    TSX    .READ,4         CALL TO IOCS                          SIOCS083
         PZE    **                                                    SIOCS084
         PZE    READ2,,READ3    EOF,,REDUN                            SIOCS085
         IORT   **,,**
         LXD    *-1,1
QQ       SXA    **,1
         TRA    EXIT                                                  SIOCS087
READ2    AXT    **,4            RESTORE IR4                           SIOCS088
         CLA    =1              SET EOF SWITCH                        SIOCS089
         STO*   6,4                                                   SIOCS090
         TRA    EXIT            RETURN                                SIOCS091
READ3    XEC    READ2           RESTORE IR4                           SIOCS092
         CLA    =2              SET PERM REDUN                        SIOCS093
         STO*   6,4             SWITCH                                SIOCS094
         TRA    EXIT            RETURN                                SIOCS095
READY    BSS    0
```

```
        SPACE   2                                                   SIOCS096
        REM     WRITE SUBROUTINE                                    SIOCS097
WRITX   SXA     EXIT,1
        TSX     SAVE,1              SAVE ROUTINE                    SIOCS099
        CLA     4,4                 FIND WRITE ADDRESS              SIOCS100
        STA     WRITE1+2                                            SIOCS101
        CLA*    5,4                 FIND NO WORDS                   SIOCS102
        PAX     0,1                                                 SIOCS103
        SXD     WRITE1+2,1                                          SIOCS104
        TSX     FVIO,1              FIND LOC(FCB)                   SIOCS105
        CLA     F.                                                  SIOCS106
        STA     WRITE1+1                                            SIOCS107
        STA     OPN+1                                               SIOCS108
        STA     CLS+1                                               SIOCS109
        PAC     0,1                                                 SIOCS110
        LDI     1,1                 FCB WORD 2 TO INDICATORS        SIOCS111
        LFT     001000              EXAMINE FOR PREVIOUS ACTIVITY   SIOCS112
        TRA     WRITE5              PREVIOUS NOT INPUT              SIOCS113
        LFT     040000              INPUT. IS FILE CLOSED           SIOCS114
        TSX     CLS,2               NO,CLOSE IT                     SIOCS115
        LDI     1,1                                                 SIOCS116
        RIL     003000              SET BITS FOR OUTPUT (01)        SIOCS117
        IIL     001000                                              SIOCS118
        STI     1,1                                                 SIOCS119
        TRA     *+2                                                 SIOCS120
WRITE5  LNT     040000              IS FILE OPEN                    SIOCS121
        TSX     OPN,2               NO,OPEN FILE.                   SIOCS122
WRITE1  TSX     .WRITE,4            CALL TO IOCS                    SIOCS123
        PZE     **                                                  SIOCS124
        IORT    **,,**
        TRA     EXIT                RETURN                          SIOCS126
WRITY   BSS     0
        SPACE   2                                                   SIOCS127
        REM     BACKSPACE FILE ROUTINE                              SIOCS128
BKSEX   SXA     EXIT,1
        TSX     SAVE,1              SAVE ROUTINE                    SIOCS130
        TSX     FVIO,1              FIND LOC(FCB)                   SIOCS131
        CLA     F.                                                  SIOCS132
        STA     CLS+1                                               SIOCS133
        STA     BSKFL1+1                                            SIOCS134
        LXA     LK.DR,4                                             SIOCS135
        CLA*    4,4                 FIND NO. OF FILES               SIOCS136
        PAX     0,1                                                 SIOCS137
        TXL     EXIT,1,0            EXIT IF 0                       SIOCS138
        TSX     CLS,2               CLOSE FILE                      SIOCS139
BSKFL1  TSX     .NDSEL,4                                            SIOCS140
        PZE     **,,6               BACKSPACE 1 FILE                SIOCS141
        TIX     BSKFL1,1,1          CONTINUE FOR M FILES            SIOCS142


        TRA     EXIT                COMPLETE GO HOME                SIOCS143
BKSEY   BSS     0
        SPACE   2                                                   SIOCS144
        REM     OPEN AND CLOSE ROUTINE                              SIOCS145
OPN     TSX     .OPEN,4                                             SIOCS146
        MZE     **                                                  SIOCS147
        TRA     1,2                                                 SIOCS148
CLS     TSX     .CLOSE,4                                            SIOCS149
        MON     **                                                  SIOCS150
        TRA     1,2                                                 SIOCS151
        SPACE   2                                                   SIOCS152
        REM     ROUTINE TO LOCATE FILE CONTROL BLOCK                SIOCS153
FVIO    CLA     3,4                 FIND LOGICAL NUMBER             SIOCS154
        STA     *+4                                                 SIOCS155
        CALL    .FVIO,(**,F.)                                       SIOCS156
        TRA     1,1                 RETURN                          SIOCS157
        SPACE   2                                                   SIOCS158
        REM     CONSTANTS AND VARIABLES                             SIOCS159
        SPACE   1                                                   SIOCS160
        REM     THE FOLLOWING CONSTANT USED TO ESTABLISH            SIOCS161
        REM     OPEN AND CLOSE PREFIX,BY SHIFTING                   SIOCS162
        REM     WITH THE DESIRED OPTION CODE, THE NORMAL PREFIXES   SIOCS163
        REM     OF -1,+2,-0, AND +0 CAN BE OBTAINED                 SIOCS164
PREFIX  MON                                                         SIOCS165
F.      PZE     0                                                   SIOCS166
LK.DR   LDIP                                                        SIOCS167
        END
```

```
$IBMAP UNITS   17,M94,DECK
       ENTRY   .UN14.
.UN14. PZE     UNIT14
UNIT14 FILE    ,A(1),INPUT,BIN,BLK=410
       ENTRY   .UN15.
.UN15. PZE     UNIT15
UNIT15 FILE    ,A(2),INOUT,BIN,BLK=1080
       ENTRY   .UN16.
.UN16. PZE     UNIT16
UNIT16 FILE    ,A(3),INOUT,BIN,BLK=1080
       ENTRY   .UN17.
.UN17. PZE     UNIT17
UNIT17 FILE    ,A(4),OUTPUT,BIN,BLK=1080
       ENTRY   .UN18.
.UN18. PZE     UNIT18
UNIT18 FILE    ,A(5),OUTPUT,BIN,BLK=1080
       END
```

```
'       END OF FILE CARD
X1856    92 RECORDS BY COUNT
 $NAM1  ITAPE=1,IP=1,IPD=10$
0    1    2    3    4    5    6    0    0    0    0    1    2    3    4    5    6    7    0    0
0    1    2    3    4    5    6    8    0    0    0    1    2    3    4    5    6    9    10   11
12   1    2    3    4    5    6    13   0    0    14   1    2    3    4    5    6    15   16   17
18   1    2    3    4    5    6    0    0    0    0    1    2    3    4    5    6    0    0    0
0    1    2    3    4    5    6    0    0    0    0    1    2    3    4    5    6    0    0    0
0    15   27   19   17   19   16   -1   0    0    0    15   27   19   17   19   16   19   0    0
0    15   27   19   17   19   16   13   -1   -1   0    15   27   19   17   19   16   18   35   15
2    15   27   19   17   19   16   6    -1   -1   5    15   27   19   17   19   16   5    7    7
19   15   27   19   17   19   16   -3   0    0    0    15   27   19   17   19   16   0    0    0
0    15   27   19   17   19   16   0    0    0    0    15   27   19   17   19   16   -2   0    0
0    1    2    3    4    5    6    7    0    0    0    1    2    3    4    5    6    8    0    0
0    1    2    3    4    5    6    9    10   11   0    1    2    3    4    5    6    12   13   14
15   1    2    3    4    5    6    16   17   18   19   1    2    3    4    5    6    20   21   22
23   1    2    3    4    5    6    24   0    0    0    1    2    3    4    5    6    0    0    0
0    1    2    3    4    5    6    0    0    0    0    1    2    3    4    5    6    25   0    0
WORD02     PITCH       15
3.50       3.36       3.22       3.08       2.94       2.79       2.65       2.50       2.36       2.21
2.07       1.93       1.77       1.63       1.49
70.        60.        50.        40.        30.        20.        10.        0.         -10.       -20.
-30.       -40.       -50.       -60.       -70.
WORD03     ROLL        27
5.00       4.27       4.12       3.98       3.83       3.68       3.53       3.39       3.25       3.10
2.95       2.79       2.65       2.50       2.36       2.21       2.07       1.92       1.77       1.63
1.48       1.34       1.19       1.05       0.91       0.84       0.00
180.       120.       110.       100.       90.        80.        70.        60.        50.        40.
30.        20.        10.        0.         -10.       -20.       -30.       -40.       -50.       -60.
-70.       -80.       -90.       -100.      -110.      -120.      -180.
WORD04     STICKO      19
.16        .60        .78        1.00       1.24       1.45       1.66       1.88       2.14       2.36
2.59       2.84       3.09       3.32       3.57       3.83       4.10       4.35       4.70
-14.9      -10.       -8.        -6.        -4.        -2.        0.         2.         4.         6.
8.         10.        12.        14.        16.        18.        20.        22.        24.9
WORD05     STICKA      17
.27        .45        .81        1.11       1.43       1.69       1.96       2.24       2.48       2.75
3.00       3.28       3.61       3.89       4.23       4.59       5.00
16.        14.        12.        10.        8.         6.         4.         2.         0.         -2.
-4.        -6.        -8.        -10.       -12.       -14.       -16.
WORD06     RUDDER      19
.07        .4         .8         1.18       1.57       1.78       2.00       2.17       2.40       2.54
2.80       3.00       3.20       3.40       3.60       4.00       4.40       4.80       5.00
24.        22.        18.        14.        10.        8.         6.         4.         2.         0.
-2.        -4.        -6.        -8.        -10.       -14.       -18.       -22.       -24.
WORD07     AIRSPD      16
.491       .7836      .9065      1.019      1.152      1.310      1.585      1.864      2.165      2.438
2.723      3.006      3.267      3.529      3.790      4.025
0.         60.        70.        80.        90.        100.       120.       140.       160.       180.
200.       220.       240.       260.       280.       300.
```

```
WORD18      ROLLRT      19
4.66        4.13        3.595       3.07        2.545       2.03        1.51        1.0         .49         0.
-.495       -1.0        -1.51       -2.03       -2.545      -3.08       -3.60       -4.125      -4.65
180.        160.        140.        120.        100.        80.         60.         40.         20.         0.
-20.        -40.        -60.        -80.        -100.       -120.       -140.       -160.       -180.
WORD28      LATACC      13
2.09        1.91        1.74        1.57        1.46        1.30        1.15        0.99        0.83        0.67
0.52        0.36        0.20
3.0         2.5         2.0         1.5         1.0         .5          0.          -.5         -1.0        -1.5
-2.0        -2.5        -3.0
WORD38      ALTITD      18
.133        .163        .225        .292        .379        .450        .647        .896        1.206       1.480
1.787       2.100       2.397       2.689       3.002       3.309       3.596       3.908
890.        1000.       1500.       2000.       2500.       3000.       4000.       6000.       8000.       10000.
12000.      14000.      16000.      18000.      20000.      22000.      24000.      26000.
WORD39      HEADNG      35
0.          .128        .281        .404        .563        .701        .840        .988        1.137       1.280
1.424       1.567       1.711       1.864       2.003       2.151       2.305       2.448       2.581       2.730
2.879       3.017       3.155       3.324       3.468       3.616       3.744       3.913       4.001       4.170
4.246       4.282       4.308       4.334       4.359
360.        350.        340.        330.        320.        310.        300.        290.        280.        270.
260.        250.        240.        230.        220.        210.        200.        190.        180.        170.
160.        150.        140.        130.        120.        110.        100.        90.         80.         70.
60.         50.         40.         30.         20.
WORD40      YAWRTE      15
4.75        4.135       3.501       2.84        2.14        1.425       .705        0.          -.73        -1.45
-2.165      -2.87       -3.54       -4.17       -4.78
70.         60.         50.         40.         30.         20.         10.         0.          -10.        -20.
-30.        -40.        -50.        -60.        -70.
WORD41      NORACC      2
-4.9        +4.9
-7.0        +7.0
WORD48      FLAPPO      6
4.86        3.76        2.85        1.90        1.00        .11
0.          20.         40.         60.         80.         100.
WORD51      THROTL      5
.23         1.72        2.76        3.72        4.64
0.          16.         32.         48.         64.
WORD58      THROTR      5
.39         1.82        2.87        3.85        4.61
0.          16.         32.         48.         64.
WORD59      RPMLFT      7
.7          1.4         2.11        2.82        3.55        4.28        5.00
14.28       28.57       42.85       57.14       71.42       85.71       100.00
WORD60      RPMRHT      7
.56         1.12        1.69        2.27        2.88        3.45        4.00
14.28       28.57       42.85       57.14       71.42       85.71       100.00
WORD61      PITCHR      19


4.98        4.47        3.92        3.36        2.79        2.23        1.66        1.095       .545        0.
-.53        -1.08       -1.635      -2.21       -2.77       -3.34       -3.90       -4.45       -4.99
90.         80.         70.         60.         50.         40.         30.         20.         10.         0.
-10.        -20.        -30.        -40.        -50.        -60.        -70.        -80.        -90.
'      END OF FILE CARD
```

```
 GUTHRE
     CALPTR      -  EFN   SOURCE STATEMENT  -  IFN(S)  -                 07/14/69

      SUBROUTINE CALBRT (M,WORDS)
      DIMENSION M(100),WORDS(100)
      COMMON /A1/ N12,N120,RECORD,IUNIT,N,TAPE,INP(100),JCOL(100),
     1XARRAY(51,18),YARRAY(51,18),JCAL(100),I24,I240
      DO 1 L=1,100
      NP=INP(L)
      IF (NP) 2,7,3
 7    WORDS(L)=0.0
      GO TO 1
 2    IGC=-NP
      GO TO (4,5,6,8),IGC
 4    WORDS(L)=0.0
      WORD=M(L)
      VOLTS=0.0051281*ABS(WORD)-0.1256
      IF (WORD.LT.0.0) VOLTS=-VOLTS
      IF (VOLTS.GE.1.0) WORDS(L)=1.0
      GO TO 1
 5    WORDS(L)=M(L)
      GO TO 1
 6    M(L)=-M(L)
C    EVENT NUMBER   P S 200 100 80 40 20 10 8 4 2 1   THAT IS BCD AND NOT
C    BINARY COUNT
      M1=(M(L)/256)*100
      M2=MOD(M(L),256)
      M1=M1+(M2/16)*10+MOD(M2,16)
      WORDS(L)=M1
      GO TO 1
 8    WORD=M(L)
      VOLTS=0.0051281*ABS(WORD)-0.1256
      IF (WORD.LT.0.0) VOLTS=-VOLTS
      WORDS(L)=VOLTS
      GO TO 1
 3    WORD=M(L)
      VOLTS=0.0051281*ABS(WORD)-0.1256
      IF (WORD.LT.0.0) VOLTS=-VOLTS
      J=JCOL(L)
      CALL AITKEN (XARRAY(1,J),YARRAY(1,J),VOLTS,WORDS(L),DIF,51,NP,1,K1
     1,JJ)                                                                   49
 1    CONTINUE
      RETURN
      END
```

```
      GUTHRE                                                          07/14/69
          AITKN        -   EFN   SOURCE STATEMENT  -  IFN(S)  -

      SUBROUTINE AITKEN (X,Y,XI,YI,DIF,M,N,INT,K1,J)                    AITKN001
C                                                                       AITKN002
      DIMENSION X(M),Y(M),XX(11),YY(11),DIFF(11)                        AITKN003
C        DECK TO DROP THE FIRST BAD POINT FROM EITHER SIDE AND CONTINUE  AITKN004
C  M=MAXIMUM DIMENSION OF X AND Y VECTORS                               AITKN005
C  N=NUMBER OF POINTS IN THE X AND Y VECTORS THIS CALL                  AITKN006
C   LEFT AND CHANGE (LRS=1)    RIGHT AND CHANGE (LRS=2)                 AITKN007
C       LEFT ALWAYS (LRS=3)        RIGHT ALWAYS (LRS=4)                 AITKN008
C    X=4 5 6 7 8   XI=5.5    K WOULD BE 2                               AITKN009
C   PARAMETERS                                                          AITKN010
C    X=INDEPENDENT VARIABLE    Y=DEPENDENT VARIABLE    N=NUMBER POINTS  AITKN011
C    XI=GIVEN X   YI=REQUIRED Y                                         AITKN012
C  K1=POSITION OF THE LEFT MOST X USED      J=THE NUMBER OF POINTS USED AITKN013
C                                                                       AITKN014
      INTEGER Z                                                         AITKN015
      J=1                                                               AITKN016
      DIF=0.0                                                           AITKN017
      DIFF(1)=1.0E37                                                    AITKN018
      K1=                                                               AITKN019
      YI=0.0                                                            AITKN020
      IF (N.GT.1) GO TO 90                                              AITKN021
      WRITE (6,4) N                                                     AITKN022      6
    4 FORMAT (3H0N=,I12,3X,50HTHERE ARE LESS THAN TWO POINTS IN THE (X,YAITKN023
     1) TABLE.)                                                         AITKN024
      CALL FXEM                                                         AITKN025      7
   90 IF (X(1).GT.X(N)) GO TO 1900                                      AITKN026
      IF (XI-X(1)) 500,600,800                                          AITKN027
  500 K=1                                                               AITKN028
      LRS=4                                                             AITKN029
      GO TO 2800                                                        AITKN030
  600 K1=1                                                              AITKN031
      YI=Y(1)                                                           AITKN032
      RETURN                                                            AITKN033
  800 IF (XI-X(N)) 1200,900,1100                                        AITKN034
  900 K1=N                                                              AITKN035
      YI=Y(N)                                                           AITKN036
      RETURN                                                            AITKN037
 1100 K=N                                                               AITKN038
      LRS=3                                                             AITKN039
      GO TO 2800                                                        AITKN040
 1200 LL=1                                                              AITKN041
      LU=N                                                              AITKN042
 1300 IF ((LU-LL).EQ.1) GO TO 1400                                      AITKN043
      LI=(LU+LL)/2                                                      AITKN044
      IF (XI-X(LI)) 1800,1700,1600                                      AITKN045
 1600 LL=LI                                                             AITKN046
      GO TO 1300                                                        AITKN047
 1700 K1=LI                                                             AITKN048
      YI=Y(LI)                                                          AITKN049
      RETURN                                                            AITKN050
 1800 LU=LI                                                             AITKN051
      GO TO 1300                                                        AITKN052
 1900 IF (XI-X(1)) 2000,600,500                                         AITKN053
 2000 IF (XI-X(N)) 1100,900,2100                                        AITKN054
 2100 LL=1                                                              AITKN055
```

```
      LU=N                                                               AITKN056
 2200 IF ((LU-LL).EQ.1) GO TO 1400                                       AITKN057
      LI=(LL+LU)/2                                                       AITKN058
      IF (XI-X(LI)) 2400,1700,2500                                       AITKN059
 2400 LL=LI                                                              AITKN060
      GO TO 2200                                                         AITKN061
 2500 LU=LI                                                              AITKN062
      GO TO 2200                                                         AITKN063
 1400 K=LL                                                               AITKN064
      LRS=2                                                              AITKN065
 2800 K1=K                                                               AITKN066
      IF (INT.EQ.0) RETURN                                               AITKN067
      IPS=0                                                              AITKN068
      XX(J)=X(K)-XI                                                      AITKN069
      YY(J)=Y(K)                                                         AITKN070
 2900 IPS=IPS+1                                                          AITKN071
 3000 J=J+1                                                              AITKN072
      IF (J.GT.11) GO TO 5800                                            AITKN073
      IF (J.LE.N) GO TO 3700                                             AITKN074
 5800 J=J-1                                                              AITKN075
      YI=YY(J)                                                           AITKN076
      DIF=DIFF(J)                                                        AITKN077
      RETURN                                                             AITKN078
 3700 GO TO (3800,4100,3900,4200),LRS                                    AITKN079
 3800 LRS=2                                                              AITKN080
 3900 K=K-IPS                                                            AITKN081
      IF (K.GT.0) GO TO 4500                                             AITKN082
      IF (LRS.EQ.3) GO TO 5800                                           AITKN083
 4000 K=K+IPS                                                            AITKN084
      LRS=4                                                              AITKN085
      IPS=1                                                              AITKN086
      GO TO 3700                                                         AITKN087
 4100 LRS=1                                                              AITKN088
 4200 K=K+IPS                                                            AITKN089
      IF (K.LE.N) GO TO 4500                                             AITKN090
      IF (LRS.EQ.4) GO TO 5800                                           AITKN091
 4300 K=K-IPS                                                            AITKN092
      LRS=3                                                              AITKN093
      IPS=1                                                              AITKN094
      GO TO 3700                                                         AITKN095
 4500 XX(J)=X(K)-XI                                                      AITKN096
      YY(J)=Y(K)                                                         AITKN097
      LD=J-1                                                             AITKN098
      DO 4600 I=1,LD                                                     AITKN099
      T1=XX(J)-XX(I)                                                     AITKN100
      IF (T1.NE.0.0) GO TO 4600                                          AITKN101
      WRITE (6,3)                                                        AITKN102     123
    3 FORMAT (27H0DIVISION BY ZERO IN AITKEN)                            AITKN103
      WRITE (6,1) XI,K1,J,(X(Z),Y(Z),Z=1,N)                                           124
    1 FORMAT (1H0,1PE20.6,2I10/1X/(1X,1P2E20.6))
      CALL EXEM                                                          AITKN104     130
 4600 YY(J)=((YY(I)*XX(J))-(YY(J)*XX(I)))/T1                             AITKN105
      DIFF(J)=ABS(YY(J)-YY(J-1))                                         AITKN106
      IF (DIFF(J).GE.DIFF(J-1)) GO TO 5900                               AITKN107
      IF (K.LT.K1) K1=K                                                  AITKN108
      IF (2-LRS) 3000,2900,2900                                          AITKN109
```

```
   SLTHRE                                                                07/14/69
      AITKN       -  EFN   SOURCE STATEMENT  -  IFN(S)  -
```

APPENDIX IV

FORTRAN PROGRAMS FOR A SAMPLING RATE STUDY

Preceding page blank

```
                                                                    03/26/70
        RESOLV      -  EFN   SOURCE STATEMENT  -  IFN(S)  -

      DIMENSION ARAY(9700)
      DIMENSION TERR(12)
      DIMENSION A(120,9),B(12,25),EVNO(50),XCNT(50),DEL(10)
      DIMENSION ARXZ(50,10),AR(50,10,12),ARTCT(50)
      DIMENSION IRTE(50),SUM(12)
      COMMON ARAY,DELTA,V,RESCL,COUNT,W,TKEEP,L
      COMMON TERR
      READ(5,500)N,M,IMON,IDAY,IYR
      WRITE(6,1000)IMON,IDAY,IYR
      WRITE(6,1003)
 1003 FORMAT(13H VAR IS PITCH/1H /)
      READ(5,501)(EVNO(I),I=1,N)
      READ(5,501)(XCNT(I),I=1,N)
      READ(5,502)(DEL(I),I=1,M)
      READ(5,730)(IRTE(I),I=1,N)
  730 FORMAT(14I5)
  500 FORMAT(5I5)
  501 FORMAT(12F5.0)
  502 FORMAT(12F6.2)
  503 FORMAT(8F8.4)
      WRITE(6,1001)
      DO 20 I=1,N
   22 READ(16)((A(IY,JY),IY=1,120),JY=1,9)
      READ(16)((B(IY,JY),IY=1,12),JY=1,25)
      DO 21 J=1,12
      X=AMOD(B(J,18),100.0)
      IF(EVNO(I)-X)21,3,21
   21 CONTINUE
      GO TO 22
    3 IA=1
   30 READ(16)((A(IY,JY),IY=1,120),JY=1,9)
      READ(16)((B(IY,JY),IY=1,12),JY=1,25)
      DO 5 K=1,120
      IF(K-1)101,101,100
  100 IF(A(K,6))800,801,801
  801 IF(A(K,6)-350.)802,802,800
  802 IF(ABS(A(K,2))-360.)803,803,800
  803 IF(B(K,6))800,800,101
  800 ARAY(IA)=ARAY(IA-1)
      GO TO 5
  101 ARAY(IA)=A(K,1)
    5 IA=IA+1
      X=IA/10
      IF(X-XCNT(I))30,6,6
    6 IA=IA-1
      RESCL=0.
      WRITE(6,1010)
 1010 FORMAT(1H /)
      DO 50 K=1,M
      DELTA=0.01
      V=DEL(K)
      L=IA
      CALL TSTRE
 1000 FORMAT(1H1,5X,33HSAMPLING ANALYSIS FOR FLIGHT OF  I2,1H-I2,1H-I2/
     11H /)
```

```
                                                                          03/26/70
          RESOLV     -  EFN   SOURCE STATEMENT  -  IFN(S)  -

1001 FORMAT(1H ,5X,4HSAMP,2X,3HNO.,6X,11HTIMES WORST/32H EVNO RATE SAMP
    1 RES. EXCED.  ERR,4X,4HTIME,2X,4H0-.5,1X,66H.5-1. 1-1.5 1.5-2. 2-2
    2.5 2.5-3 3-3.5 3.5-4  4-5  5-10 10-20  GR-20/1H /)
     WRITE(6,1002)EVNO(I),V,L,RESCL,COUNT,W,TKEEP,(TERR(KL),KL=1,12)
1002 FORMAT(F4.0,F6.2,I5,F5.1,F6.0,F8.3,F6.2,12F6.0)
     ARXZ(I,K)=COUNT
     AR(I,K,1)=TERR(1)
     DO 600 KL=2,12
     KM=KL-1
 600 AR(I,K,KL)=AR(I,K,KM)+TERR(KL)
  50 CONTINUE
     ARTCT(I)=L
  20 CONTINUE
     DO 602 I=1,N
     DO 602 J=1,M
     DO 601 K=1,12
 601 AR(I,J,K)=AR(I,J,K)/ARXZ(I,J)
 602 ARXZ(I,J)=ARXZ(I,J)/ARTCT(I)
     WRITE(6,603)
     DO 605 I=1,N
     WRITE(6,607)
     DO 604 J=1,M
     WRITE(6,606)EVNO(I),DEL(J),ARXZ(I,J),(AR(I,J,K),K=1,12)
 604 CONTINUE
 605 CONTINUE
 603 FORMAT(1H /1H /6H  EVNO,4X,3HDEL,4X,4HGT 0,4X,
    15HLE .5,3X,5HLE 1.,2X,6HLE 1.5,3X,5HLE 2.,
    22X,6HLE 2.5,3X,5HLE 3.,2X,6HLE 3.5,3X,
    35HLE 4.,3X,5HLE 5.,2X,5HLE 10,
    43X,5HLE 20,3X,6HLE INF/1H /)
 606 FORMAT(F5.0,2X,F6.2,2X,F6.1,2X,12(F6.3,2X))
 607 FORMAT(1H /)
     DO 750 LM=1,3
     DO 752 J=1,M
     WRITE(6,607)
     DO 751 LX=1,12
 751 SUM(LX)=0.
     DO 753 I=1,N
     IMT=IRTF(I)
     IF(IMT-LM)753,754,753
 754 DO 755 K=1,12
 755 SUM(K)=SUM(K)+AR(I,J,K)
     WRITE(6,606)EVNO(I),DEL(J),ARXZ(I,J),(AR(I,J,K),K=1,12)
 753 CONTINUE
     WRITE(6,780)(SUM(K),K=1,12)
 780 FORMAT(23X,12(F7.3,1X))
 752 CONTINUE
 750 CONTINUE
     STOP
     END
```

```
                                                                    03/26/70
      TST         -  EFN   SOURCE STATEMENT  -  IFN(S)  -

      SUBROUTINE TSTRE
      DIMENSION ARAY(9700)
      DIMENSION TERR(12)
      DIMENSION ANUM(13)
      COMMON ARAY,DELTA,V,RESCL,COUNT,W,TKEEP,L
      COMMON TERR
      DO 1 I=1,12
    1 TERR(I)=0.
      ANUM(1)=0.
      DO 2 I=2,8
    2 ANUM(I)=ANUM(I-1)+.5
      ANUM(9)=4.
      ANUM(10)=5.
      ANUM(11)=10.
      ANUM(12)=20.
      ANUM(13)=10000.
      TKEEP=-1.0
      W=-1000.
      M=V/DELTA
      COUNT=0.0
      LET= L-M
      DO 20 J=1,LET,M
      P1=ARAY(J)
      KT=J+M
      P2=ARAY(KT)
      DMR=J-1
      T1=DMR*DELTA
      DMR=KT-1
      T2=DMR*DELTA
      XML=(P2-P1)/(T2-T1)
      XLS=P1-XML*T1
      KAX=J+1
      KAY=J+M-1
      DO 4I=KAX,KAY
      DMR=I-1
      T=DMR*DELTA
      TEST=XML*T+XLS
      X=ARAY(I)-TEST
      XX=ABS(X)-RESCL
      IF(XX)4,4,5
    5 COUNT=COUNT+1.0
      DO 3 K=1,12
      IF(XX-ANUM(K))3,3,30
   30 IF(XX-ANUM(K+1))32,32,3
   32 TERR(K)=TERR(K)+1.0
    3 CONTINUE
      IF(XX-W)4,6,6
    6 W=XX
      TKEEP=T
    4 CONTINUE
   20 CONTINUE
      RETURN
      END
```

APPENDIX V

EXTENDED ANALYSIS OF THE NORMAL LANDING TASK

J. F. Hixson, Lt Colonel, USAFR

1. INTRODUCTION

Measurement analysis of the 360° overhead traffic pattern involves a sequential examination of the individual and combined aeronautical and procedural skills incorporated in this maneuver. For purposes of interpretation of data and analysis of skills involved, the flight maneuver is broken into eight phases. This maneuver conforms to the 360° standard overhead pattern for the T-37 as outlined in ATC Manual 51-4, (Reference 4).

The eight phases are as follows (See Figure A):

IA	Entry
IB	Approach to Runway (Overhead)
II	Initial Overhead to Pitchout
III	Pitchout and First Quarter Turn toward Downwind (0° to 90° turn)
IV	Second Quarter Turn to Downwind (90 to 180° turn)
V	Downwind
VI	First Quarter Turn to Final (180 to 270° turn)
VII	Second Quarter Turn onto Final (270 to 360 turn)
VIII	Final Approach

2. DISCUSSION OF MANEUVER SEGMENTS

a. Phases IA and B, Entry and Approach Phase of Normal Overhead Pattern (See Figure B)

The student discerns a heading that is 45° to the heading of the active runway (the runway to be landing on). He approaches the field on this heading at an altitude of 1000 feet; airspeed 200 knots; RPM 80% (approximately) to a point where his 45° turn will place his aircraft on a flight path that will begin at least two miles from the approach end of the active runway and on a ground pattern that would describe a line directly down the center line of the runway.

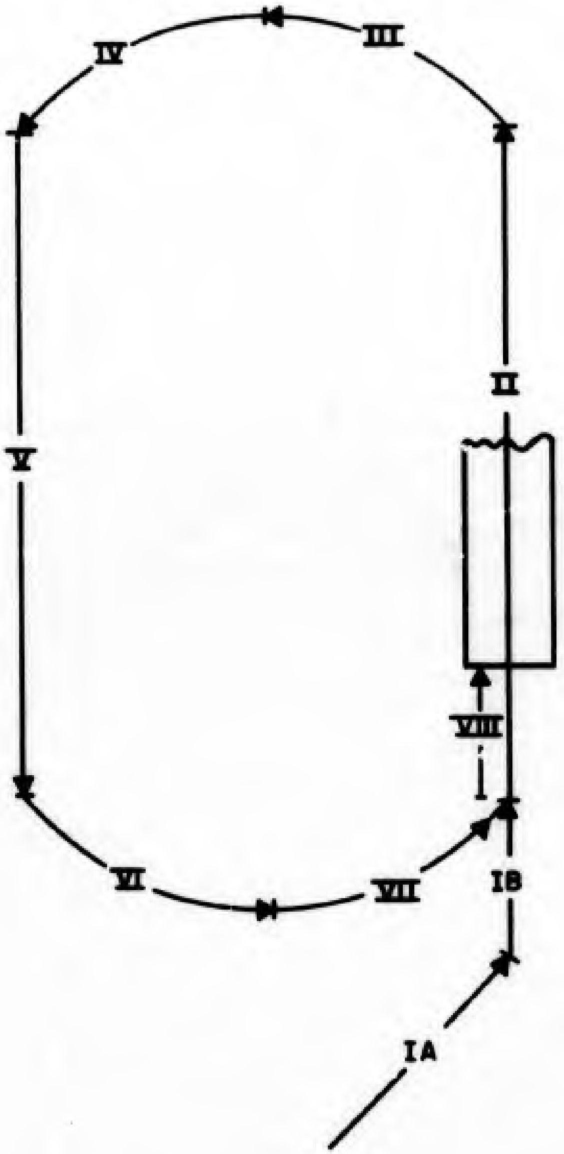


Figure A. Task Segments for 360° Overhead Landing Pattern

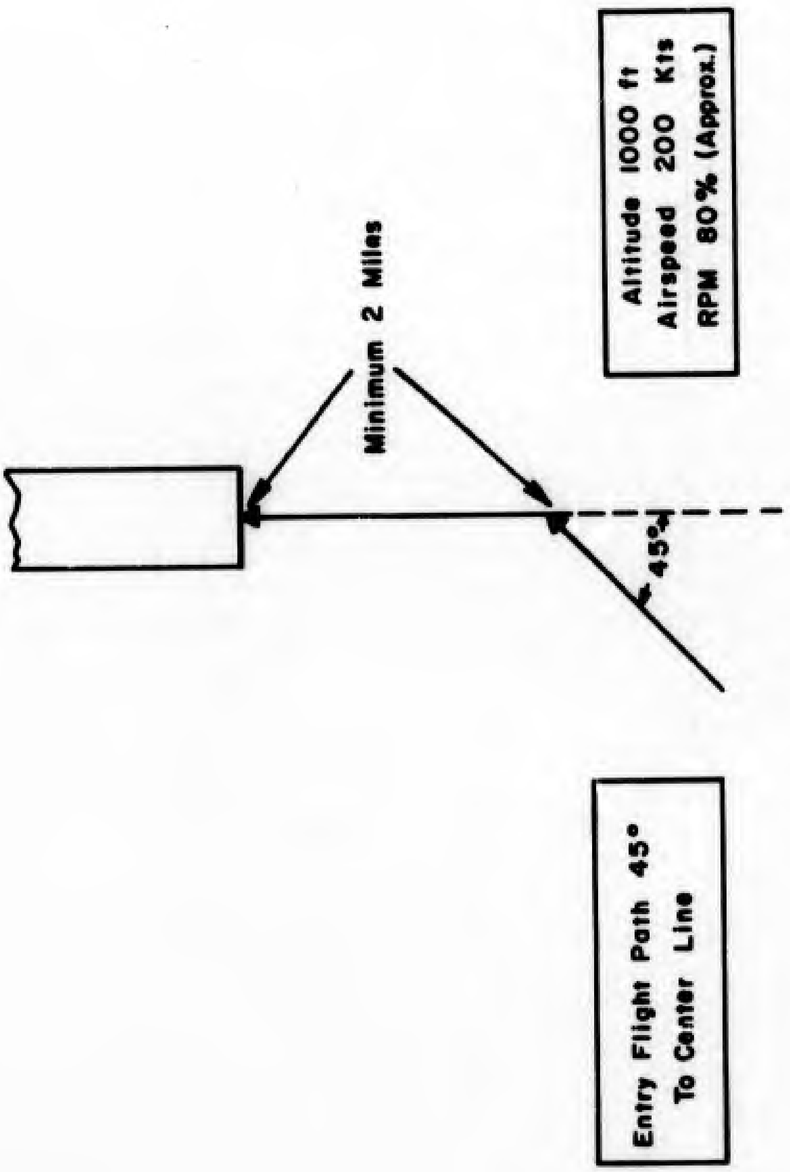


Figure B. Entry and Approach Phases of 360° Overhead Pattern

b. Phase II, Initial Overhead to Pitchout Phase of Normal Landing (See Figure C)

The student maintains an altitude of 1000 feet; 200 knots; RPM 80%, to a point at least 3000 feet beyond the approach end of the runway, and not beyond the halfway mark of the runway. Some where within this region the student executes his pitchout. At pitchout, he banks the aircraft (not over 60°) and retards his throttle setting to one of 50-60% RPM while maintaining pattern altitude (1000 feet).

c. Phases III and IV, Pitchout, First and Second Quarter Turns to Downwind of Normal Overhead Pattern (See Figures D and E)

The pitchout initiates a continuous 180° turn by the student, with consideration given to wind conditions. When properly executed, rollout will be accomplished at a point even with the pitchout initialization point and on a parallel path to the active runway. This part of the flight path is called the downwind leg. Throughout this turn, an altitude of 1000 feet is maintained. Additional back pressure (hence trim) is needed to maintain the altitude because of the decrease in the power setting at pitchout (50-60%).

d. Phase V, Downwind Leg of Normal Overhead Pattern (Figure F)

As rollout on the downwind leg is accomplished, the student lowers the speed brakes to reduce the airspeed to 150 knots or lower. As the aircraft passes below 150 knots, gear is dropped and airspeed continues to drop off. Throughout these operations, an altitude of 1000 feet <u>is maintained</u> and increased power setting may be necessary to hold airspeed and altitude. An altitude of 1000 feet is maintained throughout the landing pattern through the point of flap lowering. At <u>no time</u> on the downwind is the airspeed permitted to drop below 120 knots. (Increased power setting may be necessary as drag increaes to maintain airspeed and altitude.)

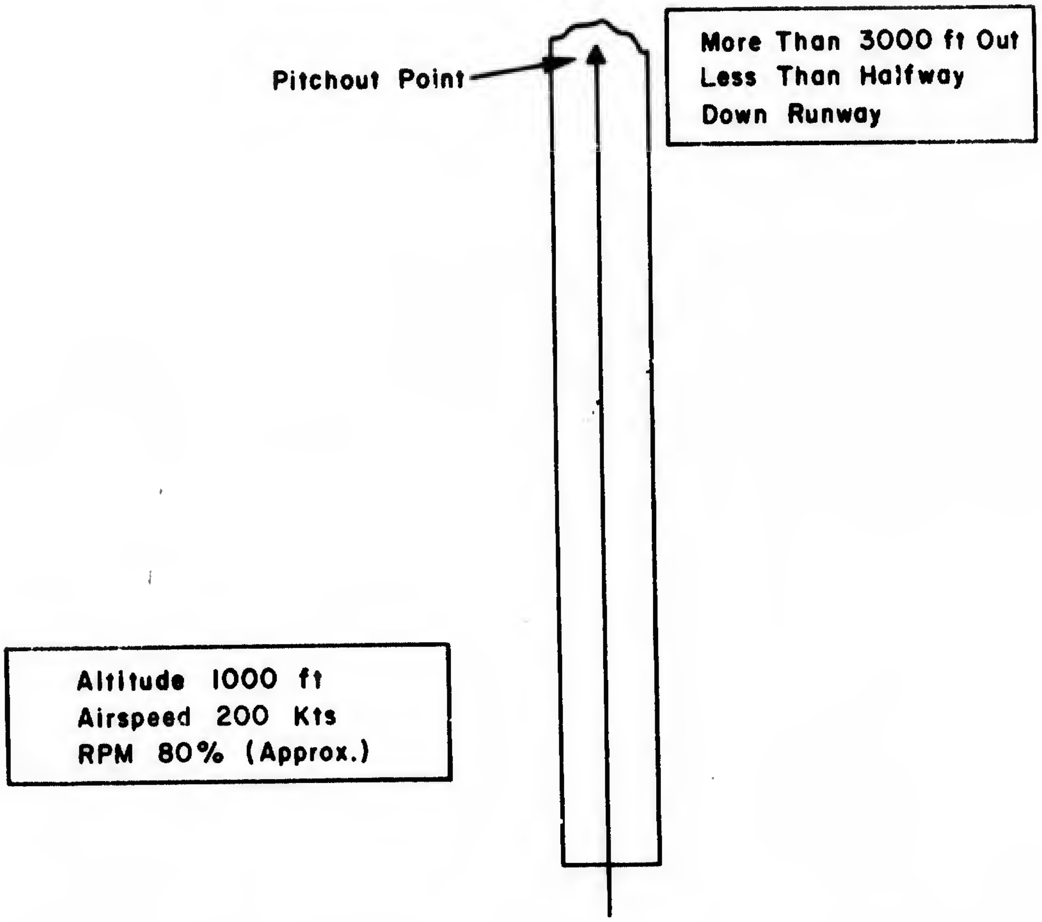


Figure C. Initial Overhead to Pitchout Phase of 360° Overhead Pattern

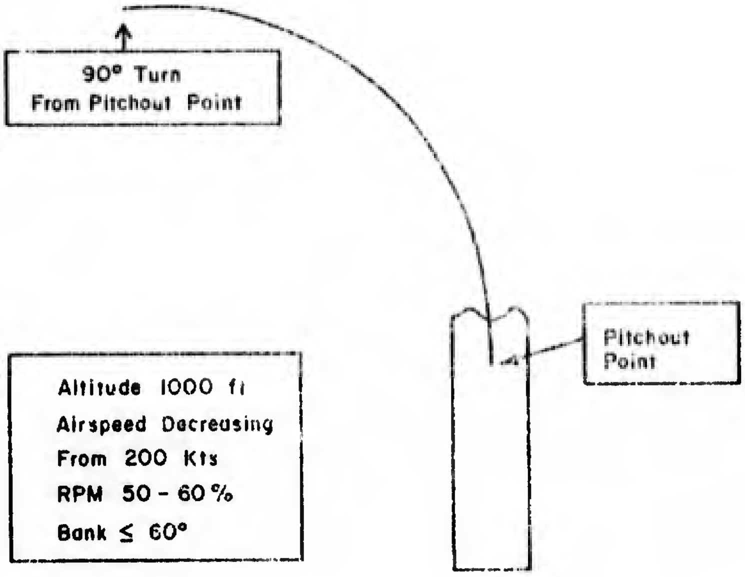


Figure D. Pitchout and 1st Quarter Turn Phase of 360° Overhead Pattern

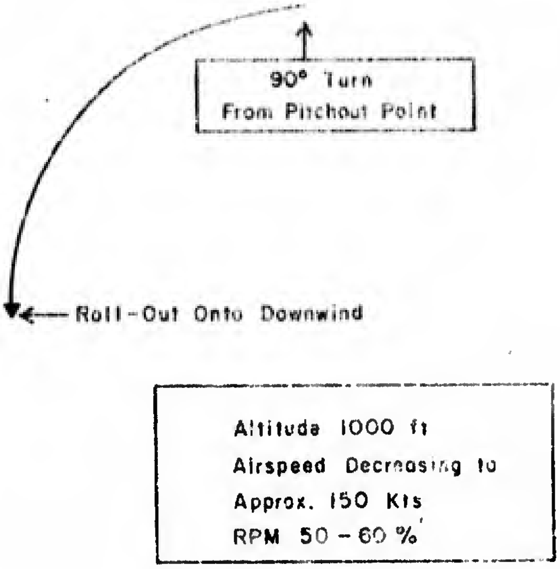


Figure E. 2nd Quarter Turn to Downwind Phase of 360° Overhead Pattern

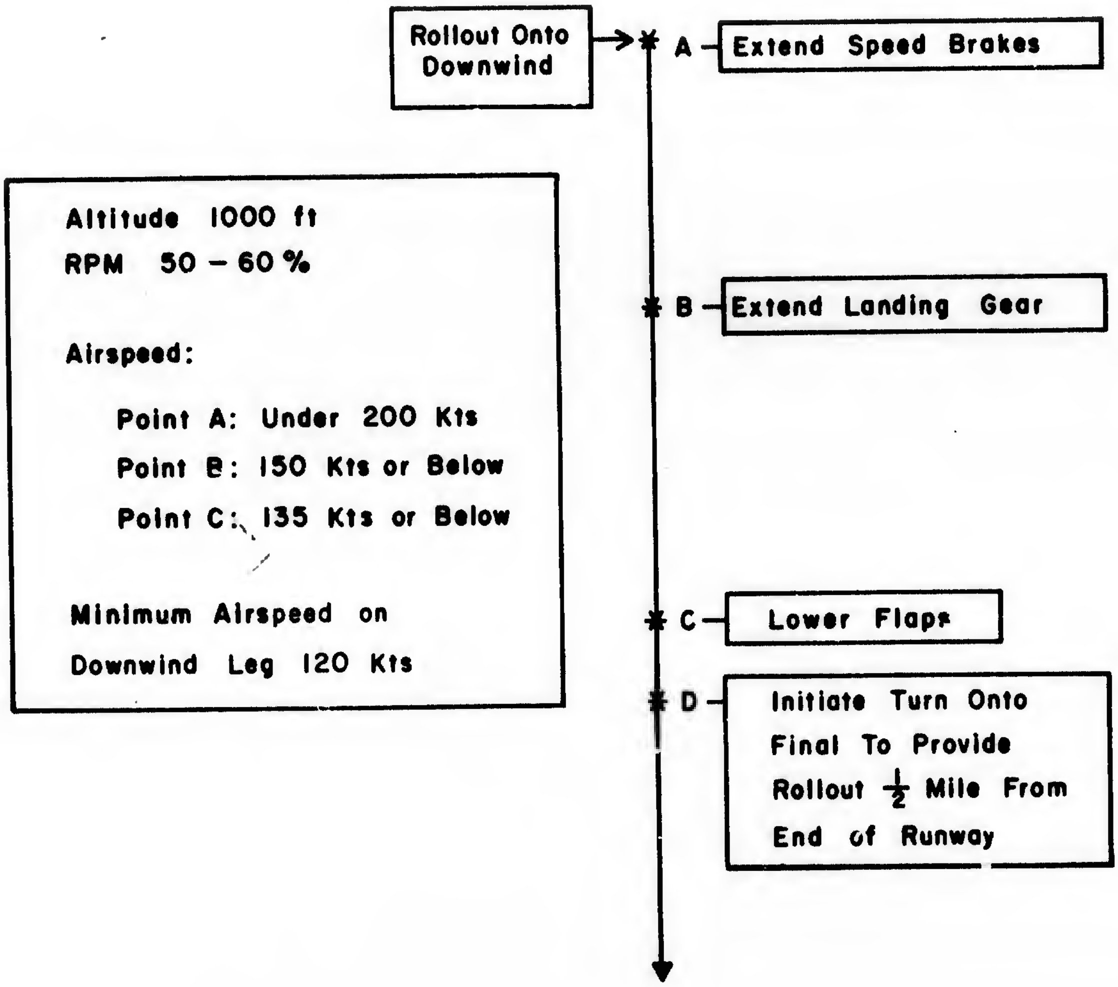


Figure F. Downwind Phase of 360° Overhead Pattern

e. Phases VI and VIII, First and Second Quarter Turn to Final Phase of Normal Overhead Pattern (Figures G and H)

A descending turn is initiated with a decrease in airspeed to 110 knots. The student takes into consideration the wind and distance from the runway so that rollout will be made at a predetermined position at least one-half mile from the end of the runway with an altitude of at least 300 feet. At no time is the bank to be over 45° or the airspeed to be less than 110 knots.

f. Phase VIII, Final Approach Phase of Normal Overhead Traffic Pattern (Figure I)

The student will rollout on the final approach at least one half mile from the approach end of the runway at an altitude of no less than 300 feet. The rollout should be at such a heading as to result in a ground path in line with the runway. Airspeed is lowered to 100 knots during the final approach and letdown.

3. NARRATIVE DESCRIPTION OF THE 360° STANDARD OVERHEAD TRAFFIC PATTERN AS OUTLINED IN ATC MANUAL 51-4*

Entry into the landing pattern is initiated at a 45° angle to the active runway. All turns in the maneuver are in the same direction, depending on whether the pattern is a right or left hand pattern. Initial pattern altitude is 1000 feet and pattern airspeed is 200 knots (approximately 80% RPM).

Initial leg of landing pattern is in line with and over the center line of the active runway.

After a position between 3000 feet from the approach end of the runway and one half of the runway is reached, pitchout is accomplished.

---

*Throughout the entire flight pattern, the student will be expected to execute coordinated flight maneuvers and evidence a smoothness in the execution of procedures. Proper clearing of area, adjustments for wind, traffic, and understanding of necessary cockpit procedures are assumed within the realm of capability and understanding of the student, as well as the expected procedure for the 360° overhead standard pattern.

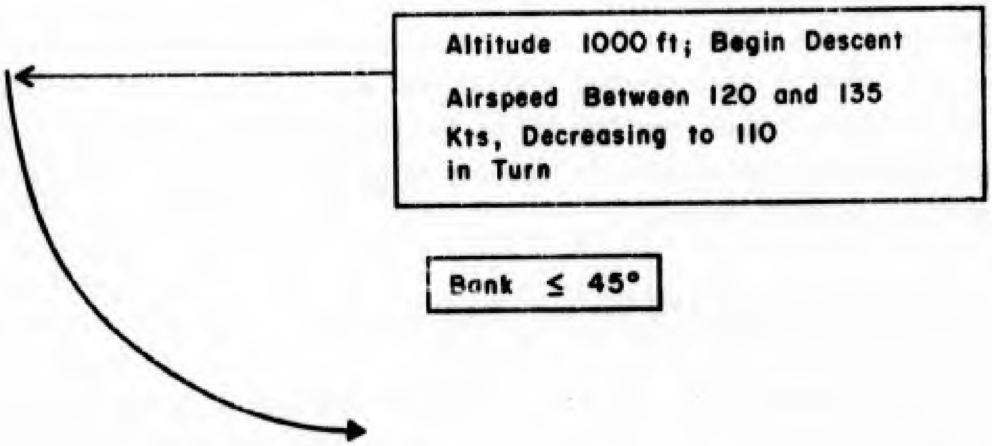


Figure G. 1st Quarter Turn to Final Phase in 360° Overhead Pattern

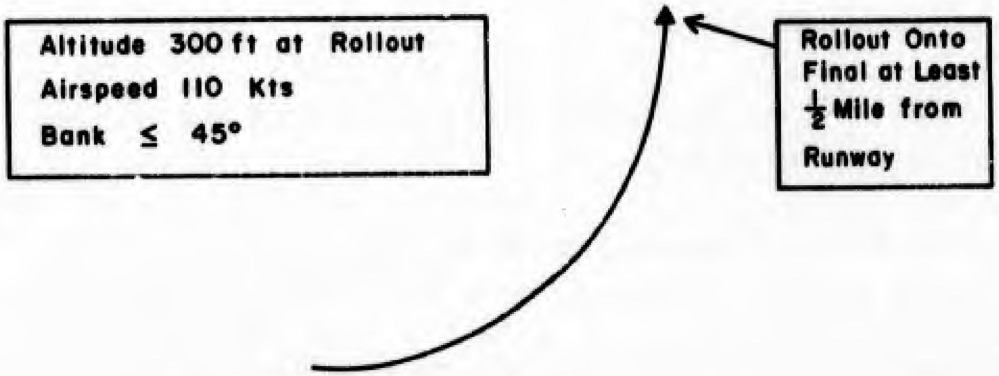


Figure H. 2nd Quarter Turn to Final Phase of 360° Overhead Pattern

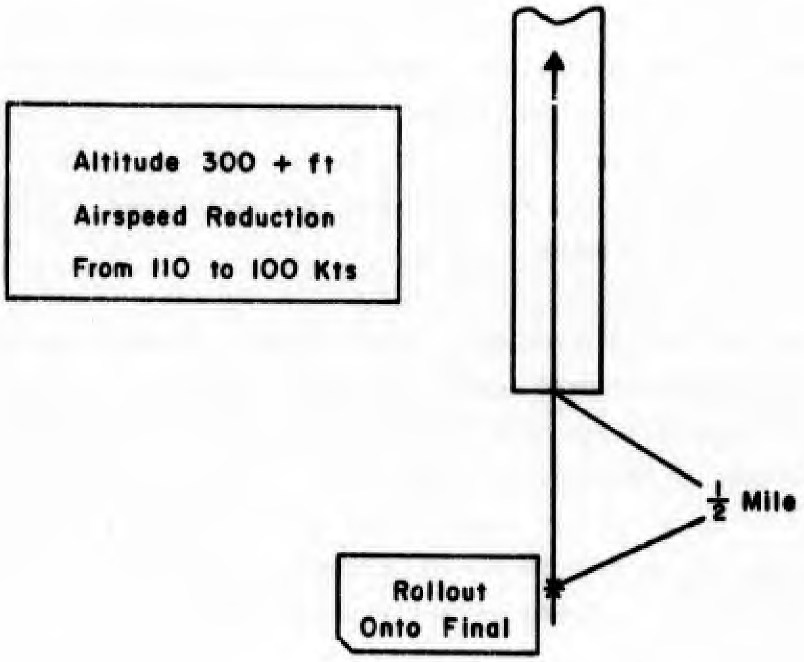


Figure I. Final Approach Phase of 360° Overhead Pattern

This constitutes a nearly simultaneous bank in pattern direction, and reduction of power to between 50 and 60%. (If one is to precede the other, bank should precede reduction in power.) The bank is not to exceed 60°.

In maintaining pattern altitude of 1000 feet, there is a continuous 180° turn designed to bring the pilot out on the downwind leg position of the pattern. The rollout for downwind should be accomplished approximately in line with the pitchout position to initiate a ground pattern parallel to the active runway. During the turning interval, the pattern altitude of 1000 feet is maintained as airspeed decreases, due to the reduction in power.

After the rollout on downwind is accomplished, speed brakes are applied to bring the airspeed down to 150 knots or below. The aircraft should be approximately one half of the way on the downwind leg. Gear should be dropped at this point, continuing the reduction of airspeed to 135 knots or below (never below 120 knots). Pattern altitude of 1000 feet above the terrain should be maintained at all times. Power necessary to maintain airspeed and altitude should be used.

Wing flaps should be dropped prior to initiating turn that will bring the aircraft out on final approach. THIS SHOULD BE DONE WHILE AIRCRAFT IS STILL IN LEVEL POSITION, AIRSPEED LESS THAN 135 KNOTS, BUT NOT LESS THAN 120 KNOTS, AND ALTITUDE STILL 1000 FEET.

Initiate continuous turn onto final approach; bank is not to exceed 45°. Nose is lowered to begin descent, and airspeed is decreased to 110 knots in the turn. Turn and descent is judged to permit aircraft to rollout on final approach at least one half mile from the end of the runway at an altitude of NOT LESS THAN 300 FEET.

A straight descent is maintained until touchdown. Airspeed is decreased to 100 knots for final approach.

4. Skills Required

Mastery of the 360° Standard Overhead Traffic Pattern is mandatory prior to a student's ability to fly an aircraft solo. The skills involved in this maneuver will have been presented the student as individual skill techniques prior to accomplishment of the landing pattern. Measurement of the basic skills are of prime importance in ascertaining proficiency. The skills in mention, and the areas of the maneuver in which they are employed, are defined as follows:

Directional Control. The skill of being able to determine and maintain a heading, determine and maintain proper ground track depending on wind conditions, rollout on a predetermined heading from varying degrees of bank from level, and ascending or descending flight.

Altitude Control. The skill of being able to maintain altitude, level off at a predetermined altitude either from a climb or descent; maintain altitude with varying airspeed or with varying degrees of bank, and in a rollout from a banked turn within varying degrees of bank.

Airspeed Control. The skill of maintaining a desired airspeed, or establishing a desired airspeed, the ability to change an airspeed, then establish the attitude to hold the airspeed as in a descent, or the skill to establish the attitude to attain a predetermined airspeed.

Rolling Into and Maintaining a Desired Bank (Without Varying). The ability to make a coordinated turn without varying airspeed or altitude, and the ability to roll into and out of this turn without over-controlling. Also, the ability to rollout onto at a predetermined heading.

The skill-composites and knowledges that need to be considered for measurement are:

Straight and Level Flight. The ability to maintain the aircraft in straight and level flight involving the maintenance of heading and altitude.

Level Turns. The ability to make a coordinated turn without losing altitude or over-controlling to maintain proper bank.

Descending Turns. The ability to maintain the proper airspeed, bank, and rate of descent without excess banking.

Maintenance of Altitude at Varying Airspeed or Power Setting. The ability to maintain a given altitude while varying the power setting. In the traffic pattern maneuver, this involves reducing the airspeed while holding altitude.

Straight Descent. The ability to maintain directional control of the aircraft while losing altitude at a given airspeed and a constant glide angle.

Varying Degrees of Bank. The ability to coordinate a roll into the desired bank and maintain this bank without loss of altitude, unless so desired. Also, the ability to determine and hold a prescribed degree of bank.

Ability to Judge Rate of Turn. The ability to predetermine the position to initiate a given rate of bank, or alter a rate of bank within limits in such a manner that the rollout places the aircraft on the desired ground path.

Ability to Rollout Onto a Desired Heading. The ability to place the aircraft on the desired heading after completion of a turn.

Ability to Determine Wind Drift and Angle. Basic knowledge of wind and wind drift angles that permits rolling out to a predetermined heading that will effect the desired ground path.

Knowledge of Procedures. Basic knowledge of aircraft procedures for landing and for the landing pattern that will produce desired changes in airspeed, altitude, direction, etc., at the prescribed position in the landing pattern are essential to accomplish the landing pattern as prescribed.

The student is expected to execute coordinated flight maneuvers and demonstrate a smoothness in the execution of procedures throughout the entire flight pattern.

5. PRELIMINARY PERFORMANCE MEASURES FOR THE NORMAL OVERHEAD 360° TRAFFIC PATTERN

Patterns will present different profiles because of the different procedural requirements due to such variations as single engine landings, touch and go landings, right or left hand patterns, and patterns executed with varying degrees of flaps. In general, measures should address at least the following parameters:

Altitude. Measurement of how well the pilot's altitude compares with ATC criteria throughout the maneuver. Measures ability to maintain altitude through different power settings, while accomplishing cockpit procedures.

Airspeed. Measurement of how well the pilot remains within the ATC limits as he follows the normal procedure for the landing pattern.

Degree of Bank. Measures the pilot's ability to accomplish a 180° turn without exceeding a given maximum bank, and his ability to judge the necessary angle of bank needed to complete the turn within a certain area, rolling out at a prescribed position on a definite heading.

Vertical Velocity. Measures the ability of the pilot to transition from level flight attitude to a descending attitude and to anticipate the required rate of descent.

Attitude. Determines the pilot's ability to hold altitude by changing the attitude at different power settings.

<u>RPM.</u> Measures how well the pilot conforms to ATC standards and procedures throughout this maneuver for either normal or single engine performance.

APPENDIX VI

EXECUTIVE PROGRAM FOR LAZY 8

This program reads the calibrated data, performs basic computations (estimated ground speed, altitude-change, and degrees of turn), prints data at a sampling rate of 2/second, calls the measurement subroutine, and generates plotting data.

```
      KNOOP
          LAZYY8       -  EFN   SOURCE STATEMENT   -  IFN(S)  -

CPRINT MEASURE VARIABLES FOR LAZY 8 MANEUVER
      DIMENSION AR(10,835)
      DIMENSION A(120,9),B(12,25),EVNO(25)
      DIMENSION XCNT(25)
      DIMENSION ZX(120),ZY(120),DATA(438)
      COMMON AR,L
      CALL PLOTS(DATA,438)
      CALL PLOT(0.0,0.8,-3)
      ICOUNT=4
      IEV=1
      READ (5,500) N
      READ (5,501) (EVNO(I),I=1,N)
  601 READ (5,501) (XCNT(I),I=1,N)
      ITEST=-10
    1 READ(16) ((A(I,J),I=1,120),J=1,9)
      READ(16) ((B(I,J),I=1,12),J=1,25)
      DO 20 I=1,12
      X=AMOD(B(I,18),100.0)
      IF(EVNO(IEV)-X) 2,3,2
    3 IF(ITEST) 4,5,5
    4 WRITE (6,300) EVNO(IEV)
      L=0
      TIME=0.0
      ITEST=0
    5 IA=10*(I-1)+1
      L=L+1
      AR(1,L)=A(IA,2)
      AR(2,L)=A(IA,1)
      AR(3,L)=B(I,7)
      AR(4,L)=B(I,6)
      AR(5,L)=A(IA,6)
      AR(6,L)=B(I,15)
      AR(7,L)=B(I,16)
      AR(8,L)=A(IA,3)
      AR(9,L)=A(IA,4)
      AR(10,L)=B(I,9)
      ANL=3.14159265*AR(2,L)/180.0
      SXLR=SIN(ANL)
      CXLR=COS(ANL)
      ALTX=SXLR*AR(5,L)*6080.0/3600.0
      GS=CXLR*AR(5,L)
      TURN=ABS(AR(3,L)-AR(3,1))
      IF(ICOUNT-4) 201,200,201
  200 WRITE (6,301) TIME,A(IA,2),A(IA,1),B(I,7),B(I,6),A(IA,6),B(I,15),
     1B(I,16),A(IA,3),A(IA,4),TURN,GS,ALTX
      TIME=TIME+0.5
      ICOUNT=0
      GO TO 600
  201 ICOUNT=ICOUNT+1
      GO TO 600
    2 IF(ITEST) 20,7,7
    7 CONTINUE
      CALL ELAZY8
      READ(5,500)IVPLOT
      IF(IVPLOT)700,82,82
```

```
      KNUOP
           LAZYY8       -  EFN   SOURCE STATEMENT  -  IFN(S)  -                  10/13/69

CSTART PLOT ROUTINE
   82 KK=0
      DO 90 IK=1,L,10
      KK=KK+1
      ZX(KK)=AR(1,IK)
   90 ZY(KK)=AR(2,IK)
      CALL SYMBOL(-0.6,-1.1,0.1,25HROLL VS. PITCH FOR LAZY 8,0,25)
      CALL SCALE(ZX,10.0,KK,1,10.0)
      CALL SCALE(ZY,9.0,KK,1,10.0)
      CALL LINE(ZX,ZY,KK,1,1,11)
      CALL AXIS(0.0,0.0,14HROLL (DEGREES),-14,10.0,0.0,ZX(KK+1),ZX(KK+2)
     1,10.0)
      CALL AXIS(0.0,0.0,15HPITCH (DEGREES),15,9.0,90.0,ZY(KK+1),ZY(KK+2)
     1,10.0)
      ZX(1)=0.
      ZX(2)=40.
      ZX(3)=80.
      ZX(4)=40.
      ZX(5)=0.
      AMX=0.0
      DO 91 LA=1,KK
      V=ABS(ZY(LA))
      IF(V-AMX)91,91,92
   92 AMX=V
   91 CONTINUE
      ZY(1)=0.
      ZY(2)=AMX
      ZY(3)=0.
      ZY(4)=-AMX
      ZY(5)=0.
      DO 93 LA=6,10
      LB=LA-5
      ZX(LA)=-ZX(LB)
   93 ZY(LA)=ZY(LB)
      ZX(11)=ZX(KK+1)
      ZX(12)=ZX(KK+2)
      ZY(11)=ZY(KK+1)
      ZY(12)=ZY(KK+2)
      CALL LINE(ZX,ZY,10,1,0,0)
      CALL PLOT(12.0,0.0,-3)
      KK=0
      DO 94 IK=1,L,10
      KK=KK+1
      ZX(KK)=KK
   94 ZY(KK)=AR(1,IK)
      CALL SYMBOL(-0.6,-1.1,0.1,34HROLL AND PITCH VS. TIME FOR LAZY 8,0,
     134)
      CALL SCALE(ZX,10.0,KK,1,10.0)
      CALL SCALE(ZY,9.0,KK,1,10.0)
      CALL LINE(ZX,ZY,KK,1,1,11)
      CALL AXIS(0.0,0.0,14HTIME (SECONDS),-14,10.0,0.0,ZX(KK+1),ZX(KK+2)
     1,10.0)
      CALL AXIS(0.0,0.0,7HDEGREES,7,9.0,90.0,ZY(KK+1),ZY(KK+2),10.0)
      KK=0
      DO 95  IK=1,L,10
      KK=KK+1
```

```
  KNEMP                                                              10/13/69
      LAZYY8      -  EFN    SOURCE STATEMENT  -  IFN(S)  -

95 ZY(KK)=AR(2,IK)
   CALL LINE(ZX,ZY,KK,1,1,1)
   CALL SYMBOL(8.0,8.8,0.1,4HROLL,0,4)
   CALL SYMBOL(8.7,8.8,0.1,11,0,-1)
   CALL SYMBOL(8.0,8.5,0.1,5HPITCH,0,5)
   CALL SYMBOL(8.7,8.5,0.1,1,0,-1)
   KK=0
   DO 96 IK=1,L,10
   KK=KK+1
96 ZY(KK)=AR(4,IK)
   CALL PLOT(12.0,0.0,-3)
   CALL SYMBOL(-0.6,-1.1,0.1,28HALTITUDE VS. TIME FOR LAZY 8,0,28)
   CALL SCALE(ZY,9.0,KK,1,10.0)
   CALL LINE(ZX,ZY,KK,1,1,11)
   CALL AXIS(0.0,0.0,14HTIME (SECONDS),-14,10.0,0.0,ZX(KK+1),ZX(KK+2)
  1,10.0)
   CALL AXIS(0.0,0.0,15HALTITUDE (FEET),15,9.0,90.0,ZY(KK+1),ZY(KK+2)
  1,10.0)
   KK=0
   DO 97 IK=1,L,10
   KK=KK+1
97 ZY(KK)=AR(5,IK)
   CALL PLOT(12.0,0.0,-3)
   CALL SYMBOL(-0.5,-1.1,0.1,28HAIRSPEED VS. TIME FOR LAZY 8,0,28)
   CALL SCALE(ZY,9.0,KK,1,10.0)
   CALL LINE(ZX,ZY,KK,1,1,11)
   CALL AXIS(0.0,0.0,14HTIME (SECONDS),-14,10.0,0.0,ZX(KK+1),ZX(KK+2)
  1,10.0)
   CALL AXIS(0.0,0.0,16HAIRSPEED (KNOTS),16,9.0,90.0,ZY(KK+1),ZY(KK+2
  1),10.0)
   KK=0
   DO 98 IK=1,L,10
   KK=KK+1
98 ZY(KK)=AR(3,IK)
   CALL PLOT(12.0,0.0,-3)
   CALL SYMBOL(-0.6,-1.1,0.1,27HHEADING VS. TIME FOR LAZY 8,0,27)
   CALL SCALE(ZY,9.0,KK,1,10.0)
   CALL LINE(ZX,ZY,KK,1,1,11)
   CALL AXIS(0.0,0.0,14HTIME (SECONDS),-14,10.0,0.0,ZX(KK+1),ZX(KK+2)
  1,10.0)
   CALL AXIS(0.0,0.0,17HHEADING (DEGREES),17,9.0,90.0,ZY(KK+1),ZY(KK+
  12),10.0)
   CALL PLOT(12.0,0.0,-3)
   ZX(1)=0.0
   ZY(1)=0.0
   KK=1
   DO 80 IK=1,L,10
   KK=KK+1
   ANGLE=3.14159265*AR(3,IK)/180.
   SXX=SIN(ANGLE)
   CXX=COS(ANGLE)
   ANGB=3.14159265*AR(2,IK)/180.
   GS=AR(5,IK)*COS(ANGB)
   ZX(KK)=ZX(KK-1)+GS*SXX
80 ZY(KK)=ZY(KK-1)+GS*CXX
   CALL SYMBOL(-0.6,-1.1,0.1,23HGROUND TRACK FOR LAZY 8,0,23)
```

```
  KNOOP                                                                   10/13/69
      LAZYY8       -  EFN   SOURCE STATEMENT   -   IFN(S)  -
      CALL SCALE(ZX,9.0,KK,1,10.0)
      CALL SCALE(ZY,9.0,KK,1,10.0)
      CALL LINE(ZX,ZY,KK,1,1,14)
      CALL SYMBOL(4.5,9.2,0.1,1HN,0,1)
      CALL SYMBOL(9.2,4.5,0.1,1HE,0,1)
      CALL SYMBOL(4.5,-0.2,0.1,1HS,0,1)
      CALL SYMBOL(-0.2,4.5,0.1.1HW,0,1)
      CALL PLOT(12.0,0.0,-3)
      KK=0
      DO 81 IK=1,L,10
      KK=KK+1
      ZX(KK)=AR(9,IK)
   81 ZY(KK)=-AR(8,IK)
      CALL SYMBOL(-0.5,-1.1,0.1,30HSTICK POSITION PLOT FOR LAZY 8,0,30)
      CALL SCALE(ZX,10.0,KK,1,10.0)
      CALL SCALE(ZY,9.0,KK,1,10.0)
      CALL LINE(ZX,ZY,KK,1,0,0)
      CALL AXIS(0.0,0.0,19HLAT. POS. (DEGREES),-19,10.0,0.0,ZX(KK+1),ZX(
     1KK+2),10.0)
      CALL AXIS(0.0,0.0,20HLONG. POS. (DEGREES),20,9.0,90.0,ZY(KK+1),ZY(
     1KK+2),10.0)
      CALL SYMBOL(ZX(1),ZY(1),0.1,14,0,-1)
      CALL PLOT(12.0,0.0,-3)
  700 CONTINUE
      IF(IEV-N)9,8,6
    9 IEV=IEV+1
      ITEST=-10
  600 XXX=XCNT(IEV)
      ALL=L
      IF(ALL-XXX)20,7,7
   20 CONTINUE
      GO TO 1
    8 CONTINUE
  500 FORMAT(I5)
  501 FORMAT(12F5.0)
  300 FORMAT(1H1,16HLAZY 8 NUMBER    F5.0/1H /1H /56X,4HLEFT,3X,5HRIGHT,
     14X,5HLONG.,6X,4HLAT.,2X/5H TIME,4X,4HROLL,3X,5HPITCH,2X,
     27HHEADING,5X,8HALTITUDE,2X,8HAIRSPEED,3X,3HRPM,4X,3HRPM,4X,
     38HST. POS.,3X,8HST. POS.,3X,4HTURN,3X,2HGS,5X,4HALTX/1H /)
  301 FORMAT(F6.1,2X,F5.0,3X,F5.0,4X,F5.0,6X,F7.0,5X,F5.0,2X,F5.0,2X,
     1F5.0,6X,F5.1,6X,F5.1,2X,F5.0,1X,F5.0,1X,F5.0)
      CALL PLOT
      STOP
      END
```

APPENDIX VII

MAJOR FUNCTIONS OF BARREL ROLL MEASUREMENT SUBROUTINE

Preceding page blank

Program	Major Functions
Subroutine Proper	1. Computes maximum and minimum points of selected arrays
	2. Computes raw measures
	3. Computes scaled combined measures
	4. Computes "scores"
	5. Calls subroutine "read" and "back" and function "amod"
Subroutine "read"	1. Reads one record of calibrated data (1.2 seconds)
	2. Places variables in common
Subroutine "back"	1. Backs-up magnetic tape to the first record whose event number is specified in the calling vector.
Function "amod"	1. Computes roll angle modulo 360 to correct for instrumentation idiosyncracy in 0 to 90° region.

APPENDIX VIII

ILLUSTRATION OF OUTPUT FROM EXPERIMENTAL MEASUREMENT PROGRAMS

DATA PRINT-OUT FOR FLIGHT OF 11-20-69

LAZY 8 NUMBER 47													
Time	Roll	Pitch	Heading	Altitude	Airspeed	Left RPM	Right RPM	Long. St . Pos.	Lat. St. Pos.	Turn	Gs	Altx	Acel
0	-0.	5.	360.	9586.	200.	87.	88.	1.0	0.2	0.	199.	32.	1.03
0.5	-0.	7.	360.	9650.	200.	87.	88.	1.1	0.1	0.	198.	40.	1.06
1.0	-1.	8.	360.	9715.	200.	87.	88.	1.2	0.1	0.	198.	46.	1.22
1.5	-1.	10.	360.	9715.	200.	87.	87.	1.3	0.1	0.	197.	56.	1.22
.	.	.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.	.	.

```
                MANEUVER NUMBER   47.          FLIGHT OF  11-20-69

                PERFORMANCE ANALYSIS FOR LAZY-8 MANEUVER

I.   INDIVIDUAL MEASURES

  S   HALF-1    HALF-2    S   HALF-1    HALF-2    S   HALF-1    HALF-2

  1   655.81    248.54    7    10.70     -1.00   13   521.62    521.62
  2   521.33    144.52    8     0.20     59.78   14   476.04    476.04
  3     1.28      3.15    9     5.64     17.68   15   510.92    510.92
  4   728.67    377.83   10    19.63     13.69   16    18.29     18.29
  5     0.      353.66   11    17.24      3.86   17     0.        0.
  6    84.14     81.74   12   380.16    380.16   18     0.        0.
                                                 19    42.19     46.13

    SCALED COMBINED MEASURES          WEIGHTED

  MEASURE        HALF-1      HALF-2     HALF-1     HALF-2

  BANK            81.50       94.32     45.51      41.66
  PITCH           81.77       90.53     45.66      39.98
  R/C             98.88       97.34
  R/C             37.94      105.80
  AIRSPEED        78.72       74.91     78.73      79.08
  ALTITUDE        61.73       61.73
  ALTITUDE        64.00       64.00
  G-FORCE        100.00      100.00
  RPM             77.64       75.55

II.  OVERALL SCORES

SCORE HALF-1=        73.64

SCORE HALF-2=        81.41

    MANEUVER TIME =          72.00  SECONDS

MAX PITCH 1 = 38.   MAX PITCH 2 = 45.   MAX ALT = 12148.  AT    72.  DEG OF TURN

MIN PITCH 1 = -28.  MIN PITCH 2 = -25.

ANALYZED    402.   SAMPLES 1st HALF AND    318.   SAMPLES 2ND HALF.

NO.  RR REVERSALS=   12          NC.  PR REVERSALS=   28

      1.256       0.925       0.006       1.537     353.662     165.884
     33.320      21.095     380.158     521.623     476.037     510.923
      0.123
      9.700       0.083      23.325
     18.294       0.          0.
```

```
      MANEUVER NUMBER    19.          FLIGHT OF  12-17-69

      PERFORMANCE ANALYSIS FOR BARREL ROLL MANEUVER

I.  INDIVIDUAL MEASURES

  S      MEASURE        S       MEASURE        S       MEASURE

  1     16693.30        7         25.82       13      13579.30
  2     14042.13        8         16.24       14          2.07
  3         3.76        9         0.          15         0.
  4         5.30       10         0.          16         0.
  5         0.34       11       1139.60       17          0.70
  6        46.37       12        434.86       18         20.04

        SCALED COMBINED MEASURES
  MAIN PARAMETERS       MEASURE
  ENTRY AIRSPEED         100.00
  ATTITUDE  (1)           44.36
  ATTITUDE  (2)           53.19
  ATTITUDE  (HDG.)        39.36
  ATTITUDE  (PITCH),      75.72
  ATTITUDE  (ALT.)        73.76
  ATTITUDE  (TOT.),       79.61
  RPM                     79.28
  G-FORCE                 99.06
  ROLL-RATE               98.66
  ATTITUDE  (3)           54.74

 II.  OVERALL SCORE=      71.99

     MANEUVER TIME =      25.00  SECONDS

       101.42       100.86       -99.64       104.28       100.52
       100.52       100.17        98.98         8.89        21.18
       -33.72       -47.00         3.76
```

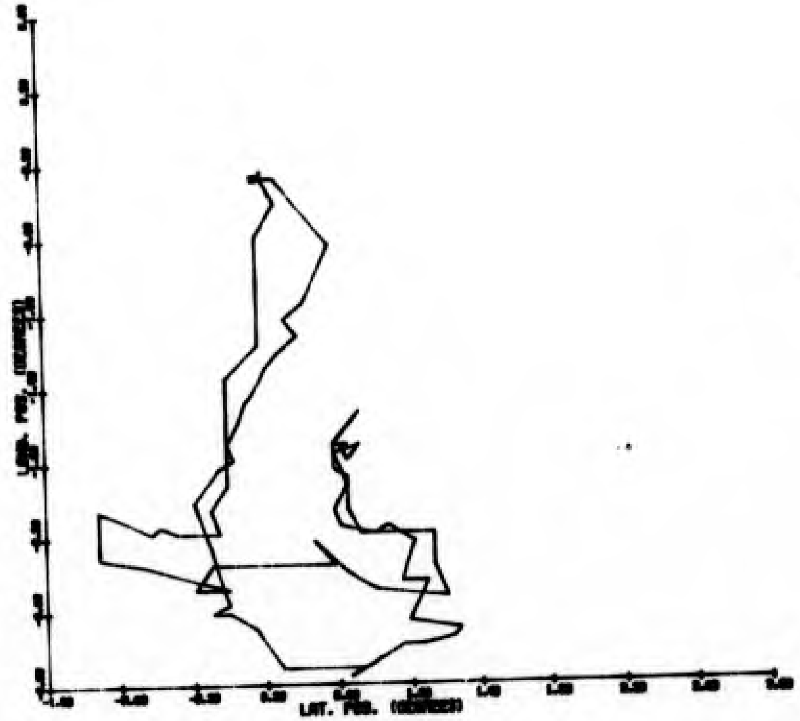
AFHRL-TR-72-6

APPENDIX IX

INITIAL PLOTS GENERATED FOR NINE LAZY 8 PERFORMANCES

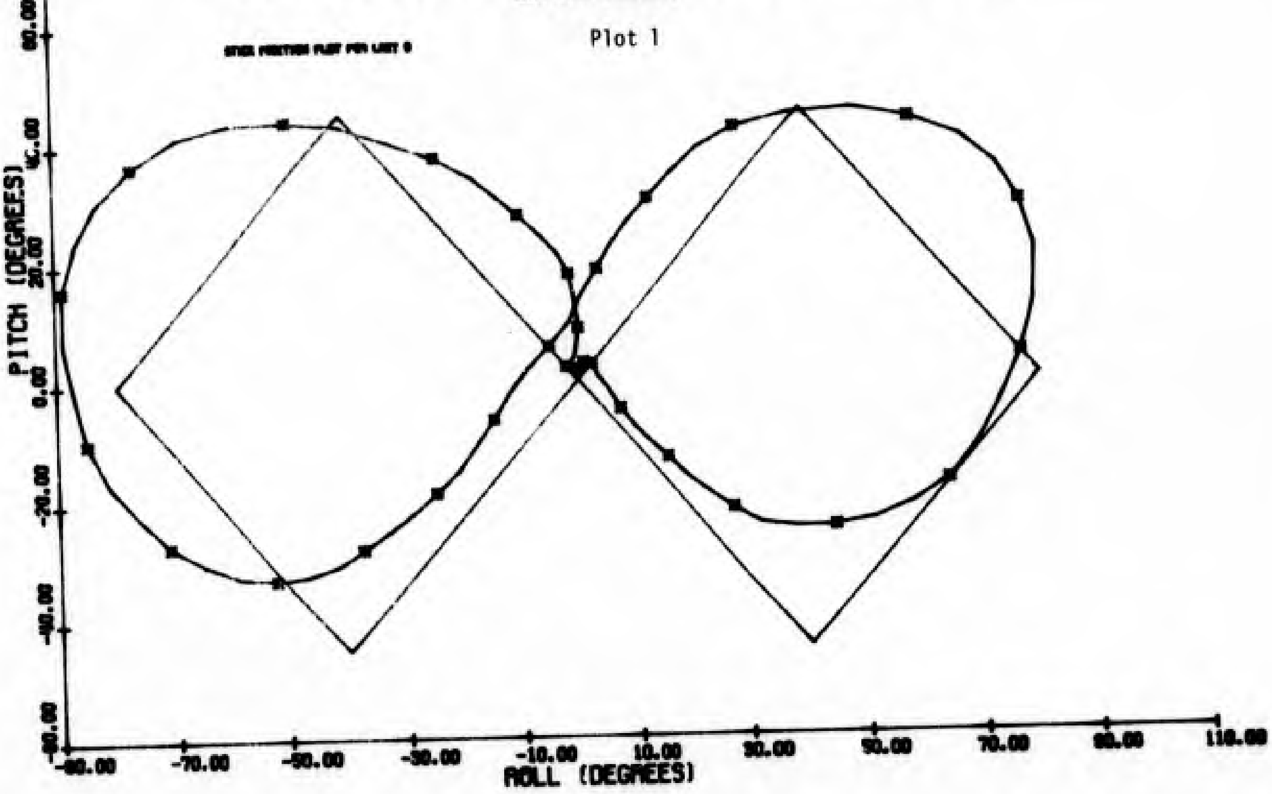
12-17-69-21

Low
Excellent



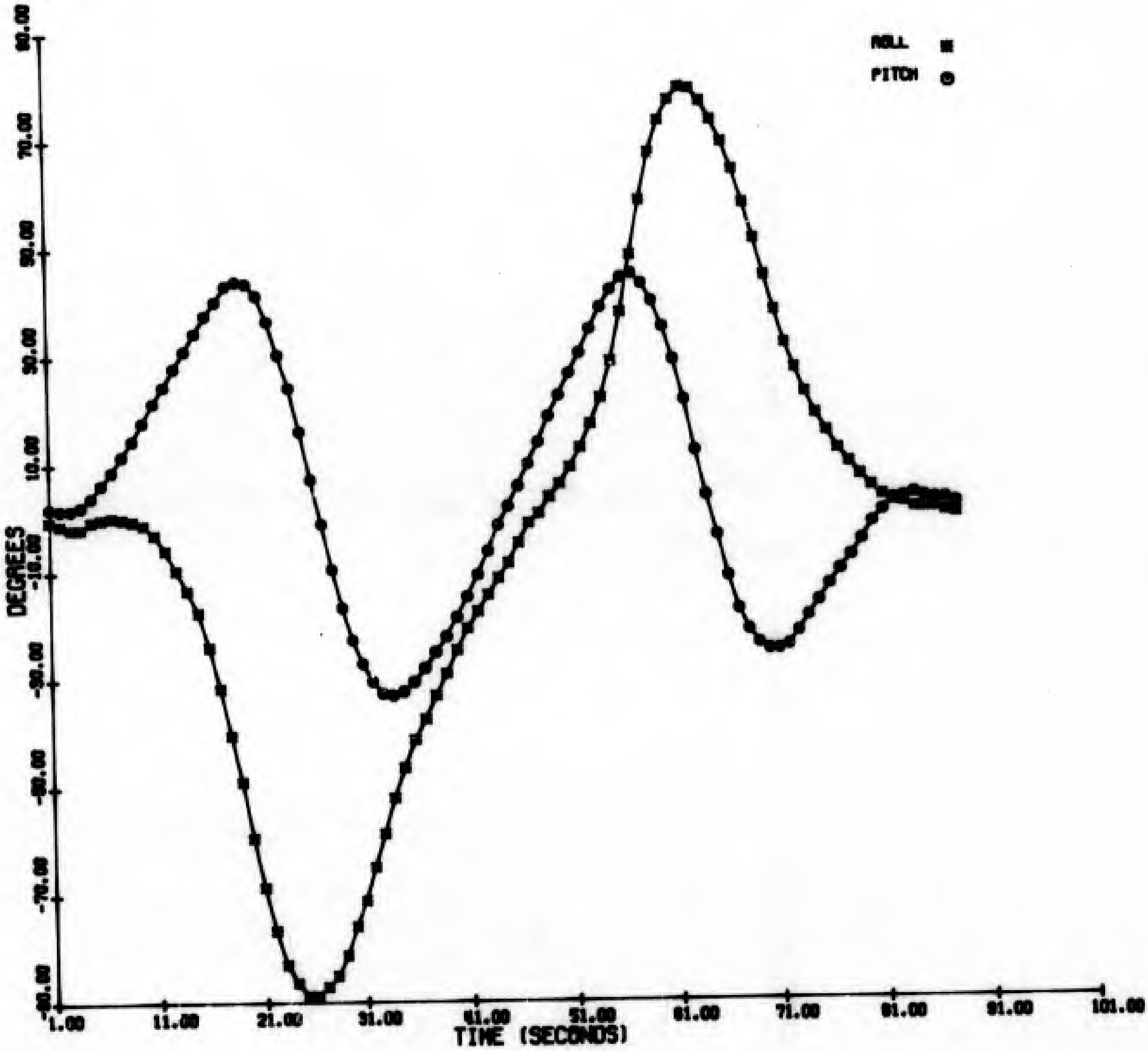
Plot 1

STICK POSITION PLOT FOR LAZY 8



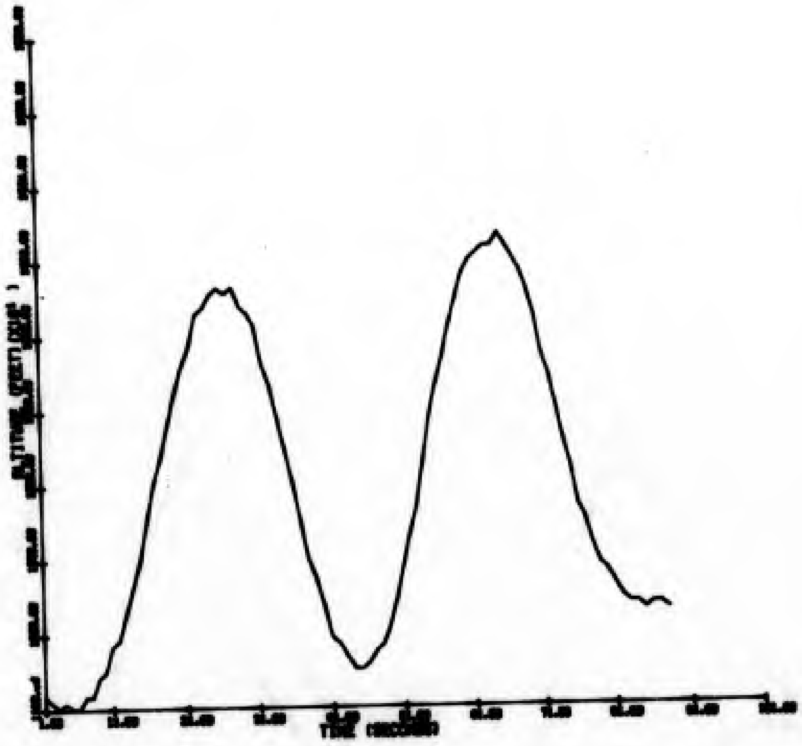
Plot 2

ROLL VS. PITCH FOR LAZY 8

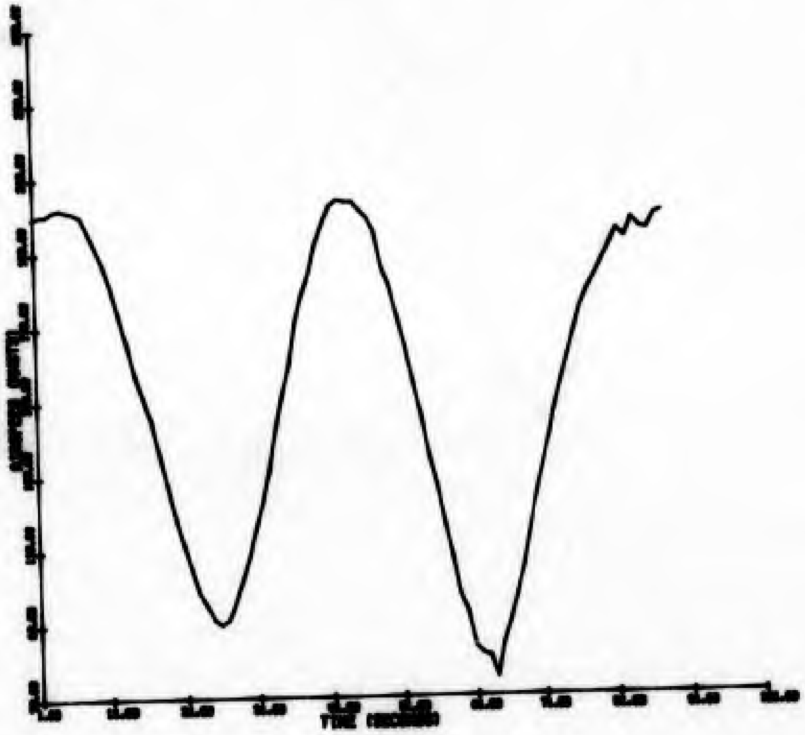


Plot 3

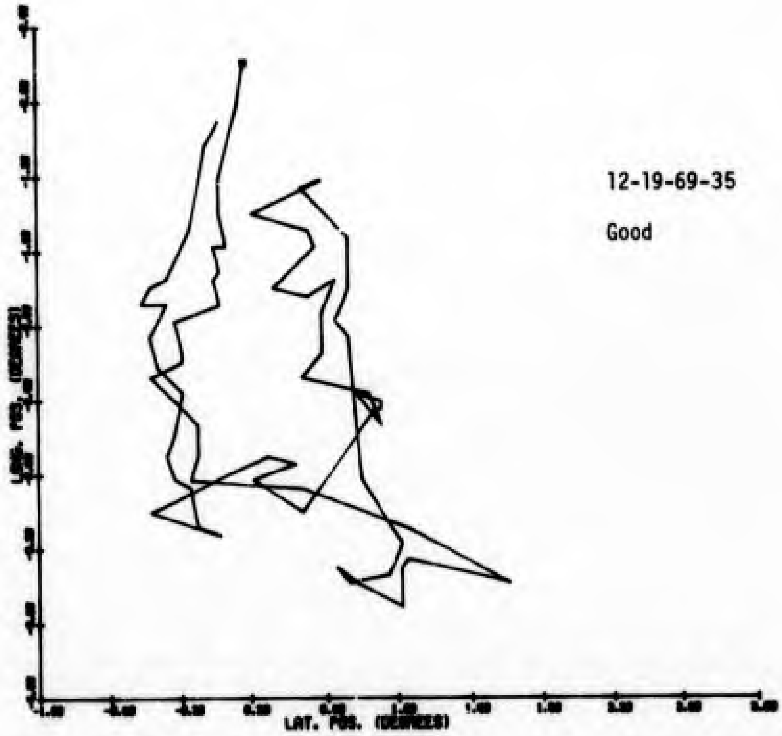
ROLL AND PITCH VS. TIME FOR LAZY 8



Plot 4



Plot 5

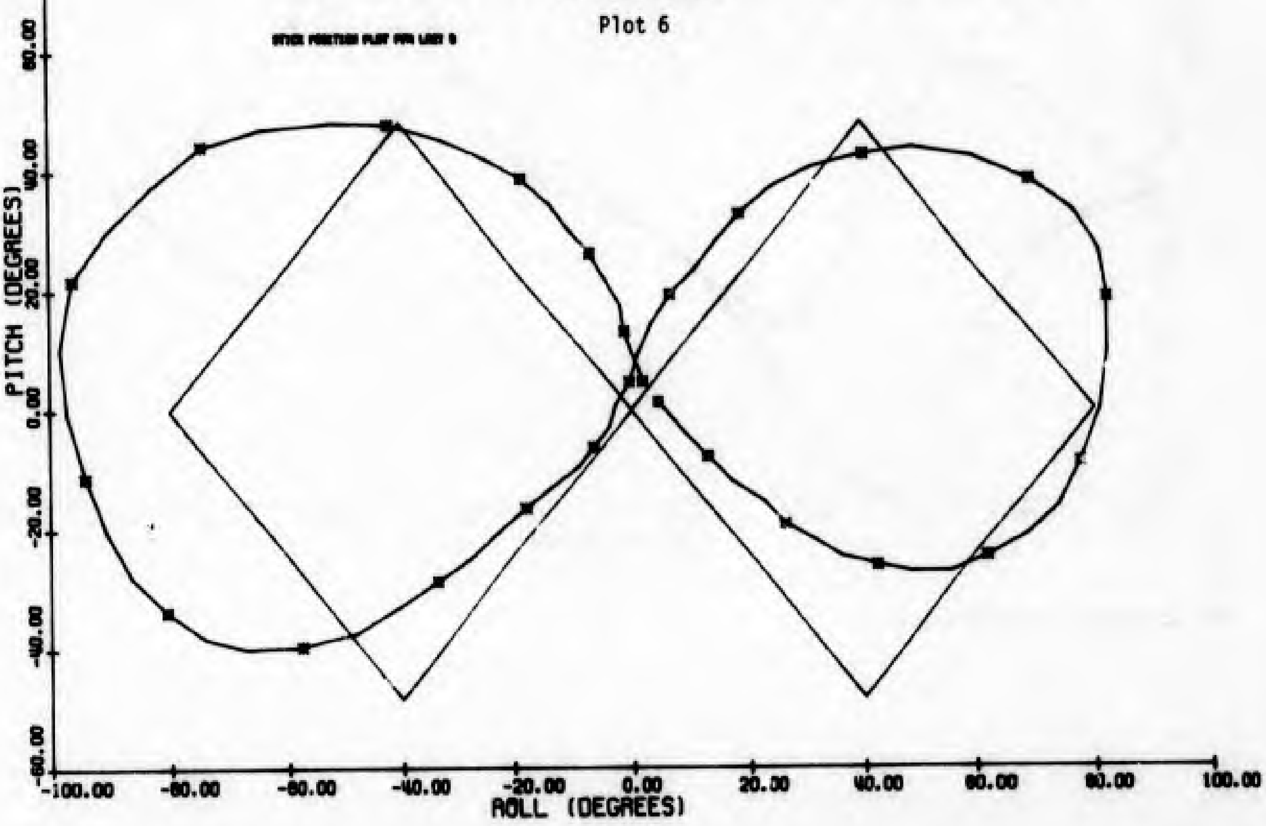


12-19-69-35

Good

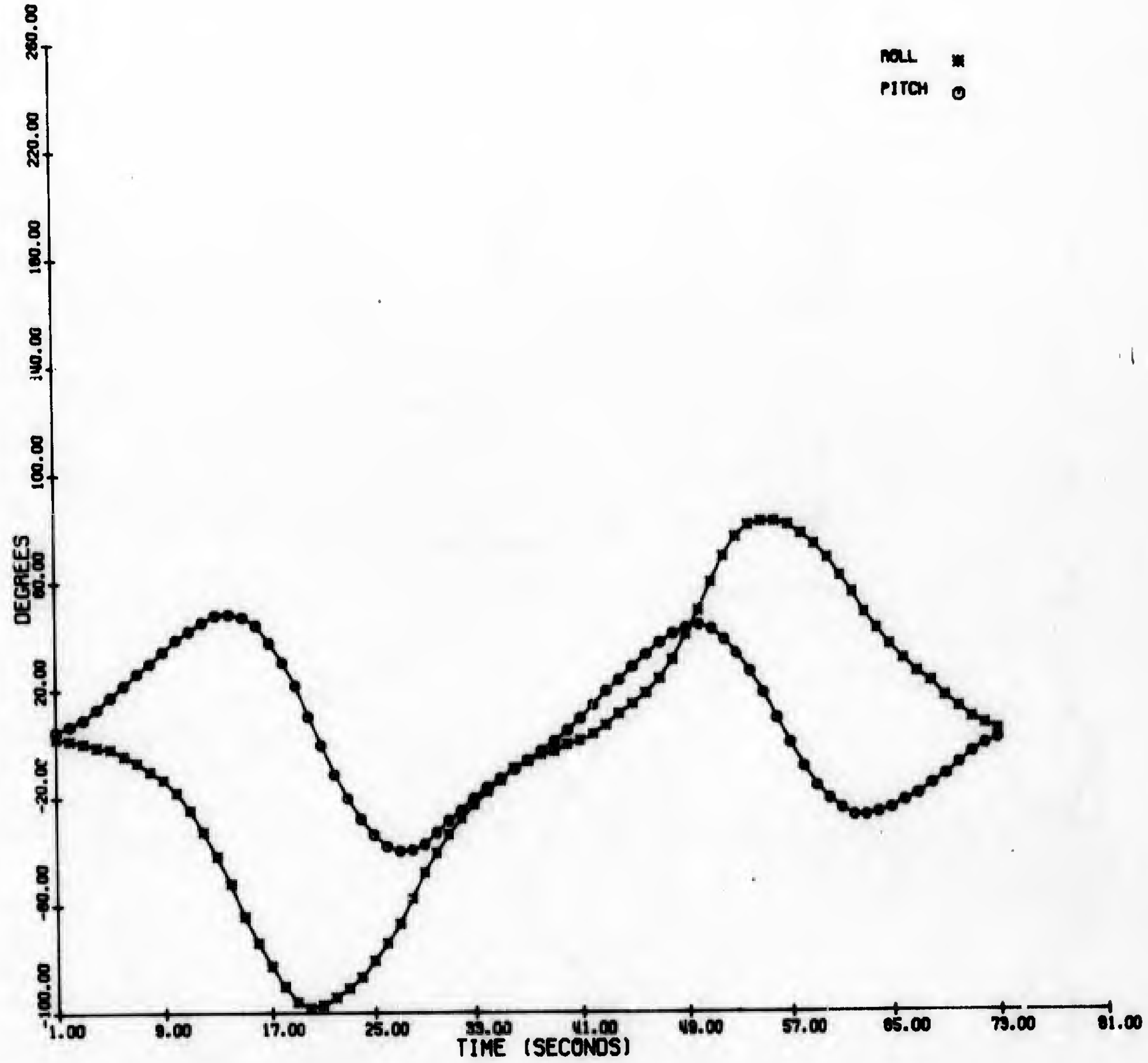
Plot 6

STICK POSITION PLOT FOR LAZY 8



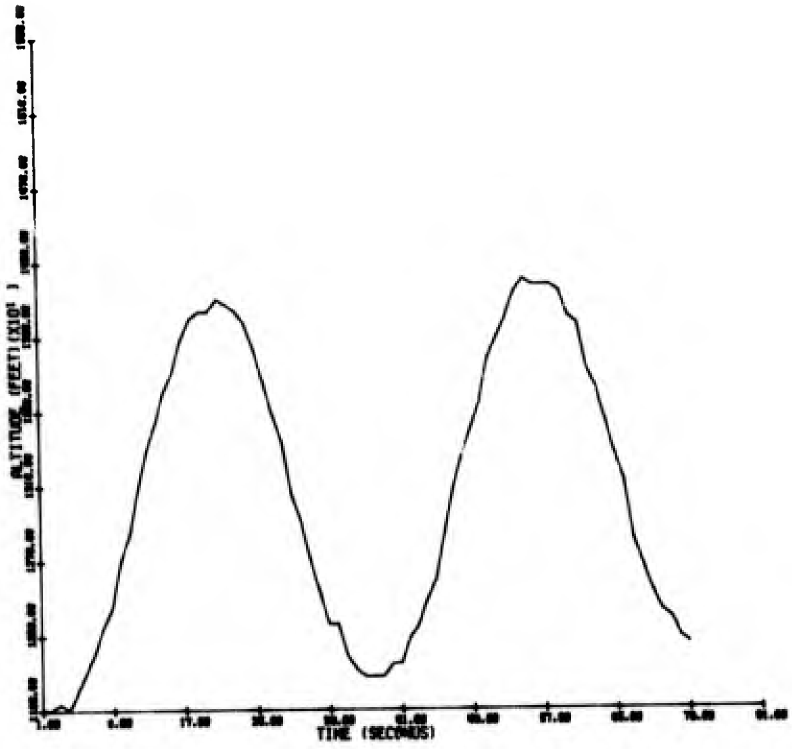
Plot 7

ROLL VS. PITCH FOR LAZY 8



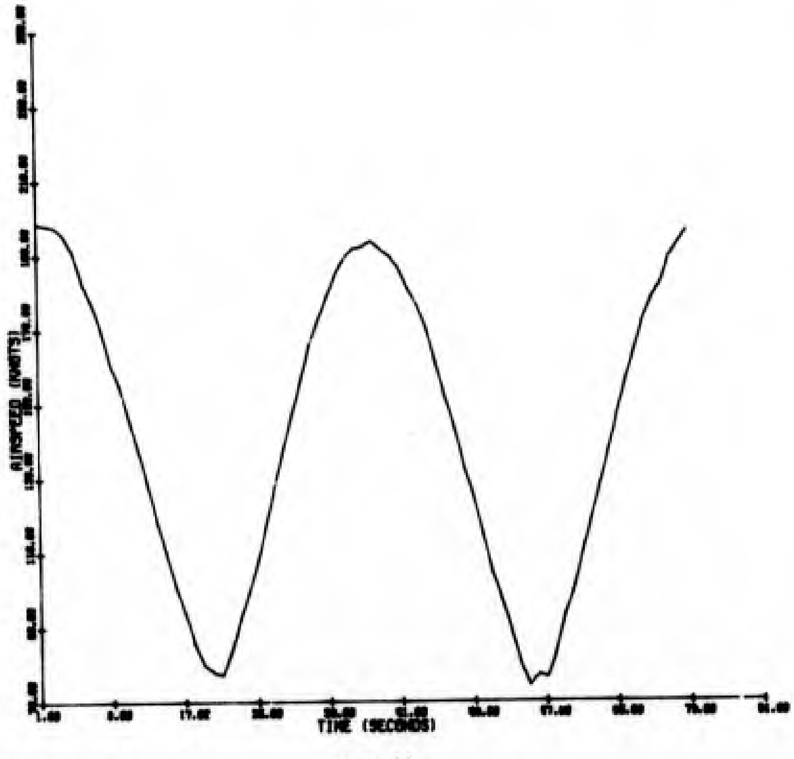
Plot 8

ROLL AND PITCH VS. TIME FOR LAZY 8



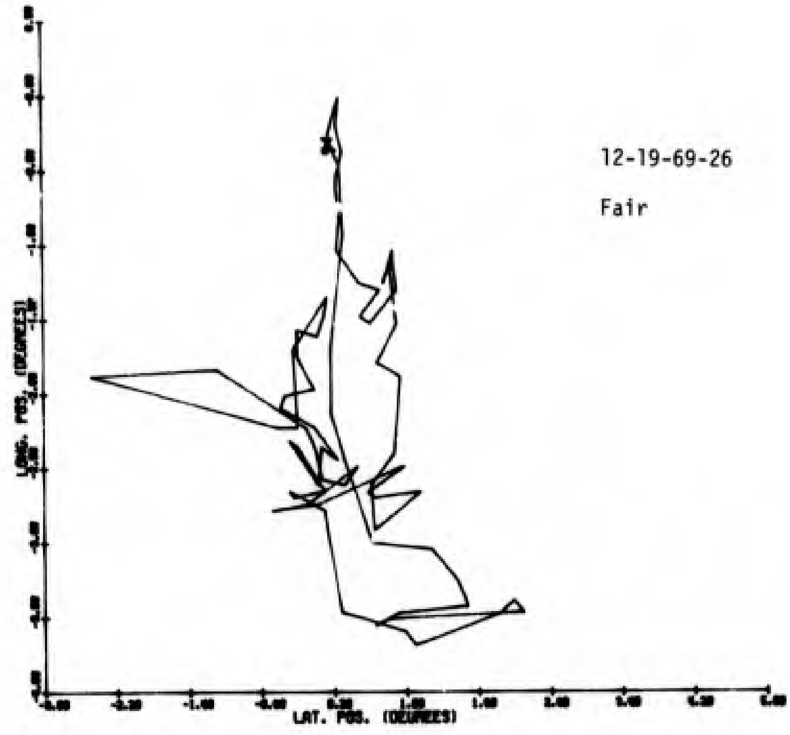
Plot 9

ALTITUDE VS. TIME FOR LAST 9



Plot 10

AIRSPEED VS. TIME FOR LAST 9

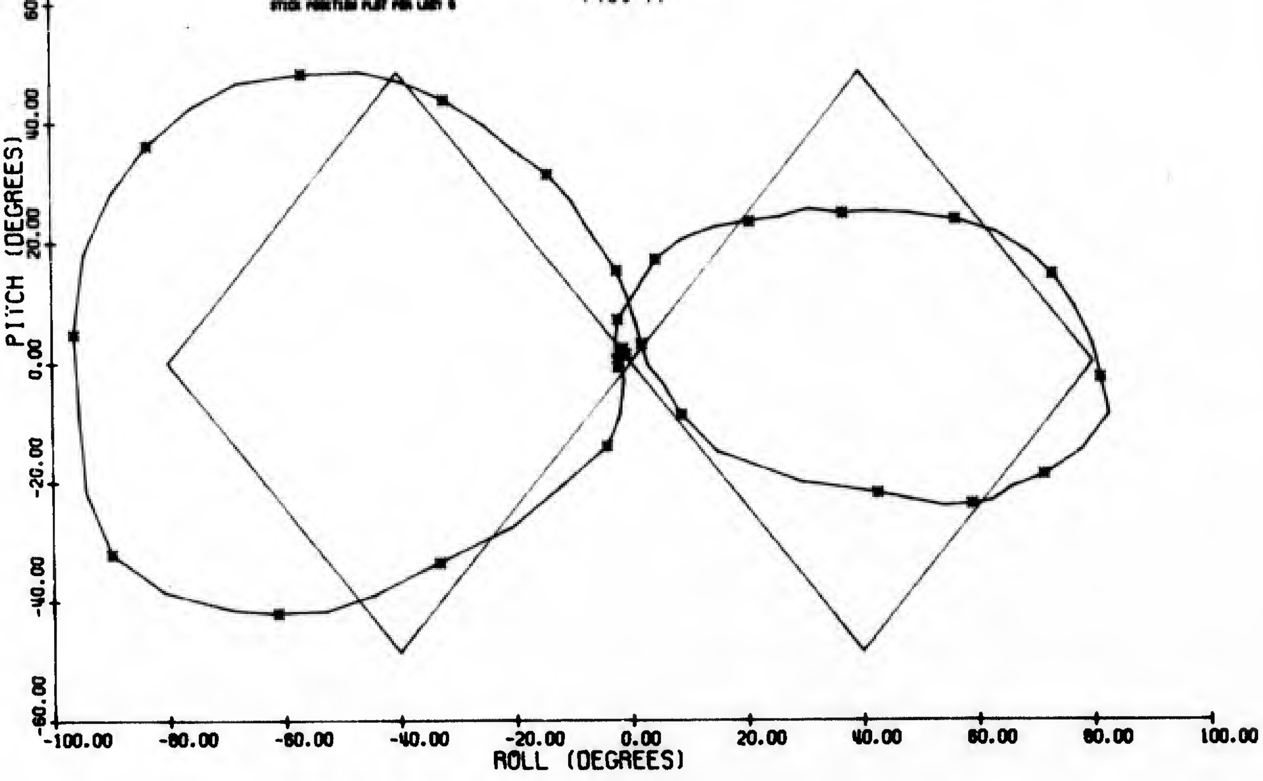


12-19-69-26

Fair

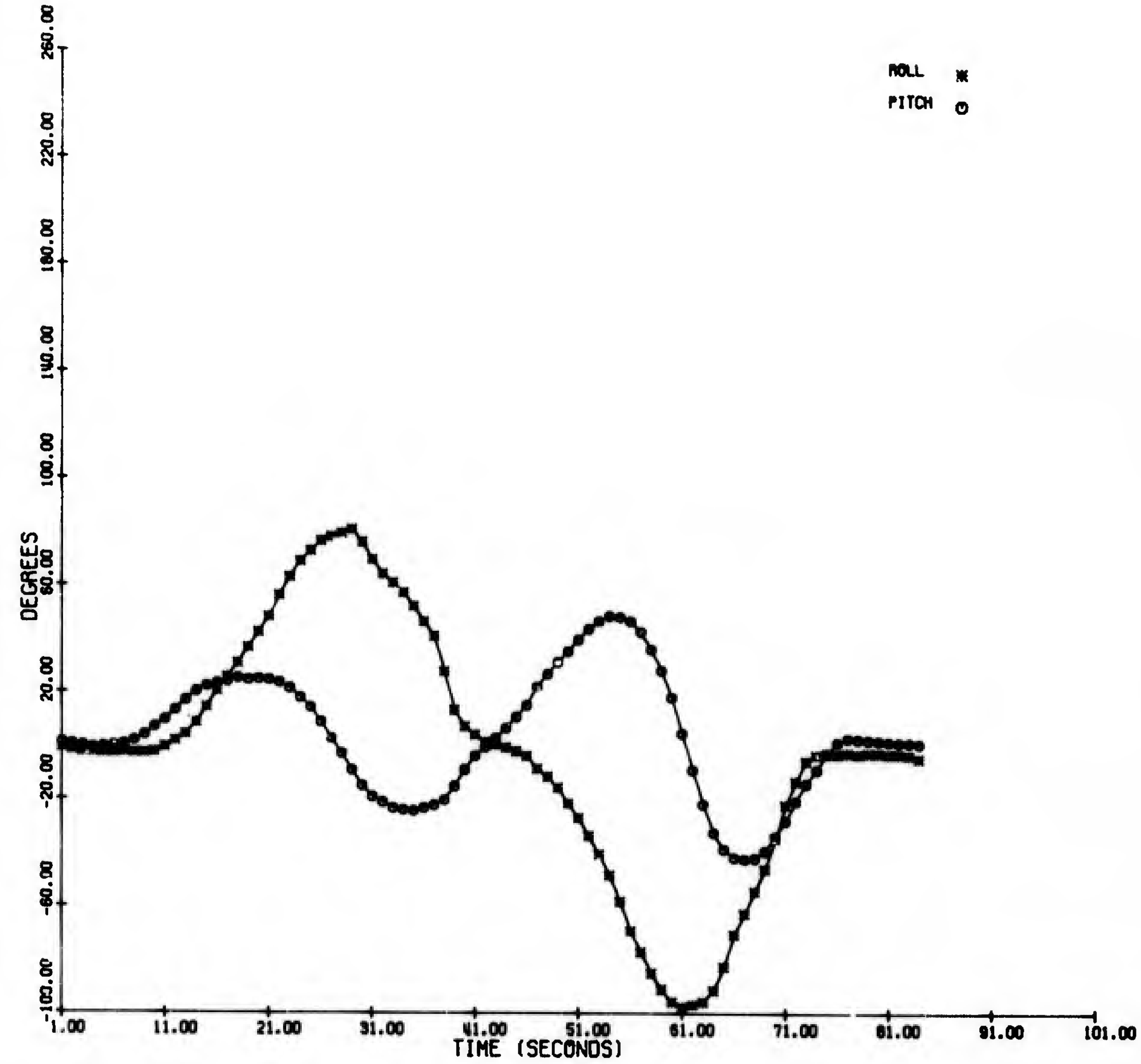
STICK POSITION PLOT FOR LAZY 8

Plot 11



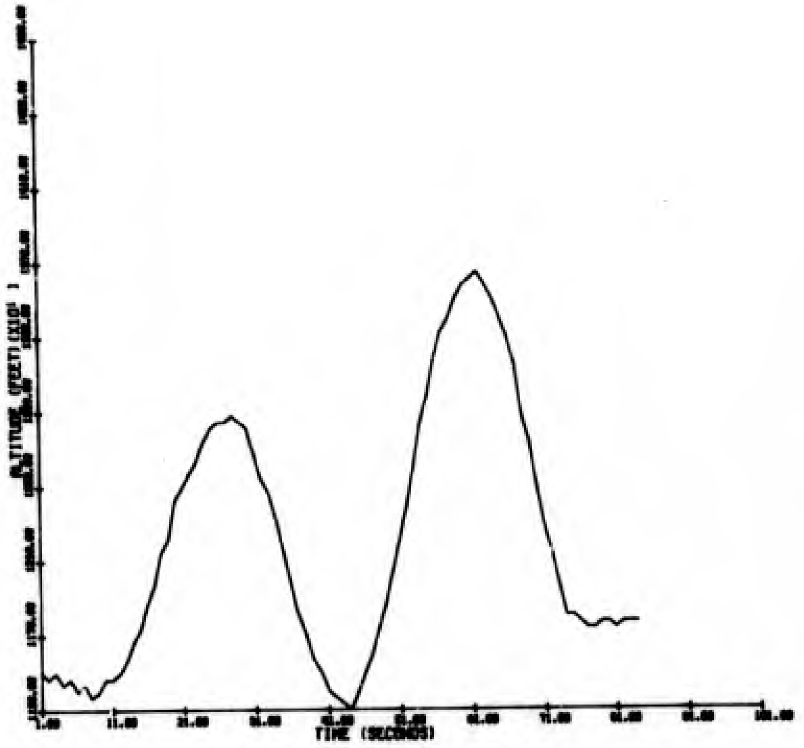
Plot 12

ROLL VS. PITCH FOR LAZY 8

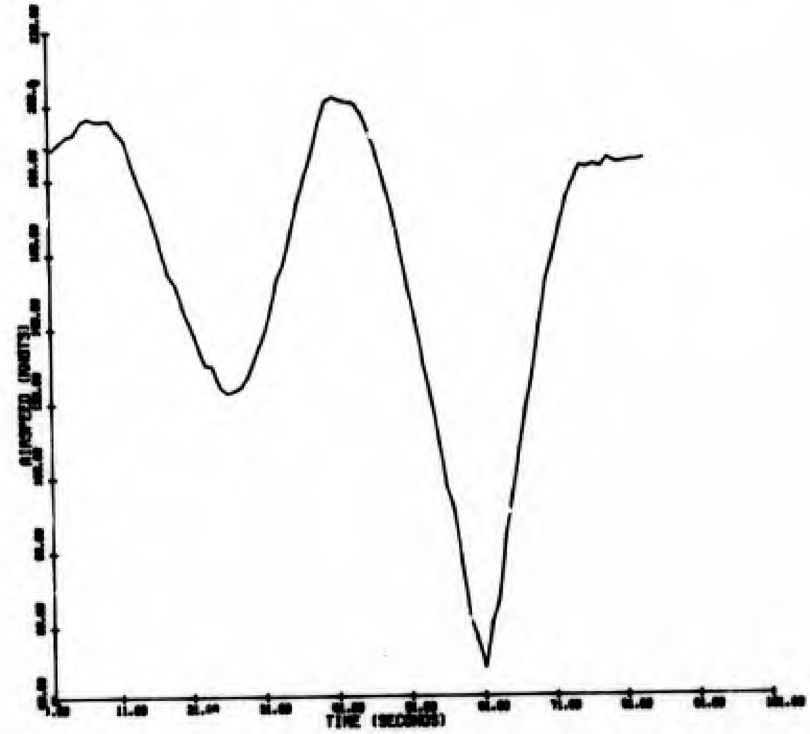


Plot 13

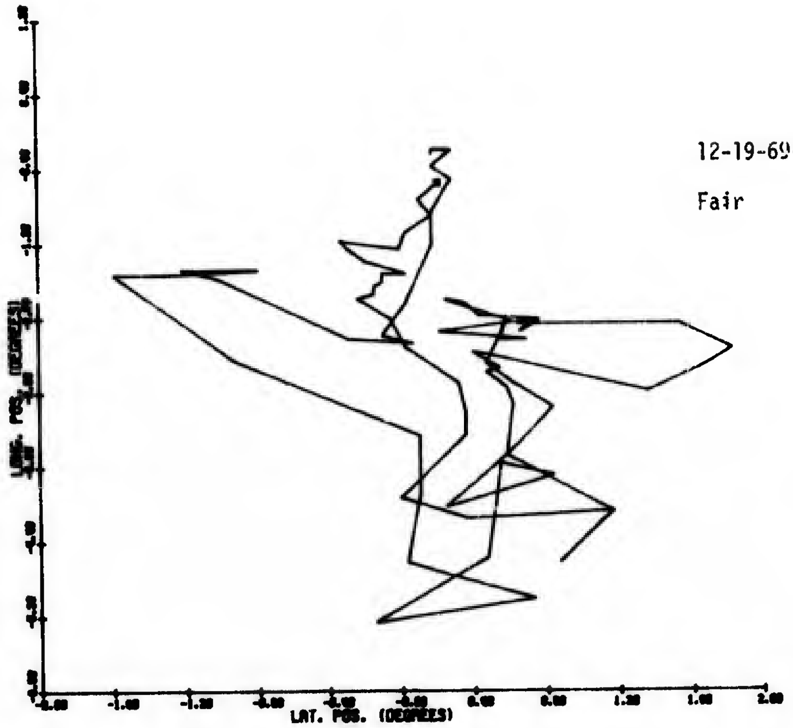
ROLL AND PITCH VS. TIME FOR LAZY 8



Plot 14



Plot 15

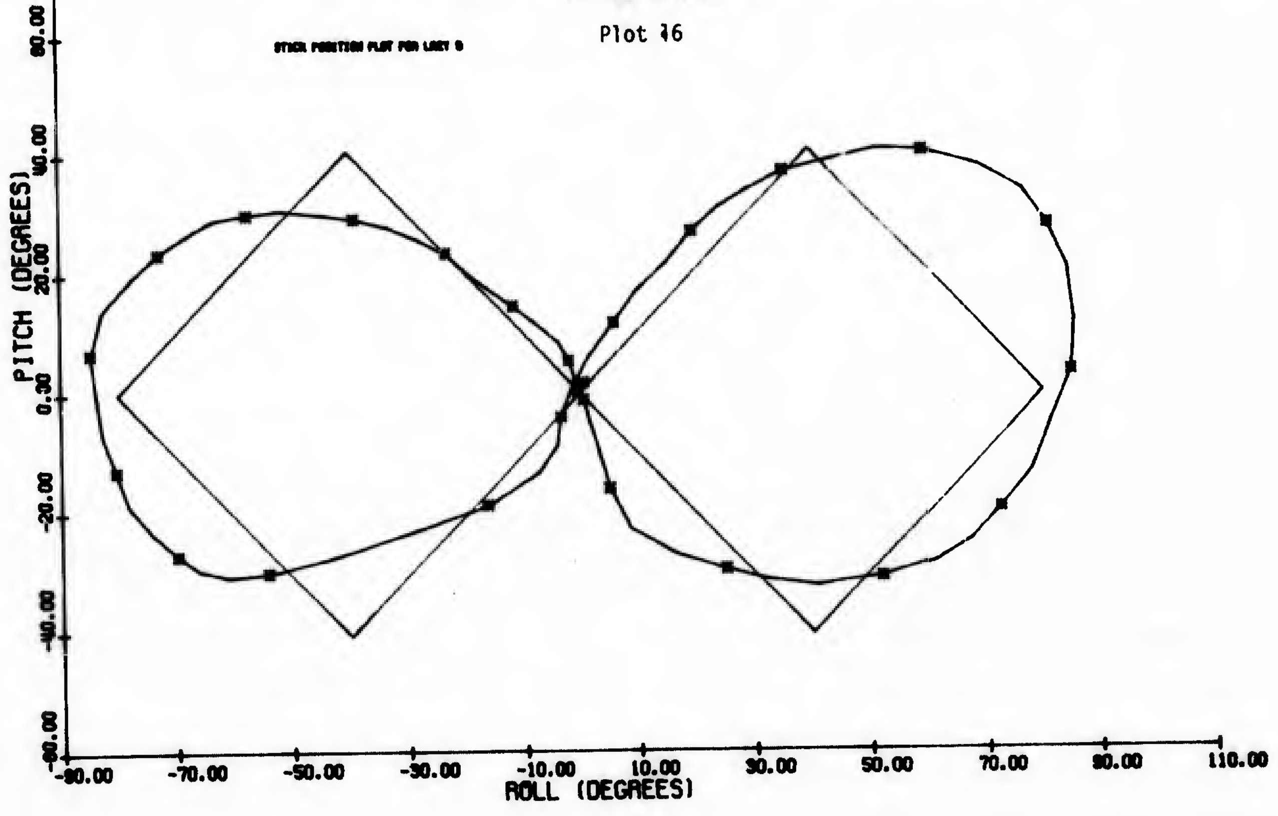


12-19-69-28

Fair

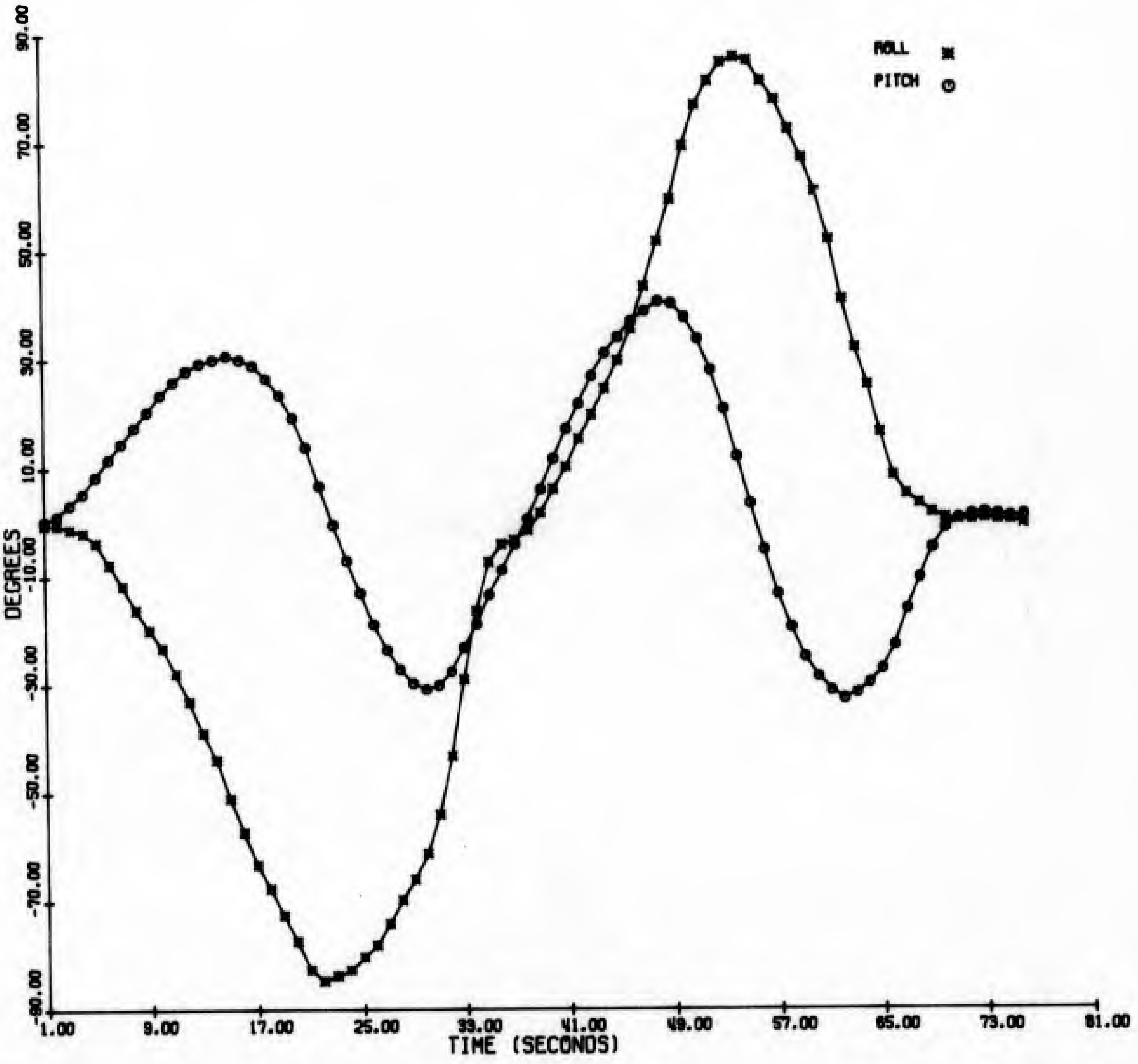
STICK POSITION PLOT FOR LAZY 8

Plot 16



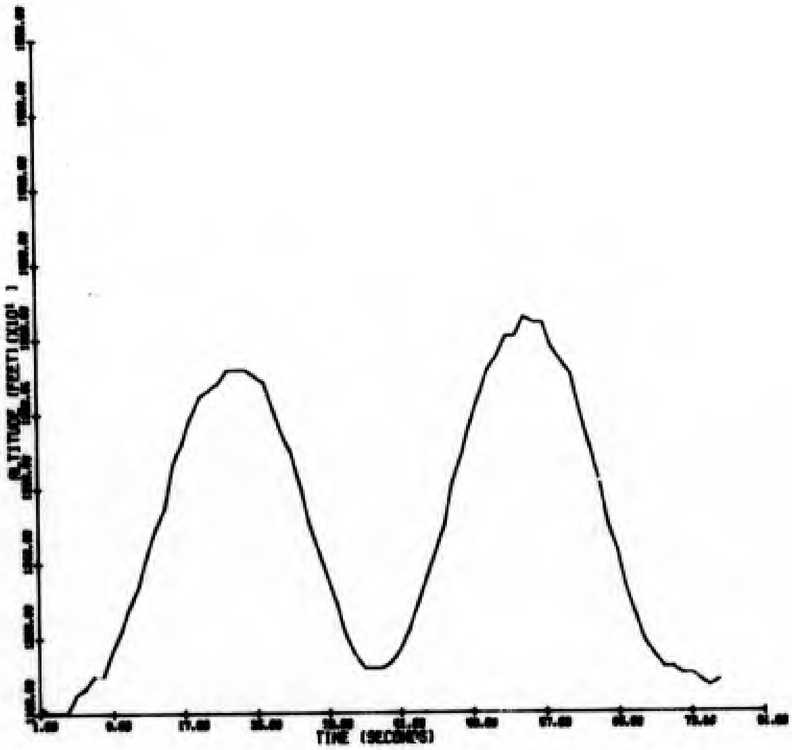
Plot 17

ROLL VS. PITCH FOR LAZY 8

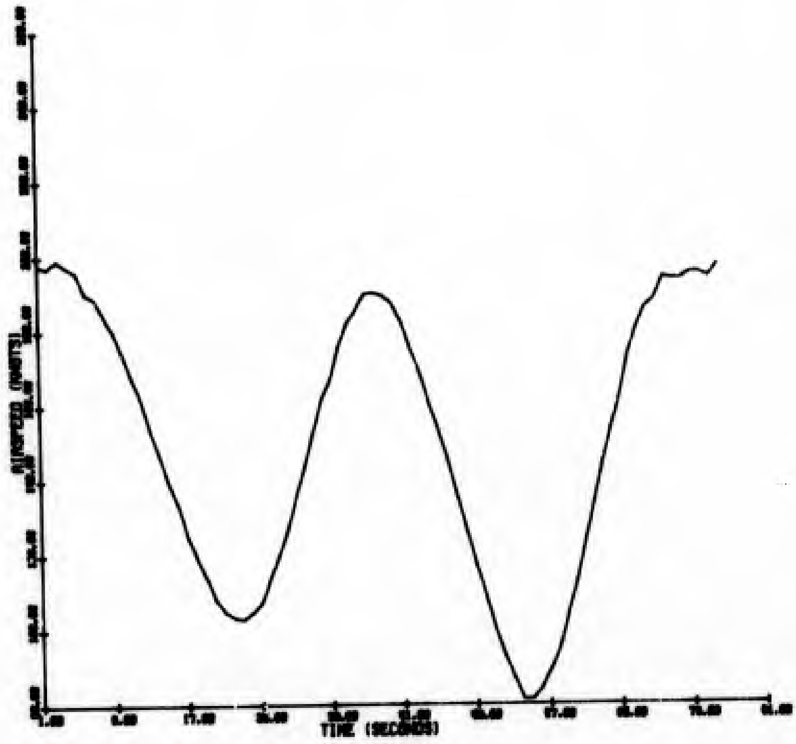


Plot 18

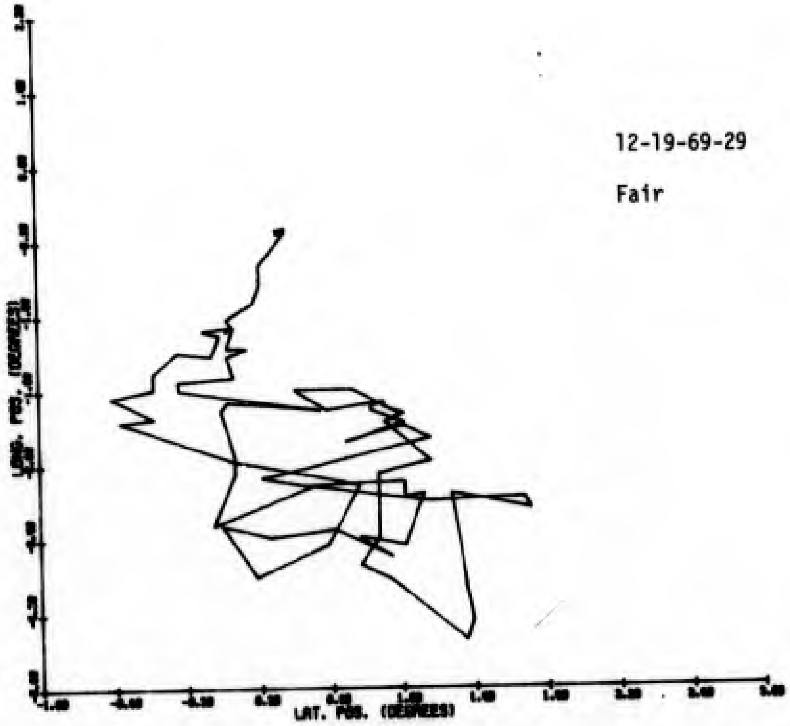
ROLL AND PITCH VS. TIME FOR LAZY 8



Plot 19

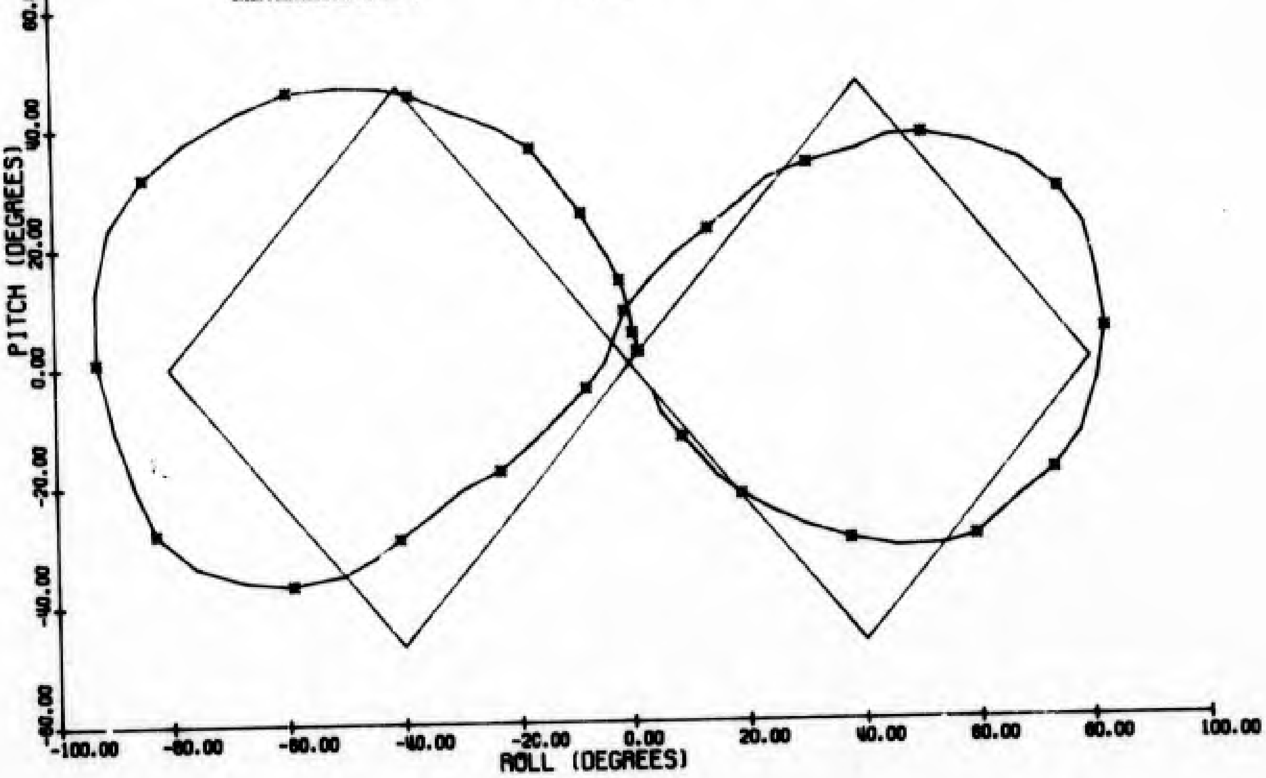


Plot 20



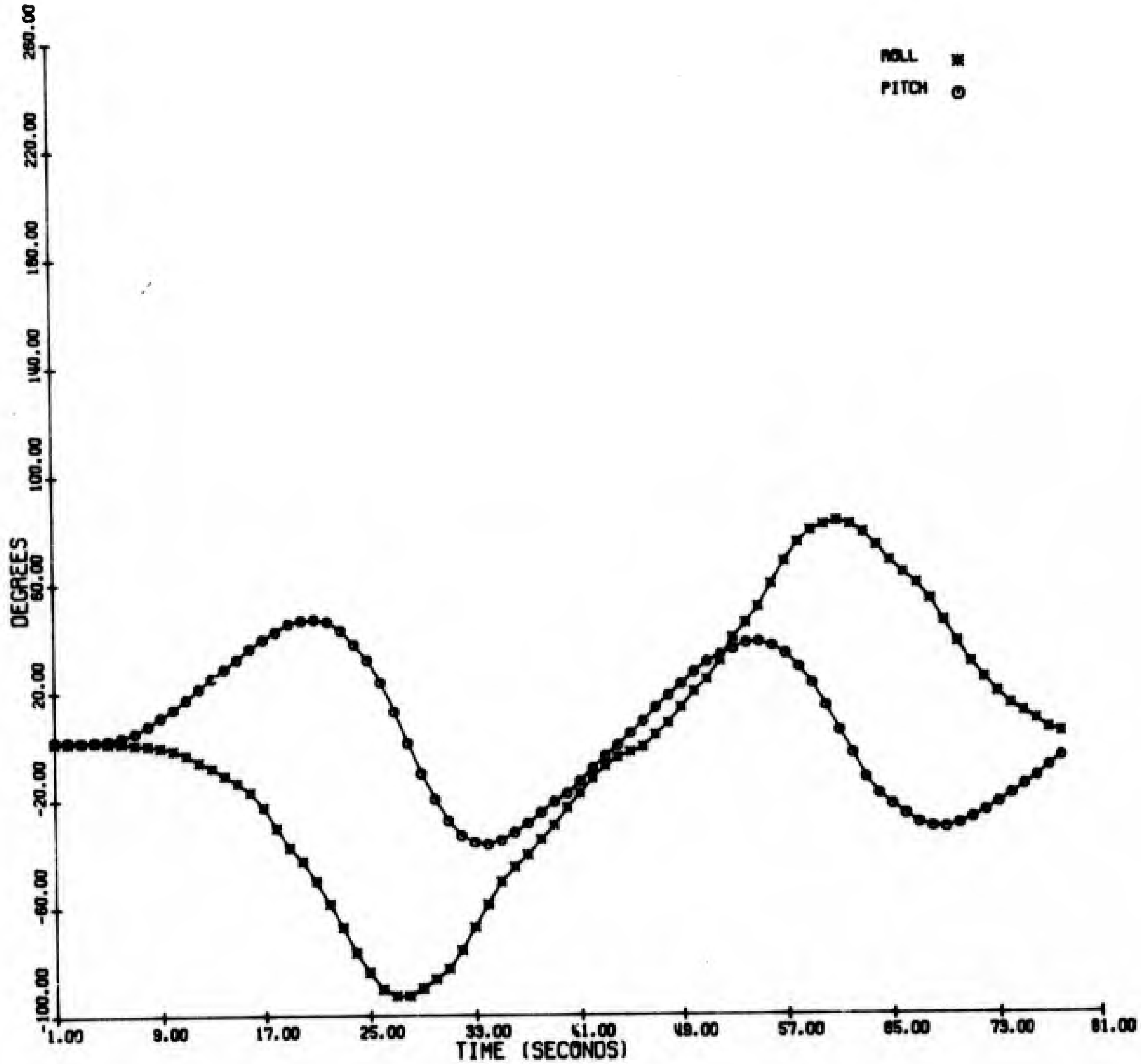
STICK POSITION PLOT FOR LAZY 8

Plot 21



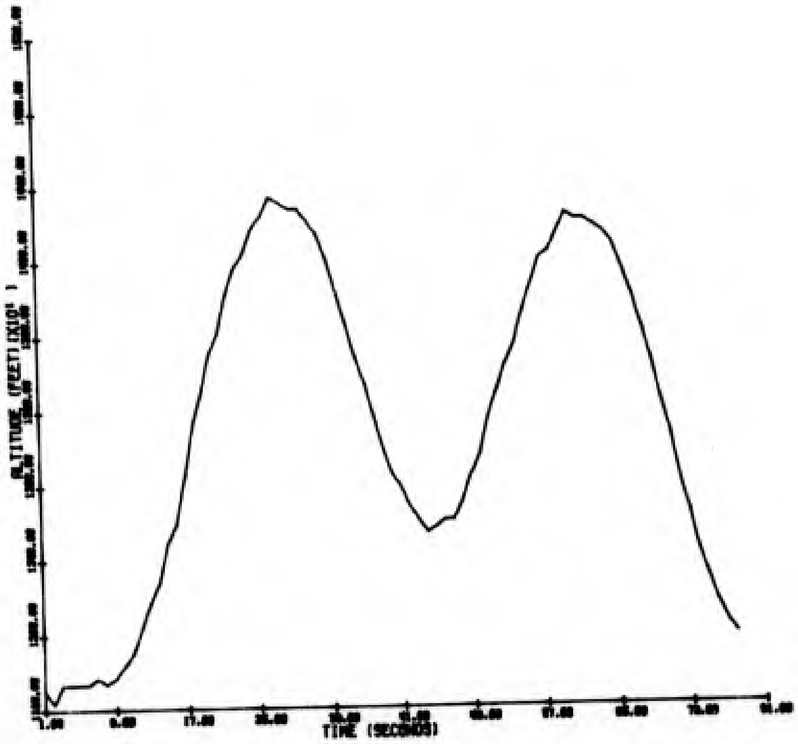
Plot 22

ROLL VS. PITCH FOR LAZY 8



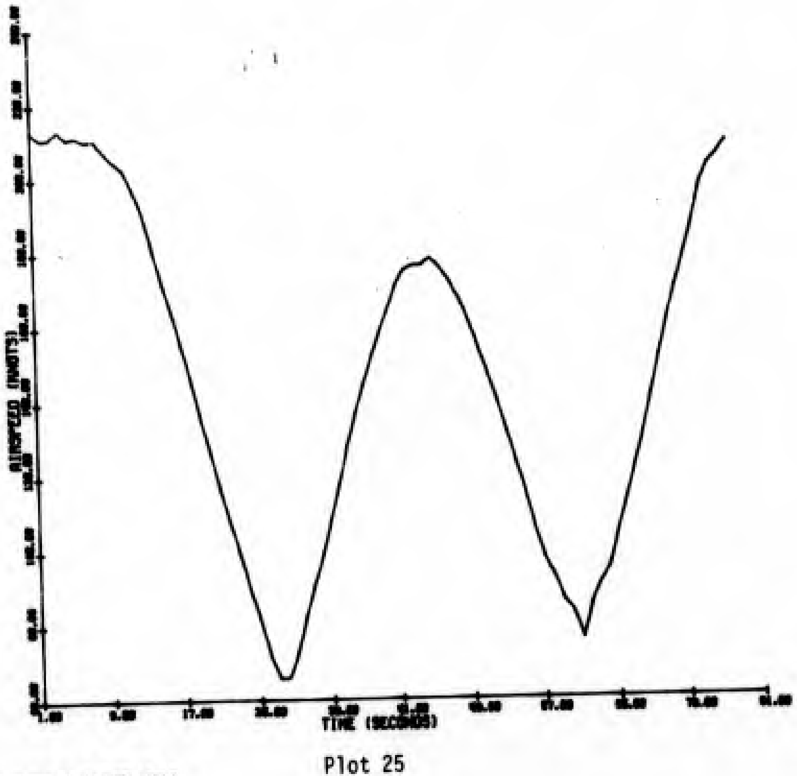
Plot 23

ROLL AND PITCH VS. TIME FOR LAZY 8



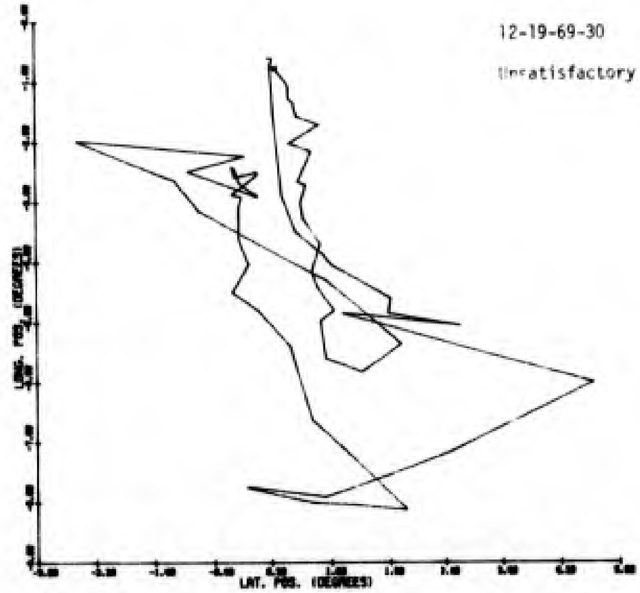
Plot 24

ALTITUDE VS. TIME FOR LAST 9



Plot 25

AIRSPEED VS. TIME FOR LAST 9

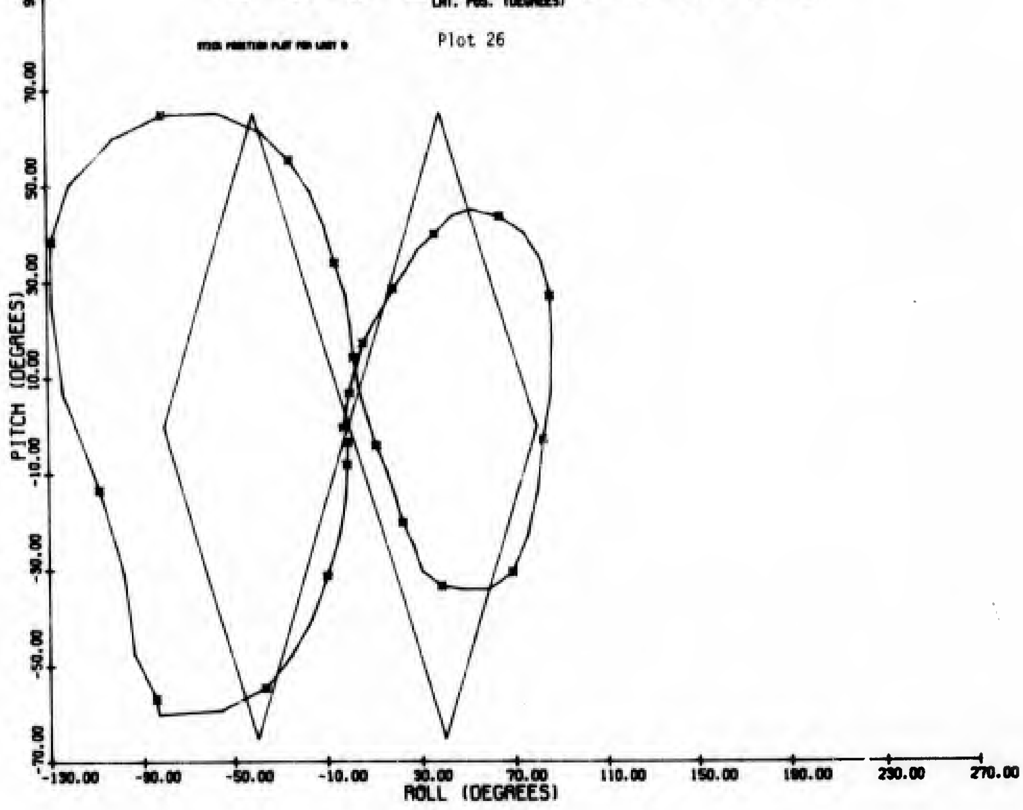


12-19-69-30

Unsatisfactory

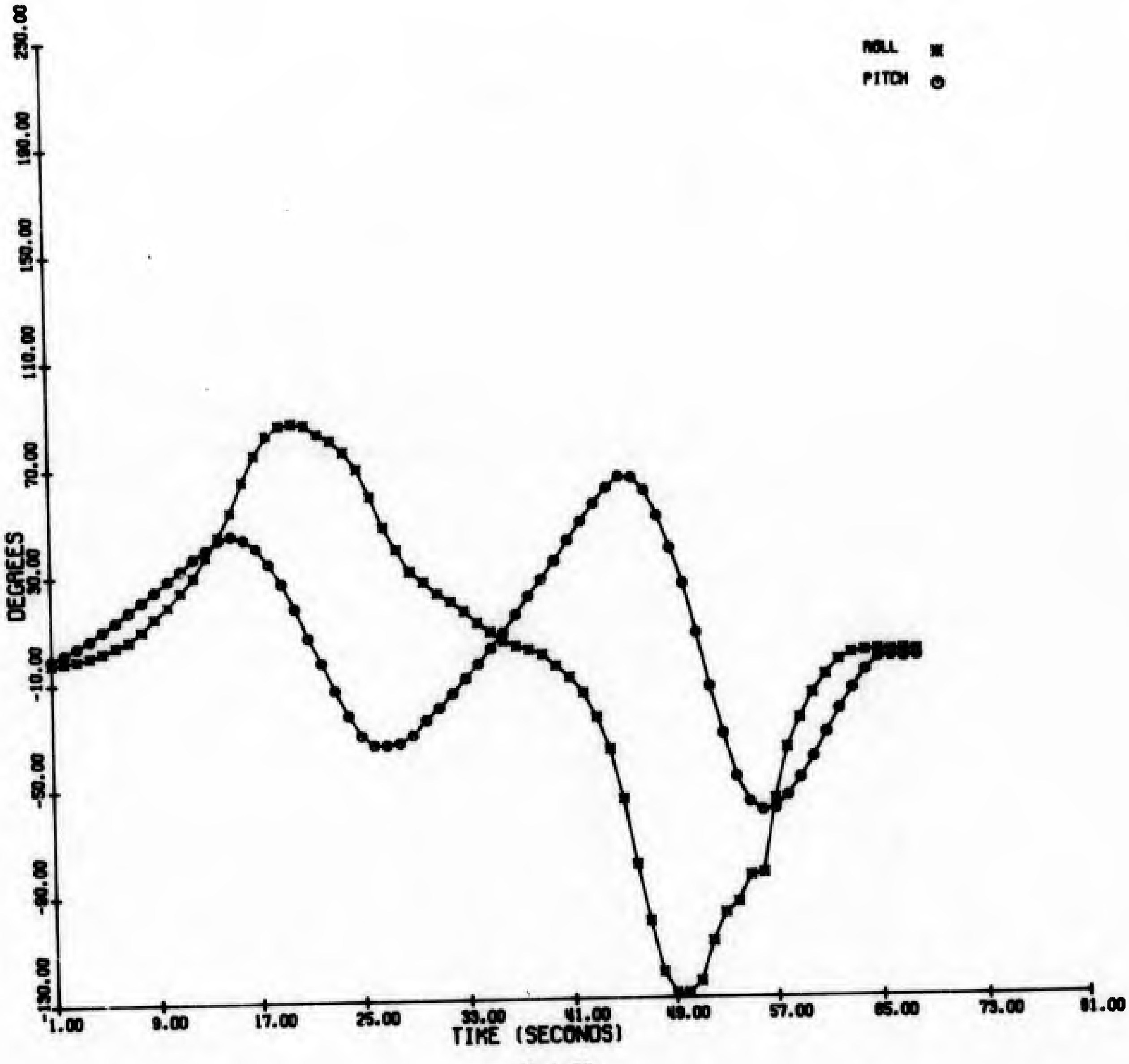
STICK POSITION PLOT FOR LAZT 8

Plot 26



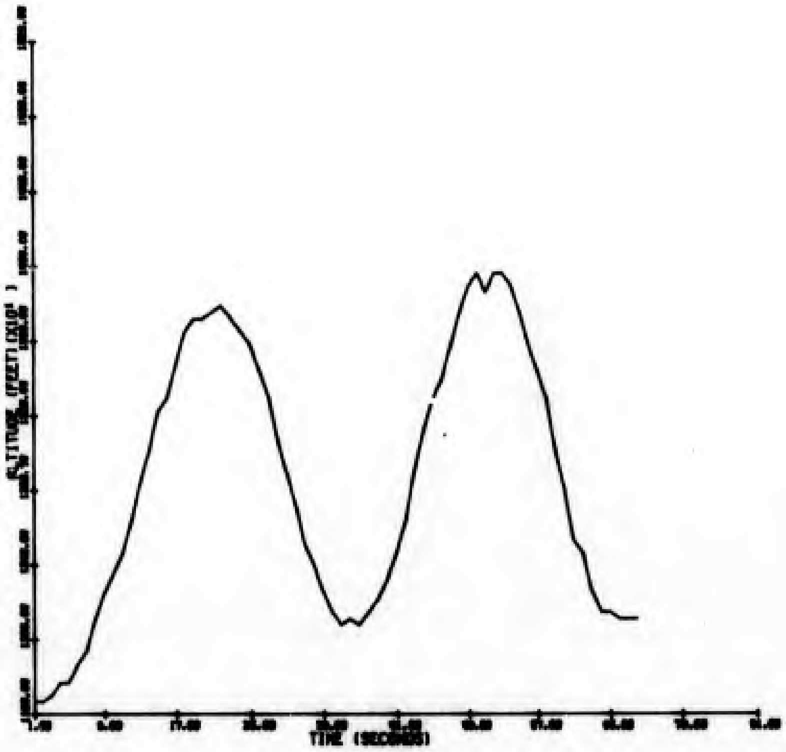
Plot 27

ROLL VS. PITCH FOR LAZT 8



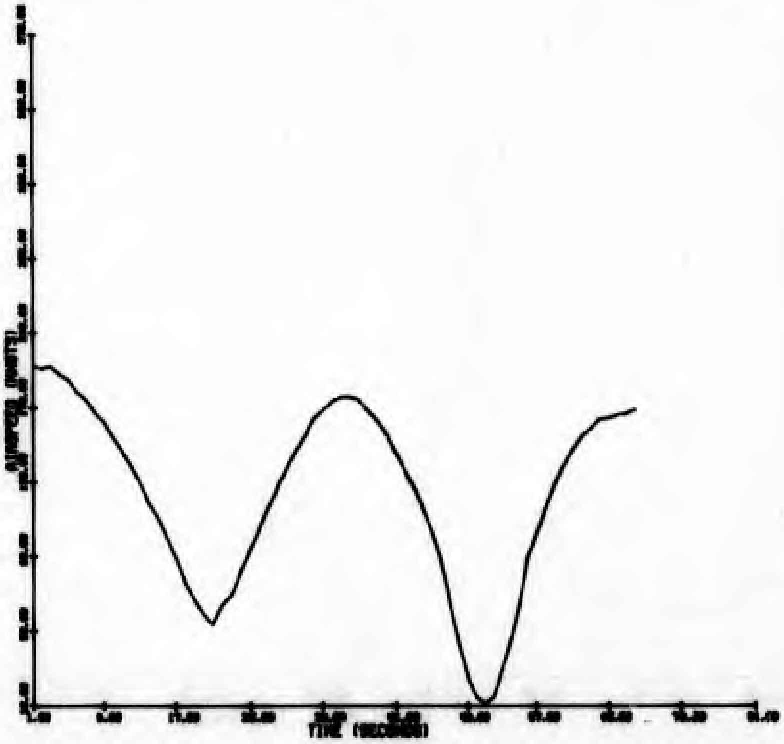
Plot 28

ROLL AND PITCH VS. TIME FOR LAZY 8



Plot 29

ALTITUDE VS. TIME FOR LAST 9

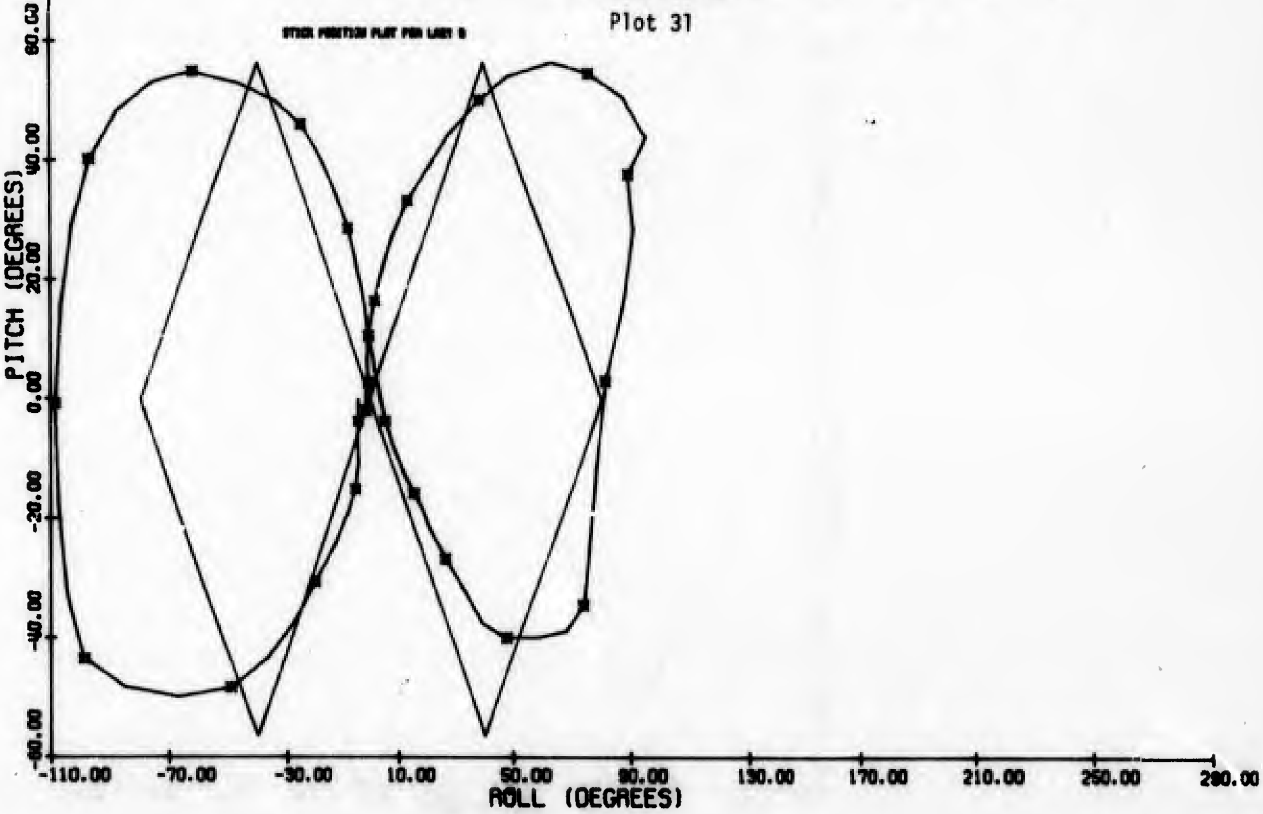


Plot 30

AIRSPEED VS. TIME FOR LAST 9

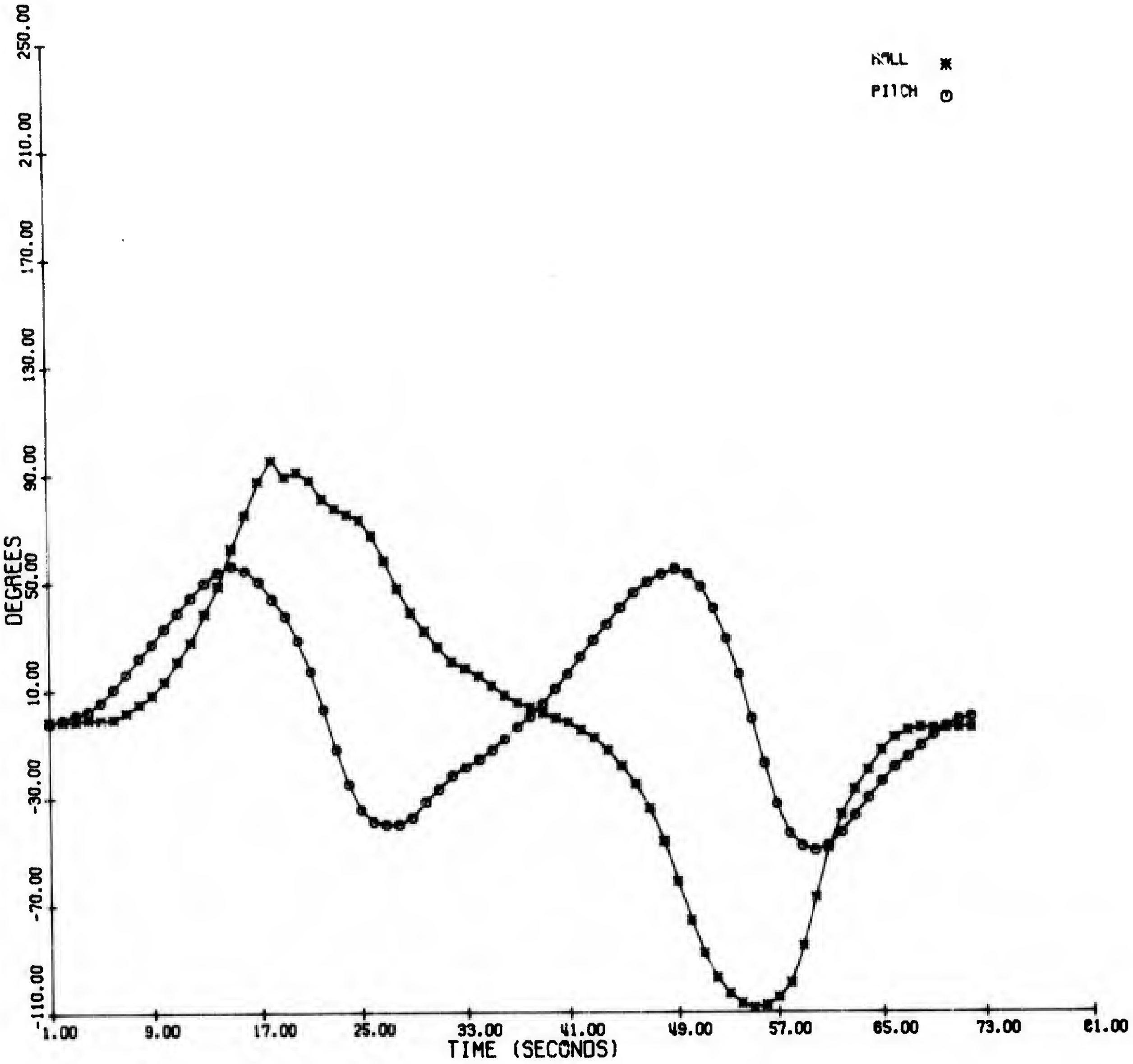
Plot 31

STICK POSITION PLOT FOR LAZY 8



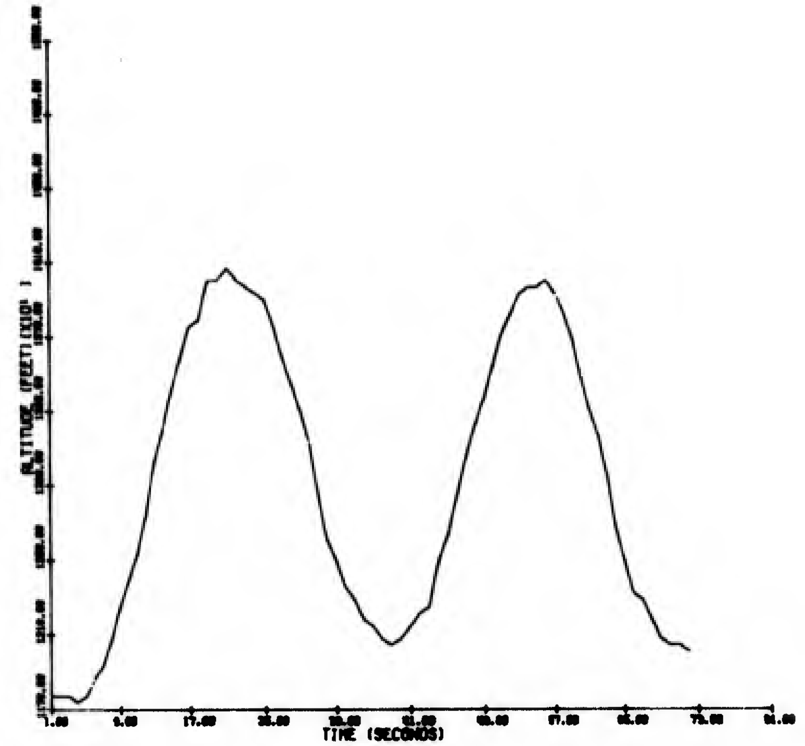
Plot 32

ROLL VS. PITCH FOR LAZY 8

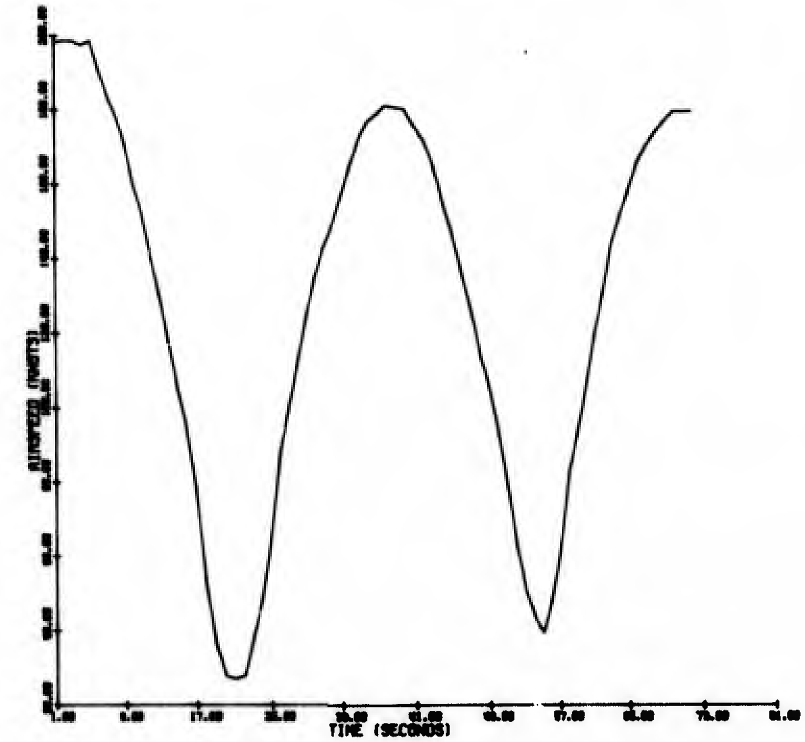


Plot 33

ROLL AND PITCH VS. TIME FOR LAZY 8



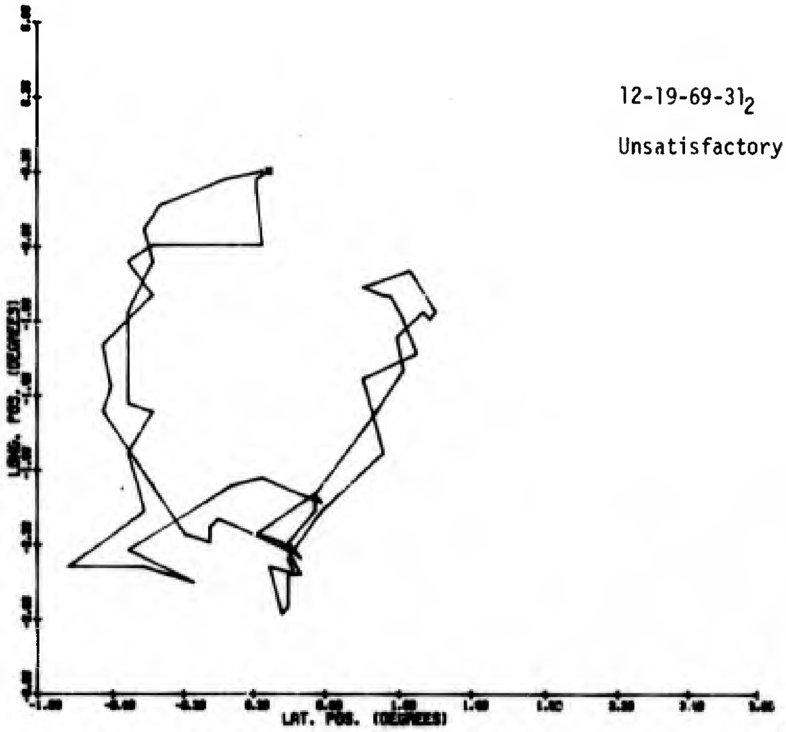
Plot 34



Plot 35

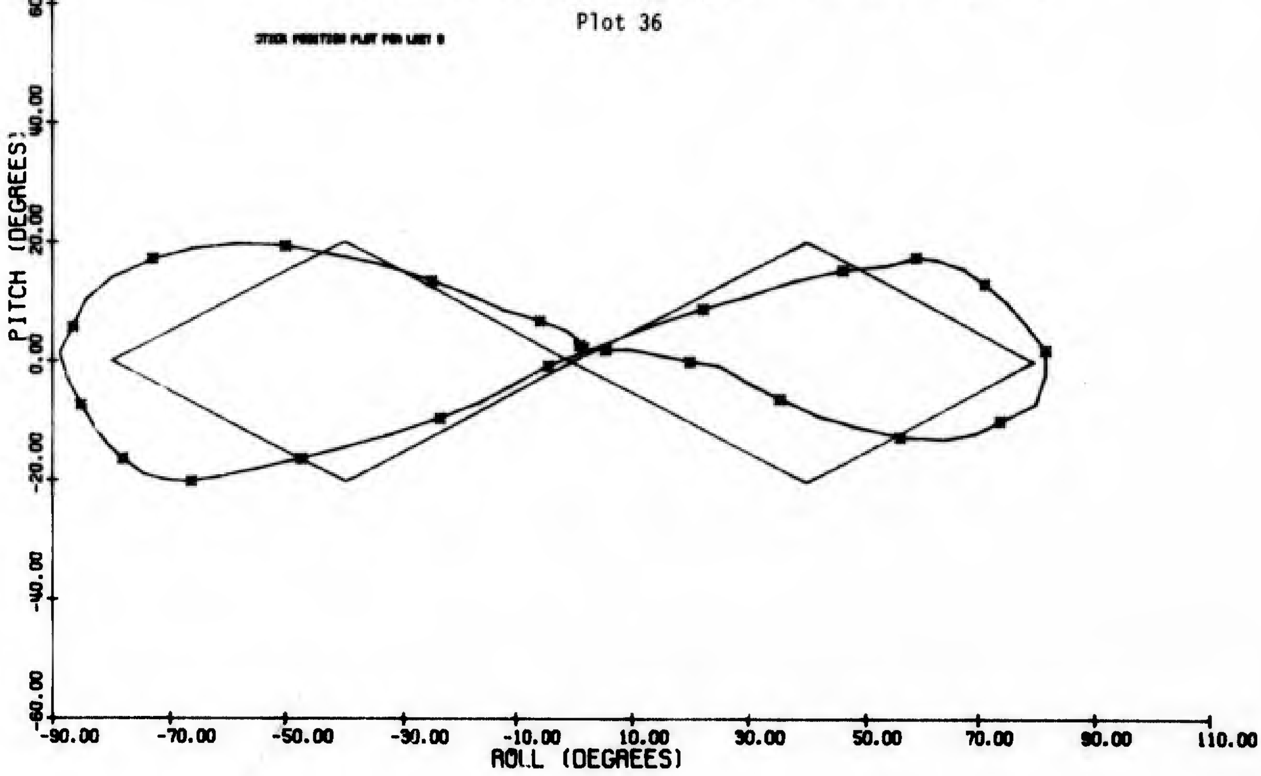
12-19-69-31$_2$

Unsatisfactory



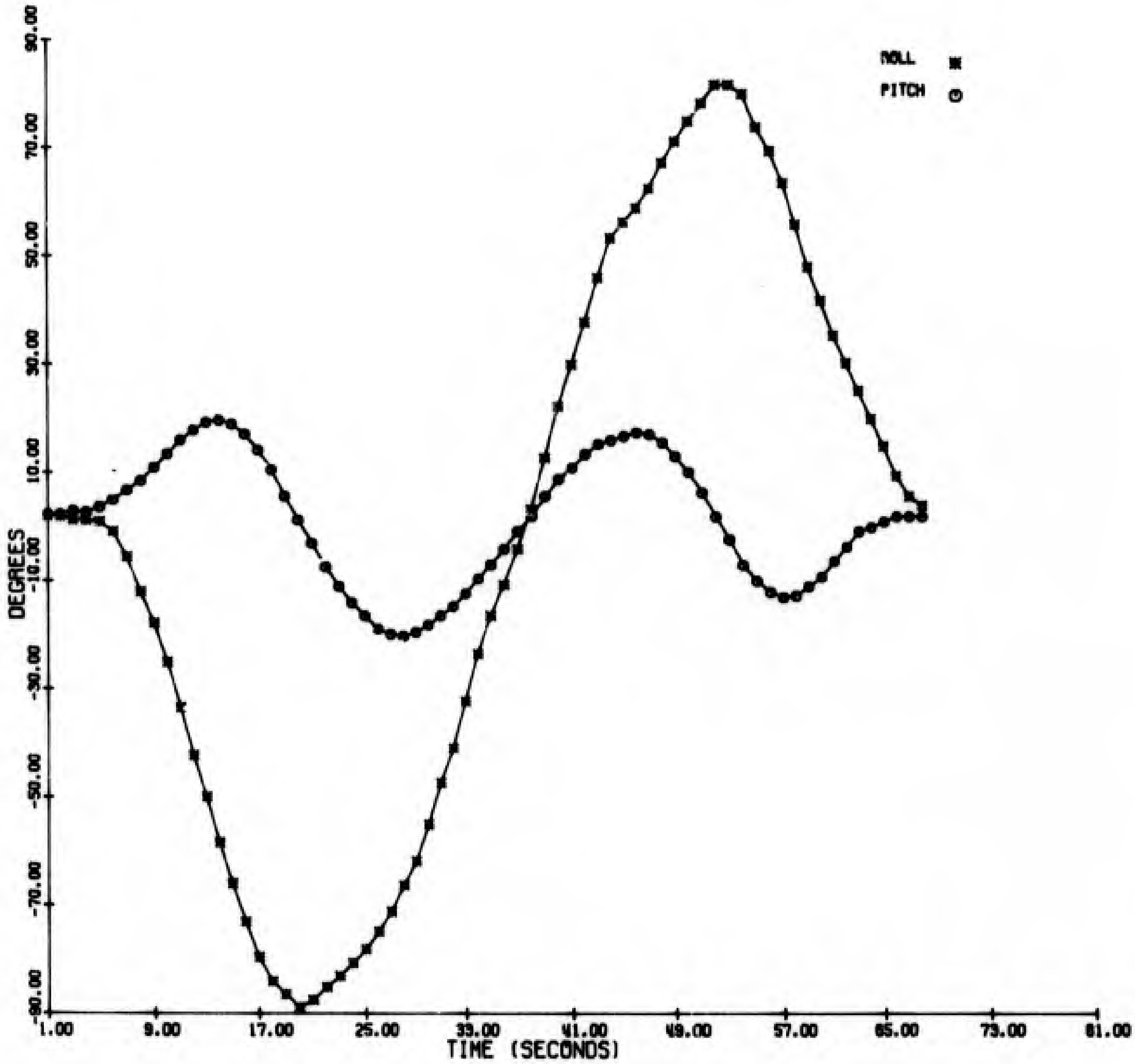
Plot 36

STICK POSITION PLOT FOR LAZY 8



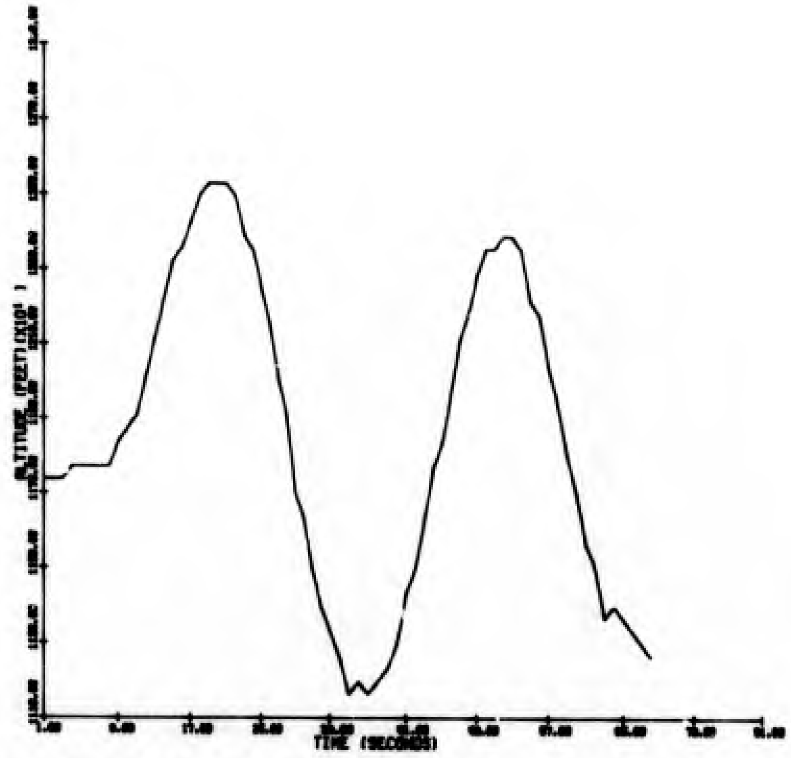
Plot 37

ROLL VS. PITCH FOR LAZY 8

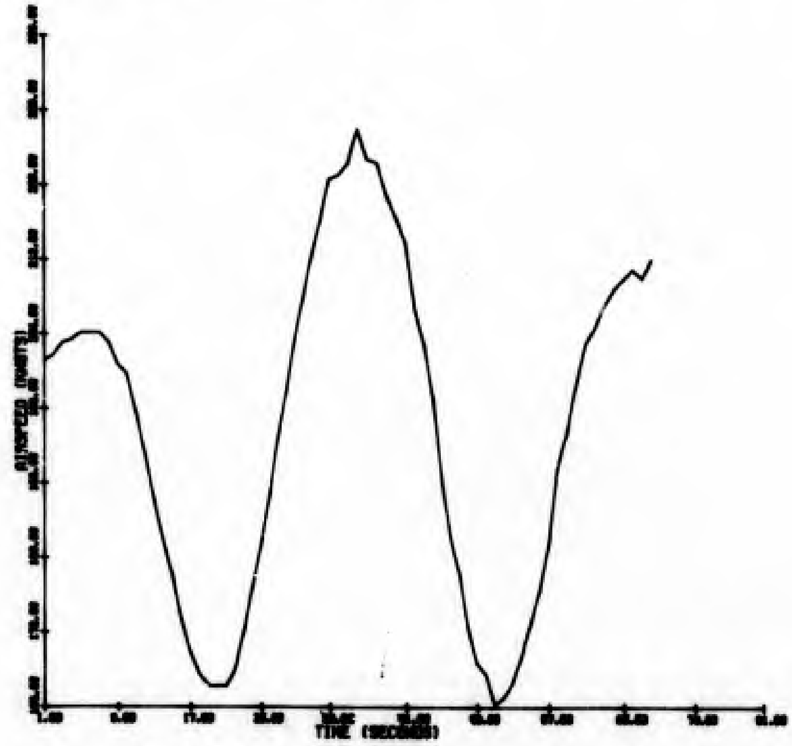


Plot 38

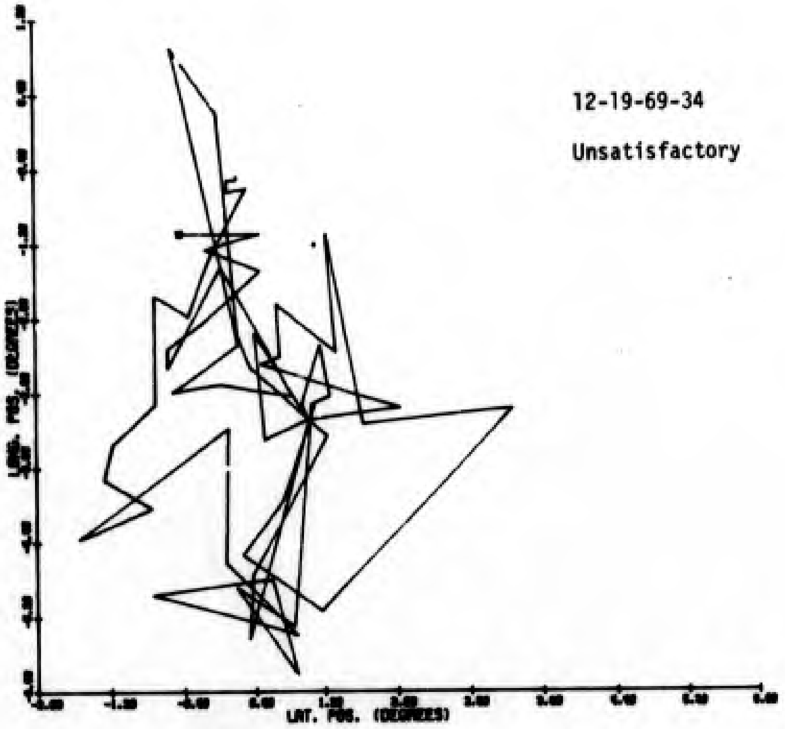
ROLL AND PITCH VS. TIME FOR LAZY 8



Plot 39



Plot 40

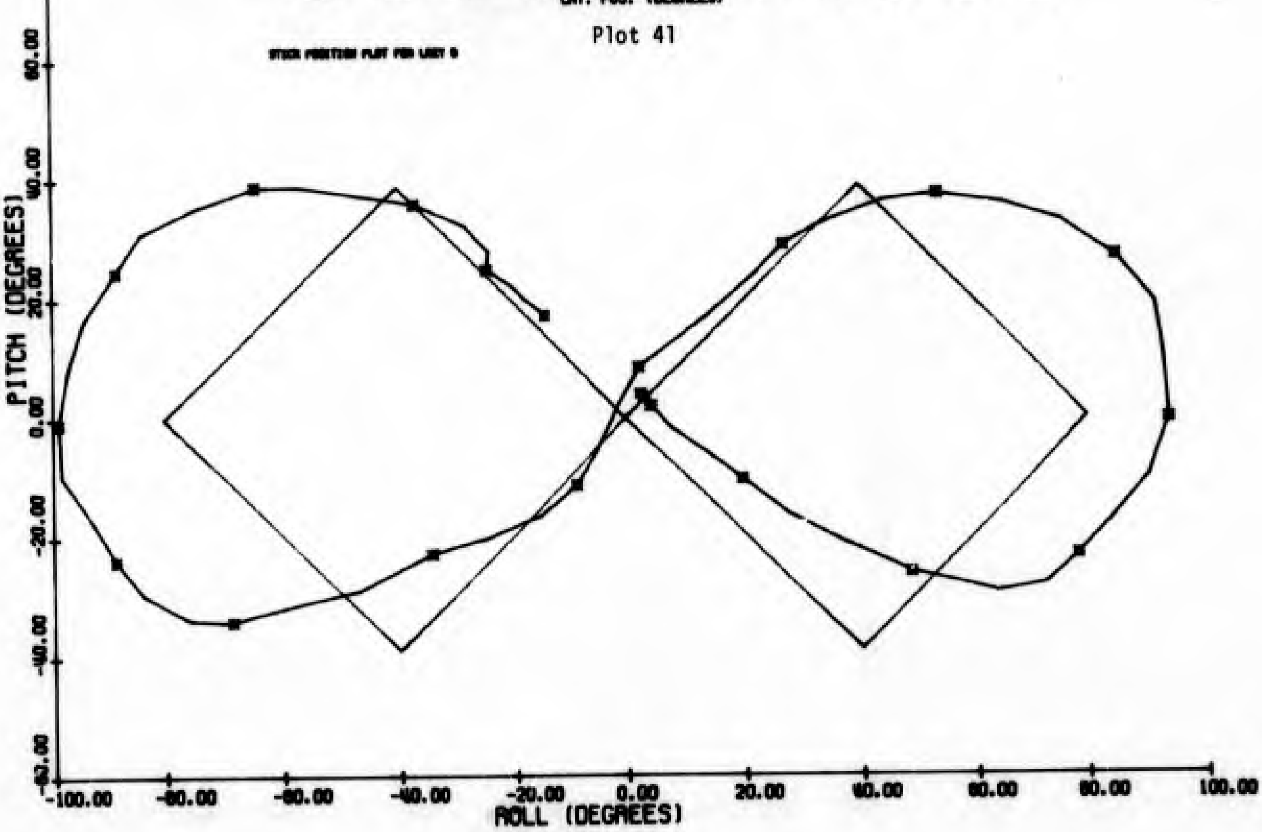


12-19-69-34

Unsatisfactory

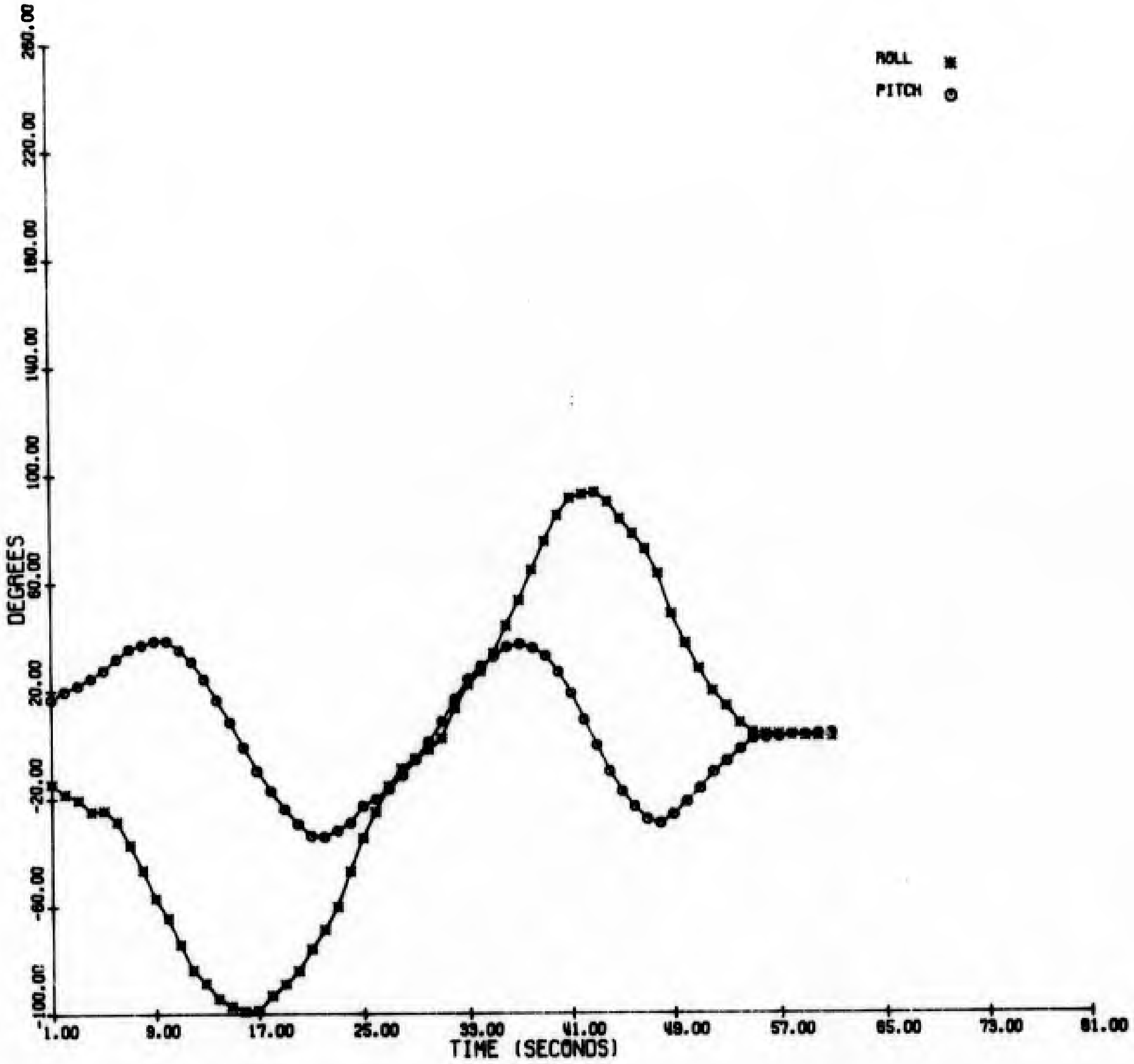
Plot 41

STICK POSITION PLOT FOR LAZY 8



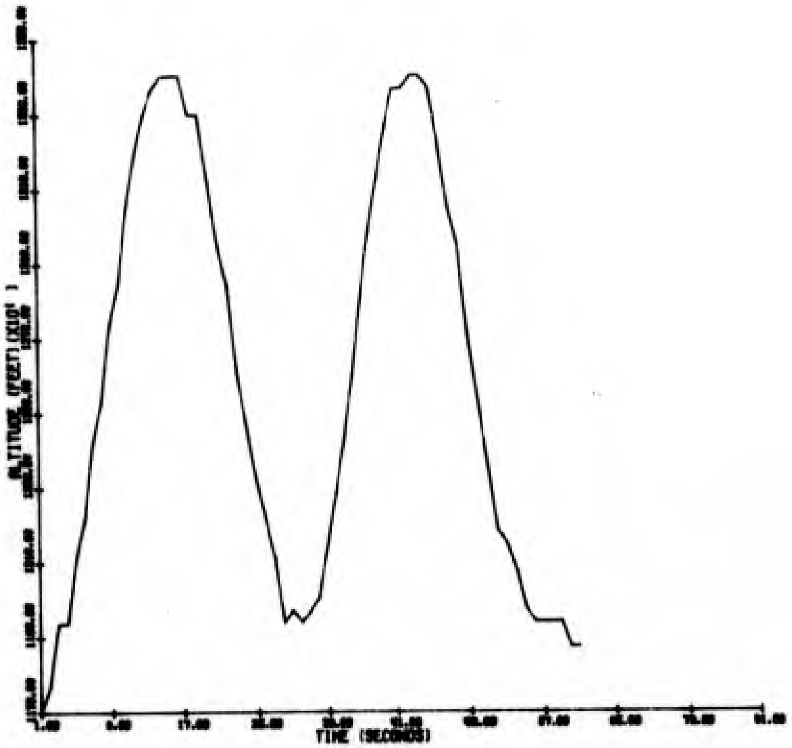
Plot 42

ROLL VS. PITCH FOR LAZY 8



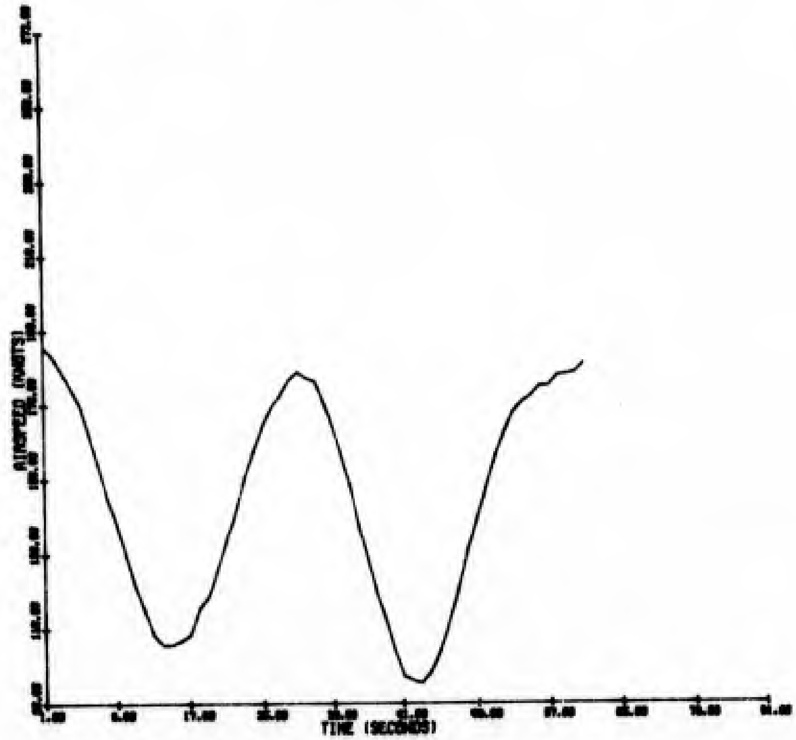
Plot 43

ROLL AND PITCH VS. TIME FOR LAZY 8



Plot 44

ALTITUDE VS. TIME FOR LAST 9

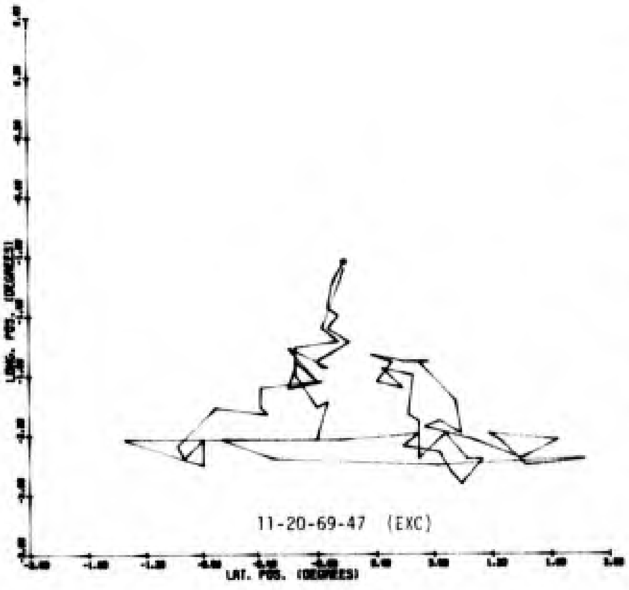


Plot 45

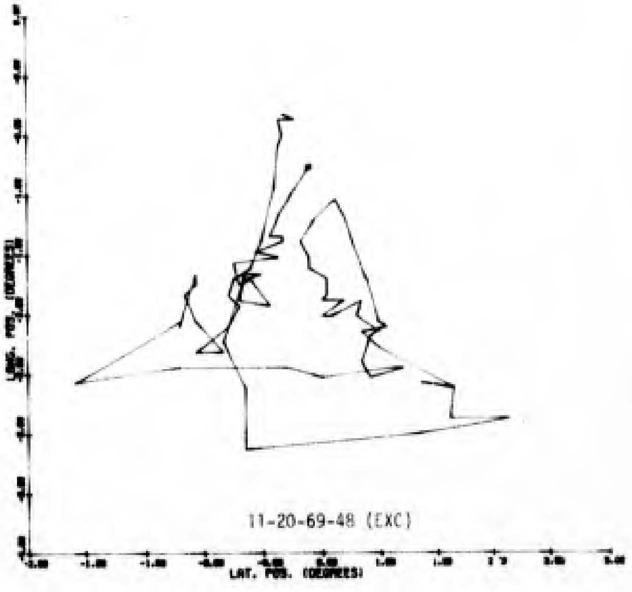
AIRSPEED VS. TIME FOR LAST 9

APPENDIX X

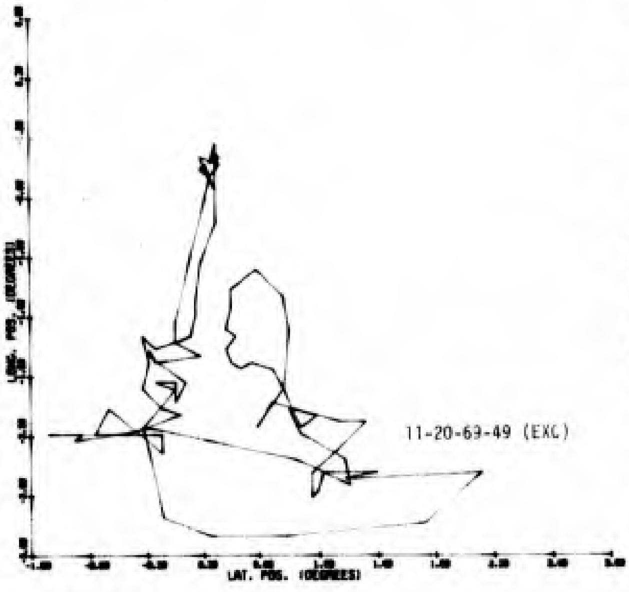
STICK POSITION PLOTS FOR REPRESENTATIVE LAZY 8 MANEUVERS



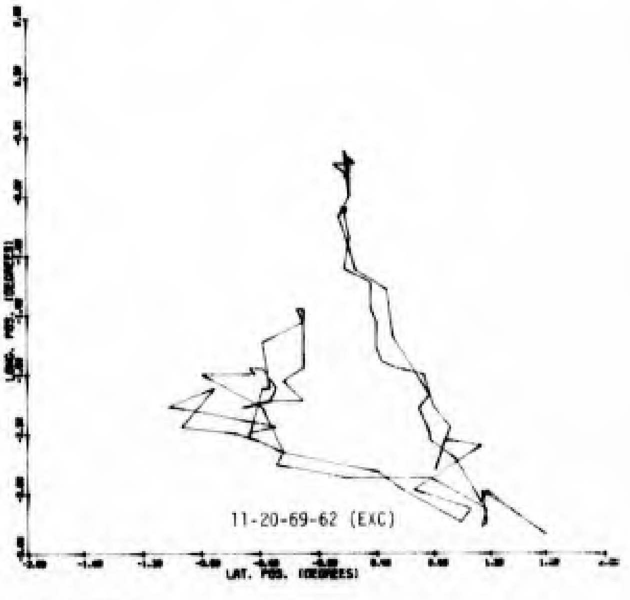
STICK POSITION PLOT FOR LAST 9



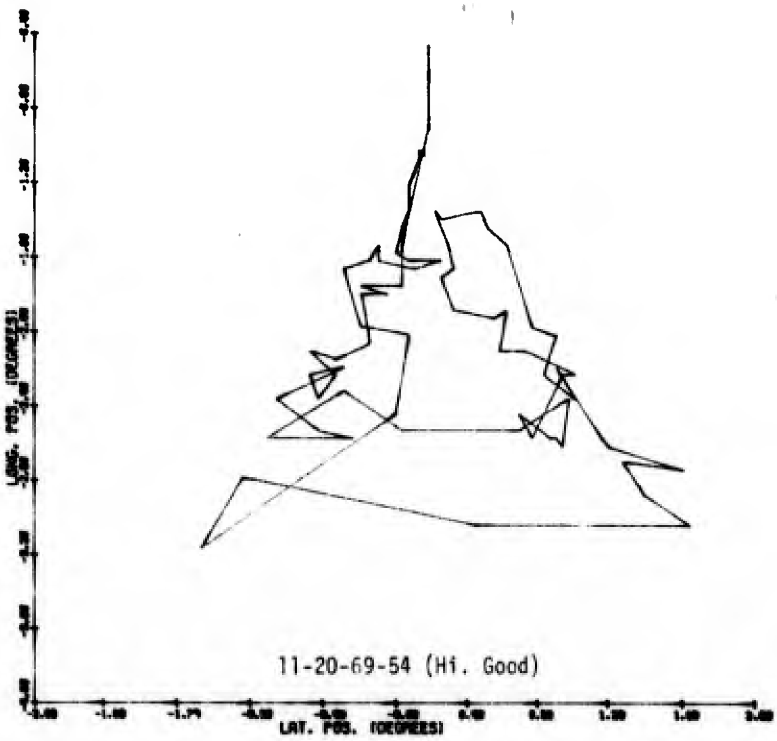
STICK POSITION PLOT FOR LAST 9



STICK POSITION PLOT FOR LAST 9

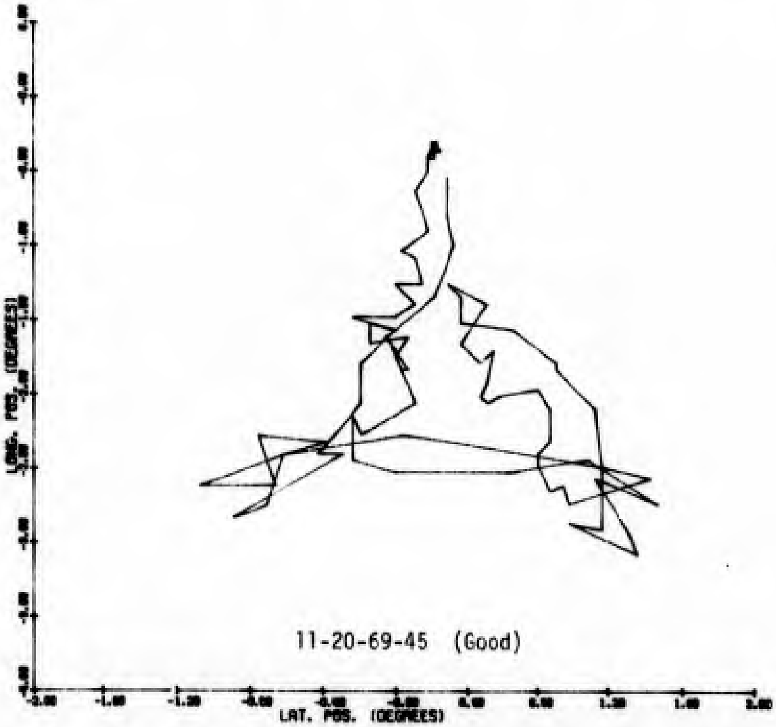


STICK POSITION PLOT FOR LAST 9



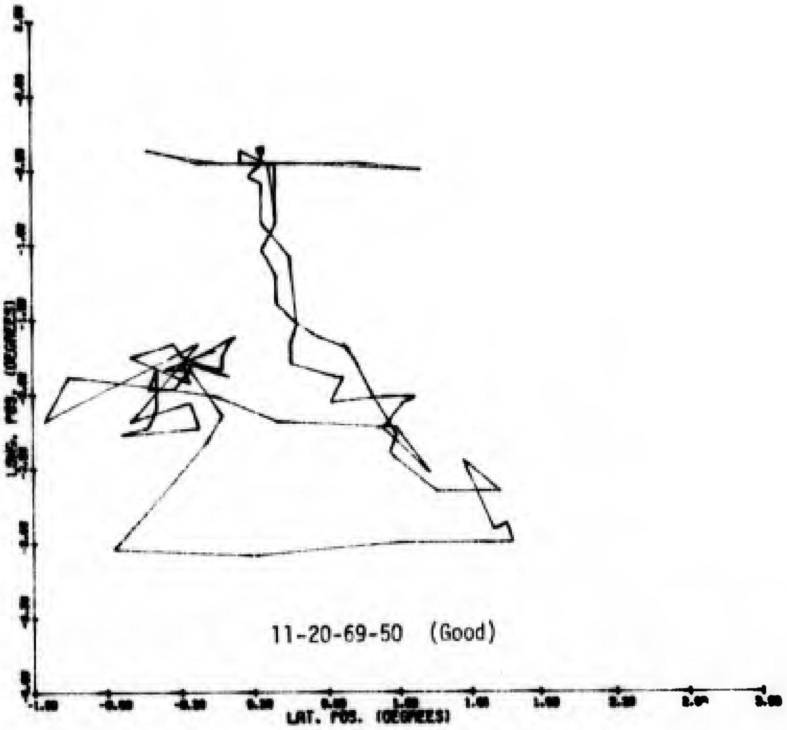
11-20-69-54 (Hi. Good)

STICK POSITION PLOT FOR LAZY 8



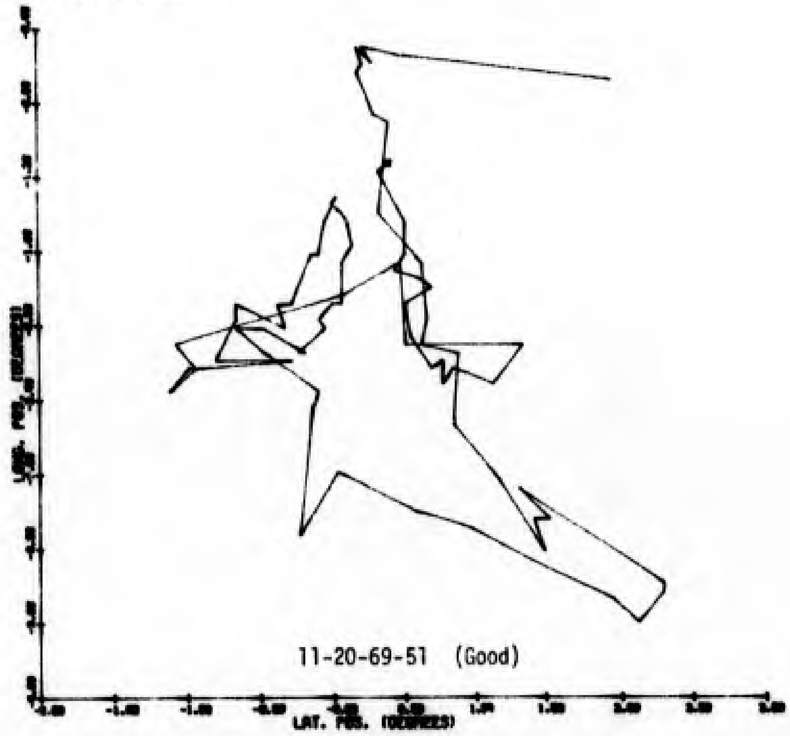
11-20-69-45 (Good)

STICK POSITION PLOT FOR LAZY 8



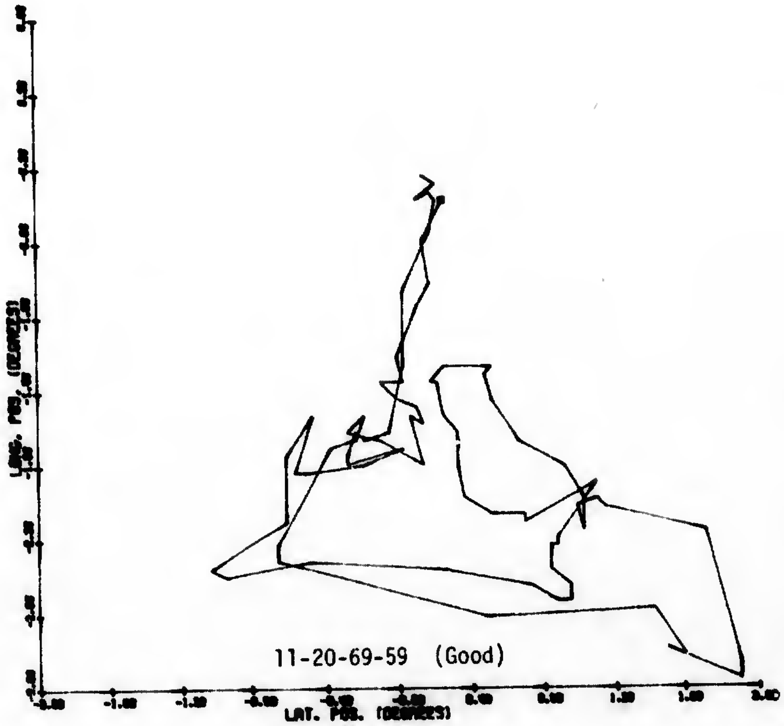
11-20-69-50 (Good)

STICK POSITION PLOT FOR LIST 0



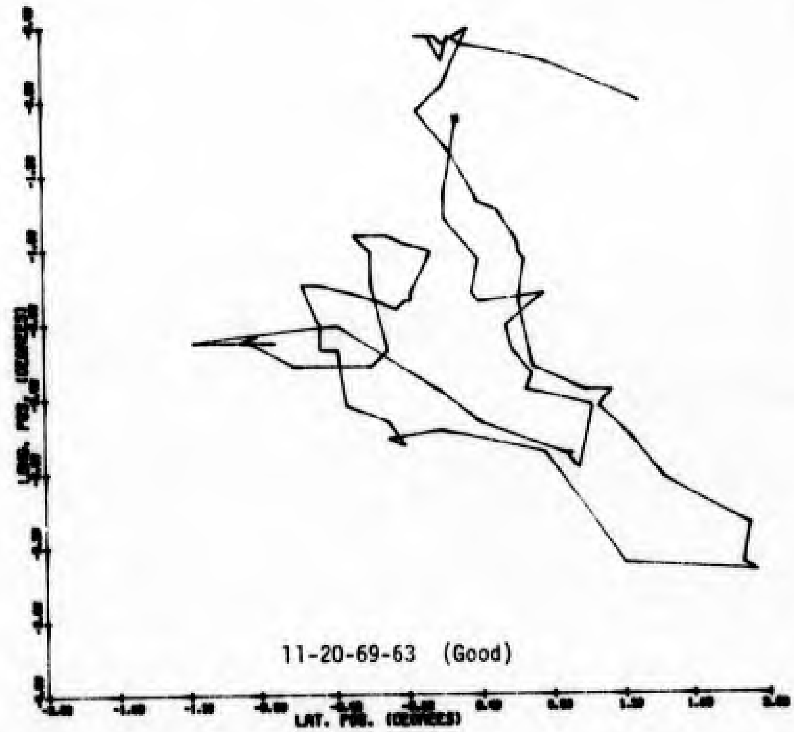
11-20-69-51 (Good)

STICK POSITION PLOT FOR LIST 0



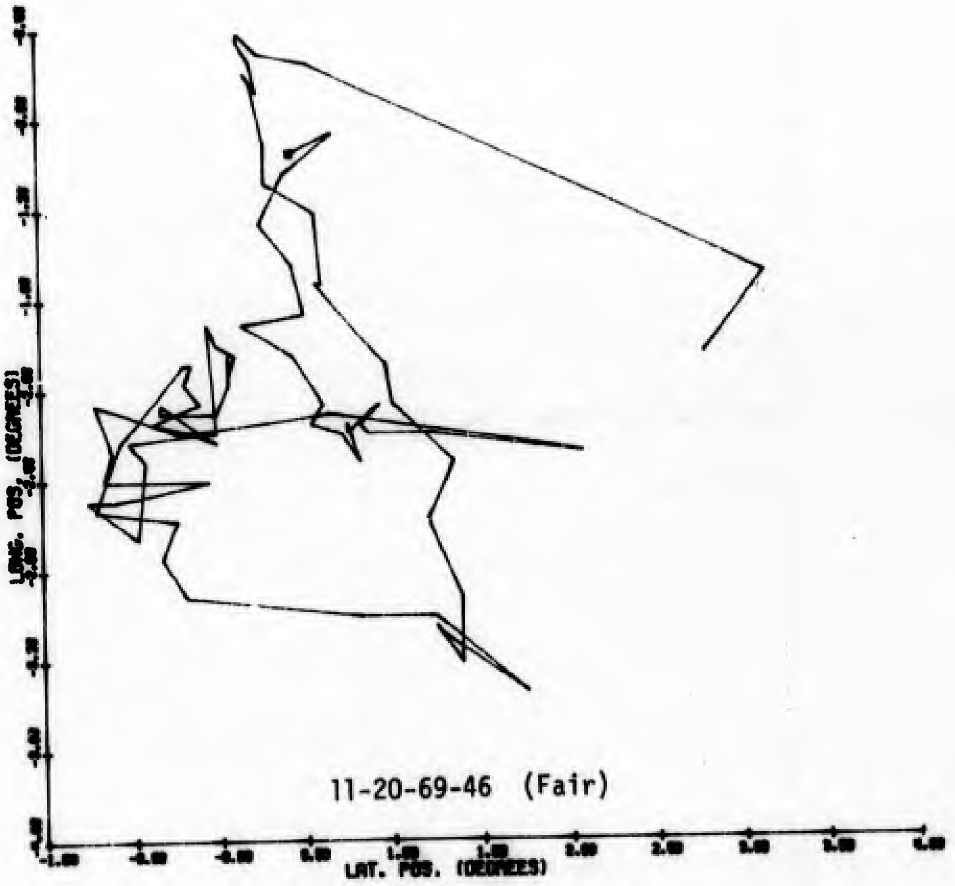
11-20-69-59 (Good)

STICK POSITION PLOT FOR LIST 9



11-20-69-63 (Good)

STICK POSITION PLOT FOR LIST 9

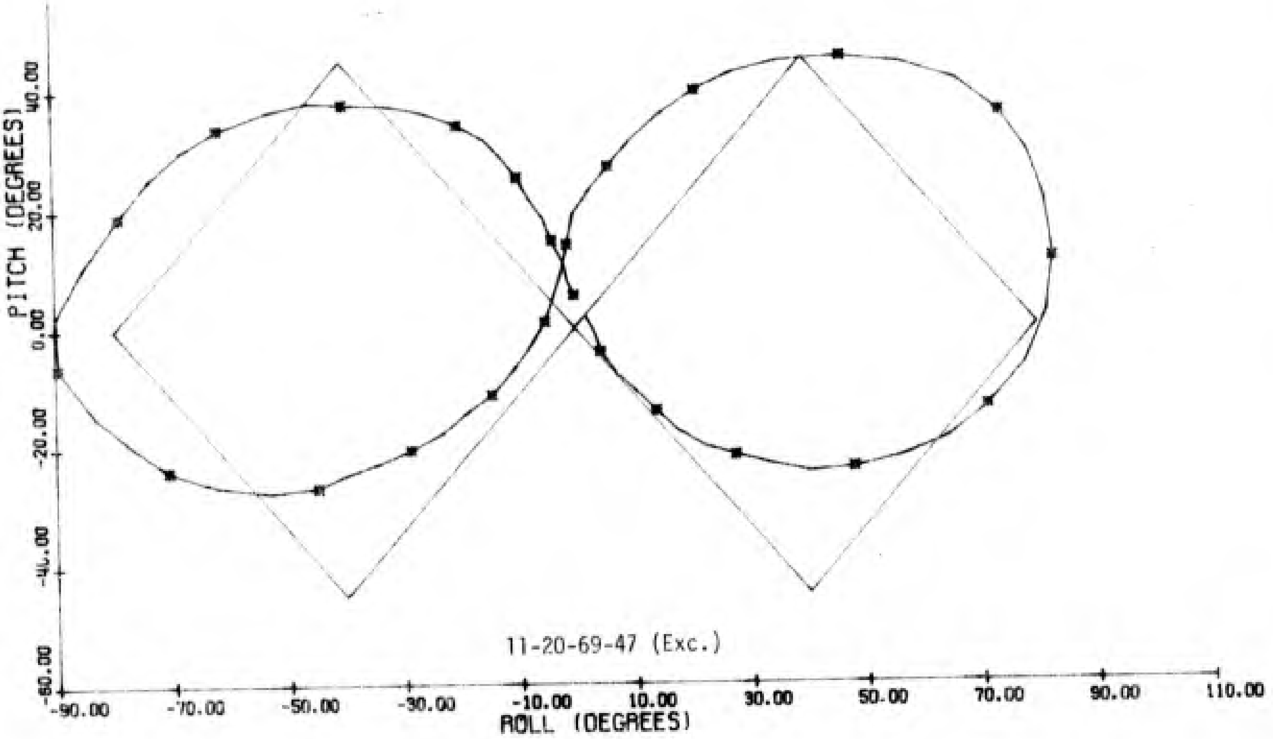


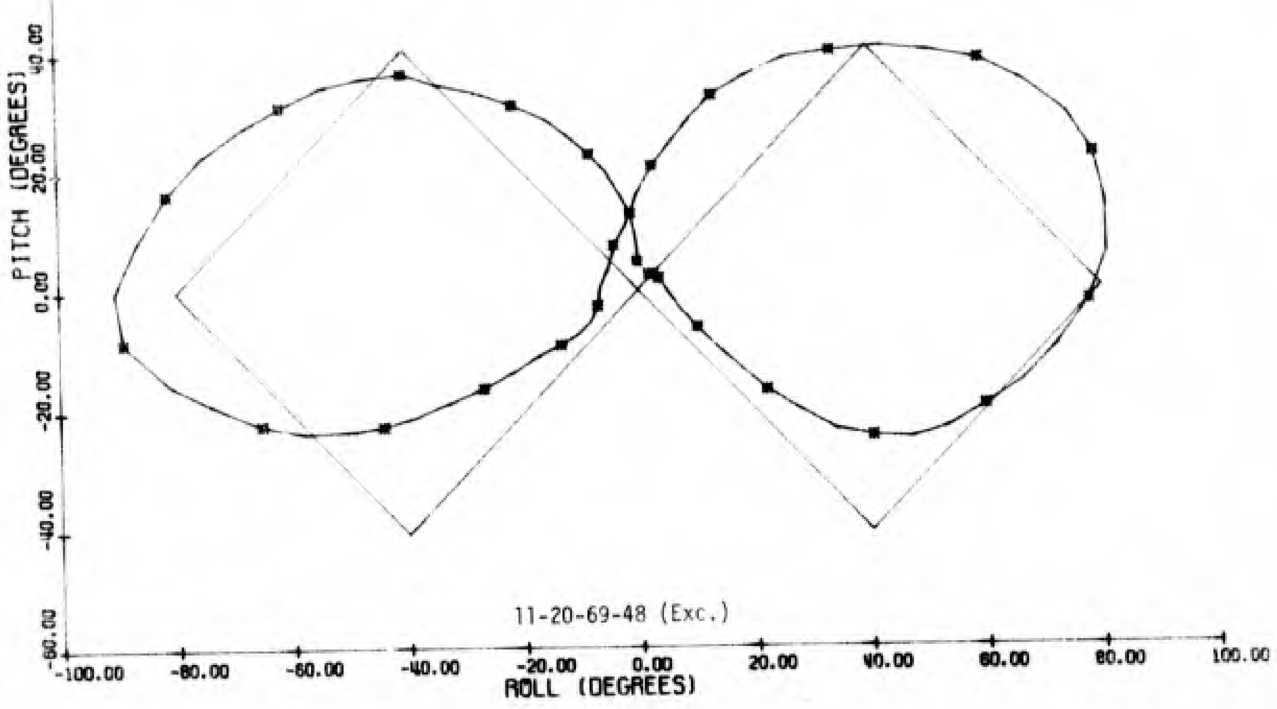
11-20-69-46 (Fair)

STICK POSITION PLOT FOR LACY 9

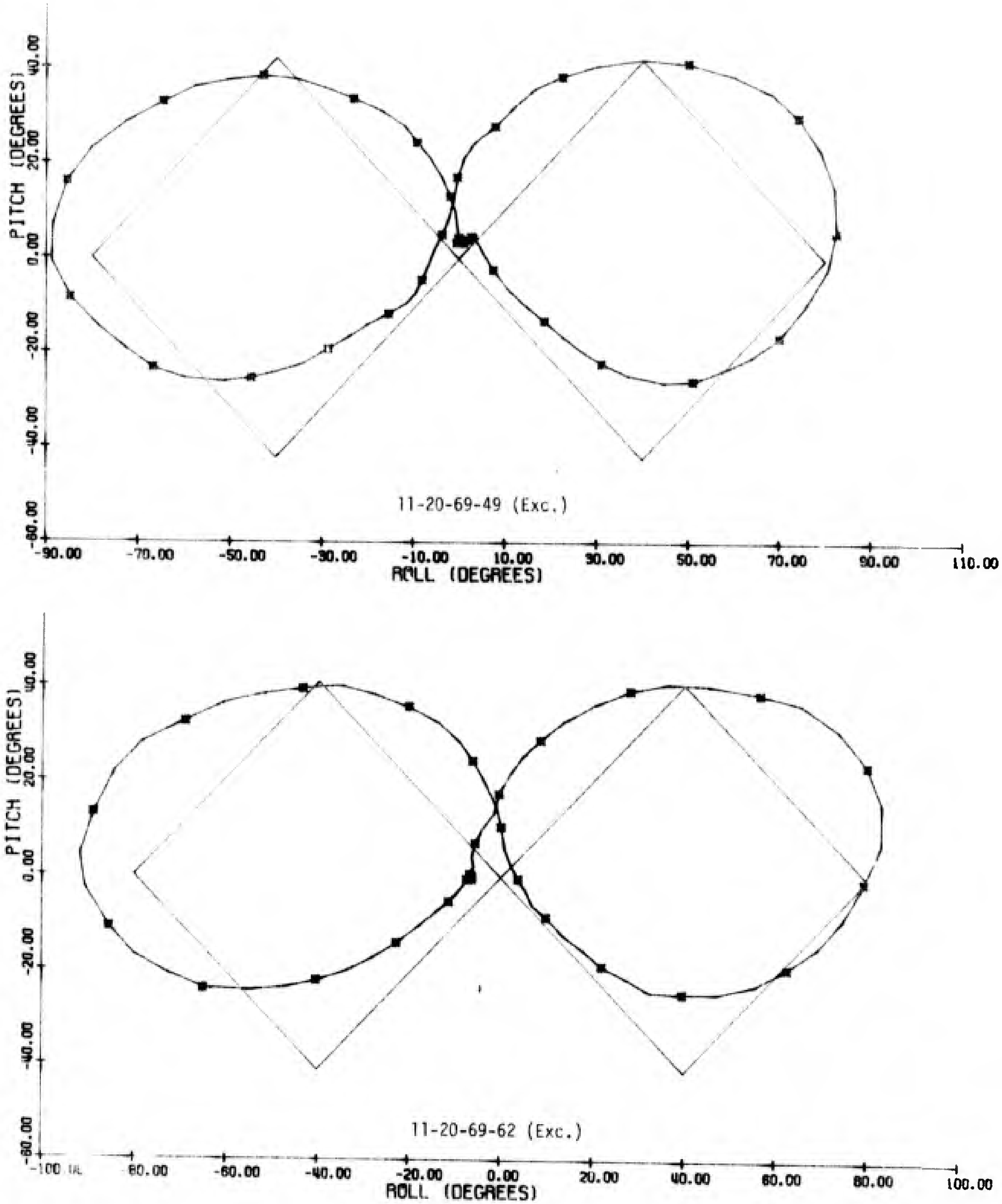
APPENDIX XI

ROLL VS PITCH PLOTS FOR REPRESENTATIVE LAZY 8 MANEUVERS

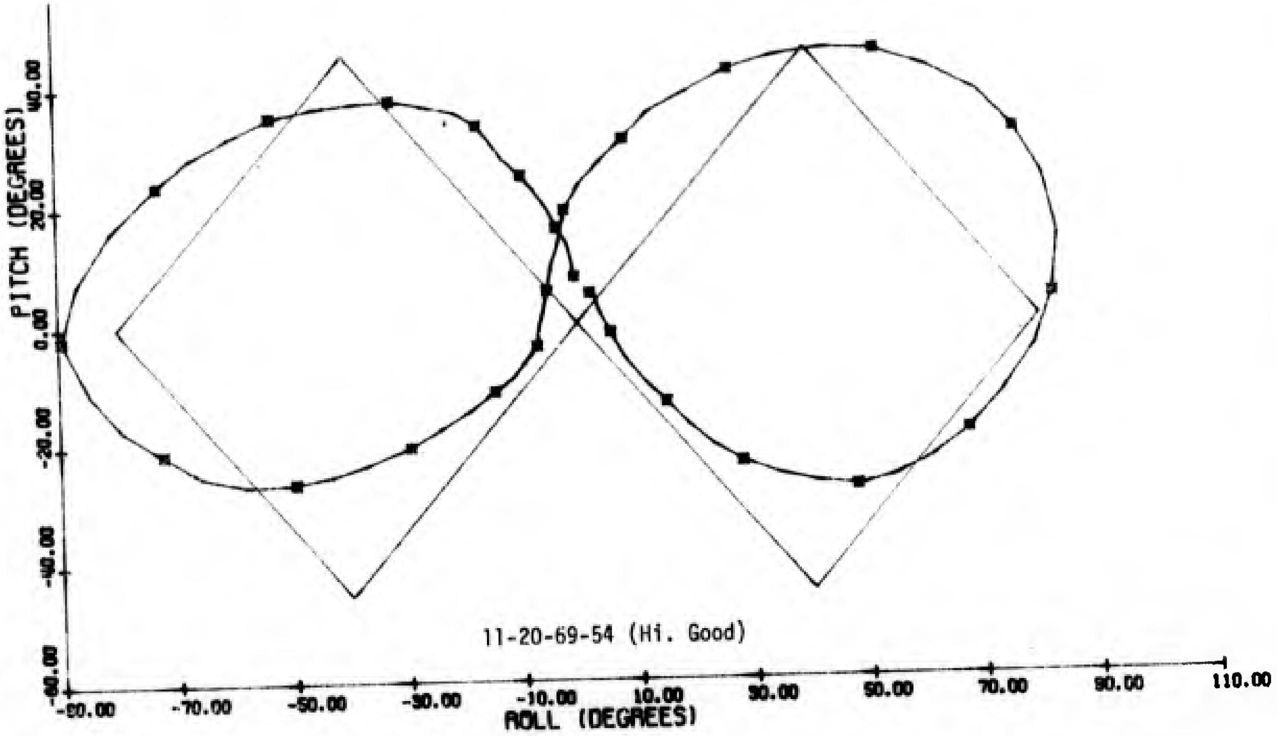

11-20-69-47 (Exc.)


11-20-69-48 (Exc.)

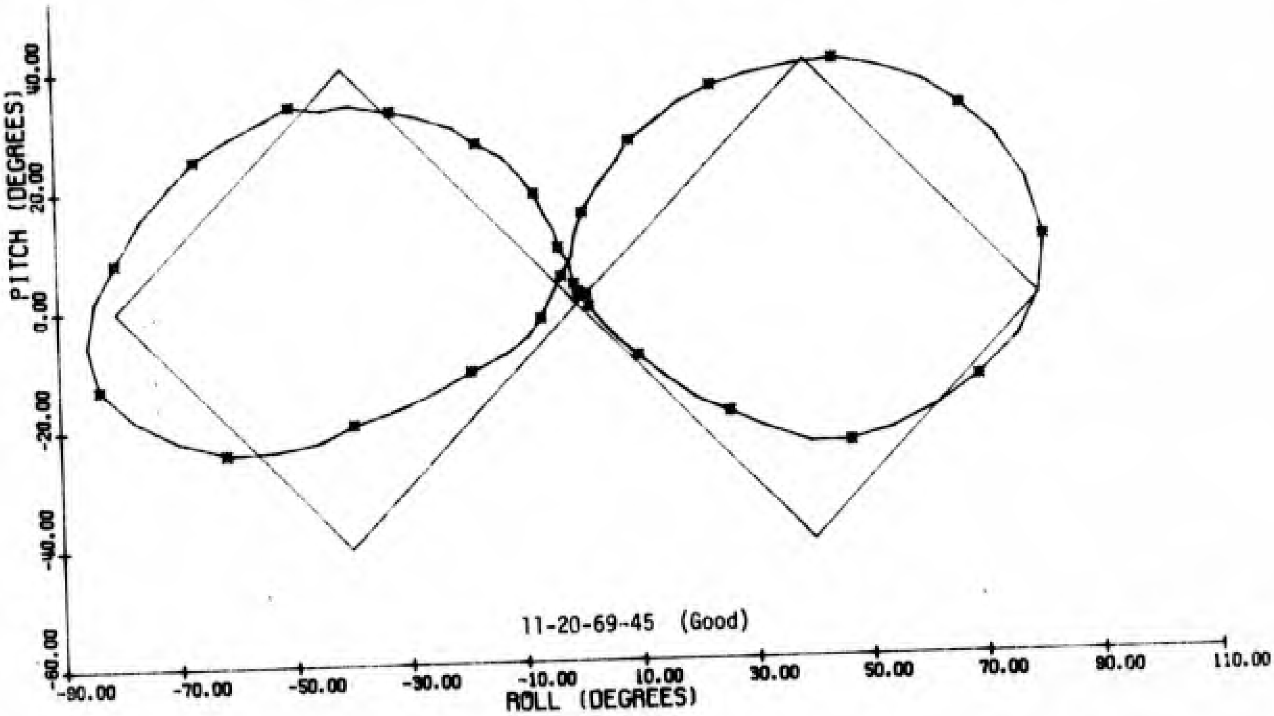
ROLL VS. PITCH FOR LAZY 8



ROLL VS. PITCH FOR LAZY 8

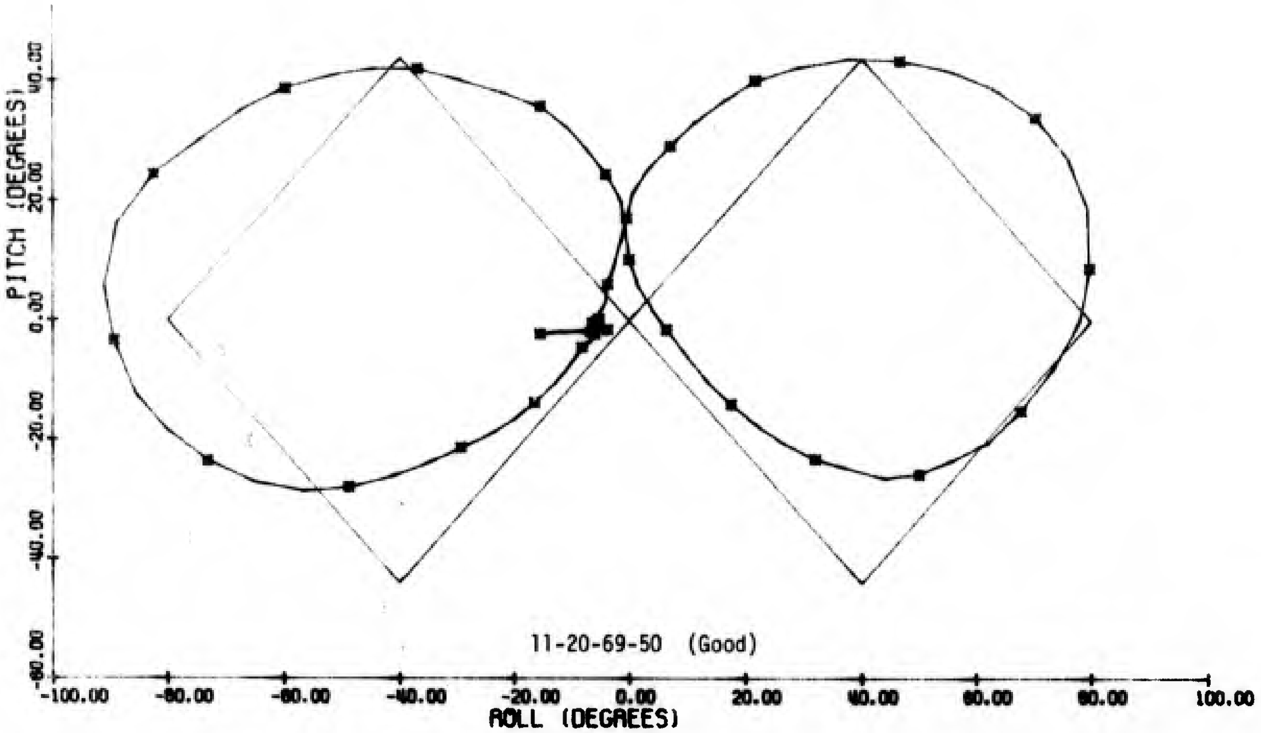


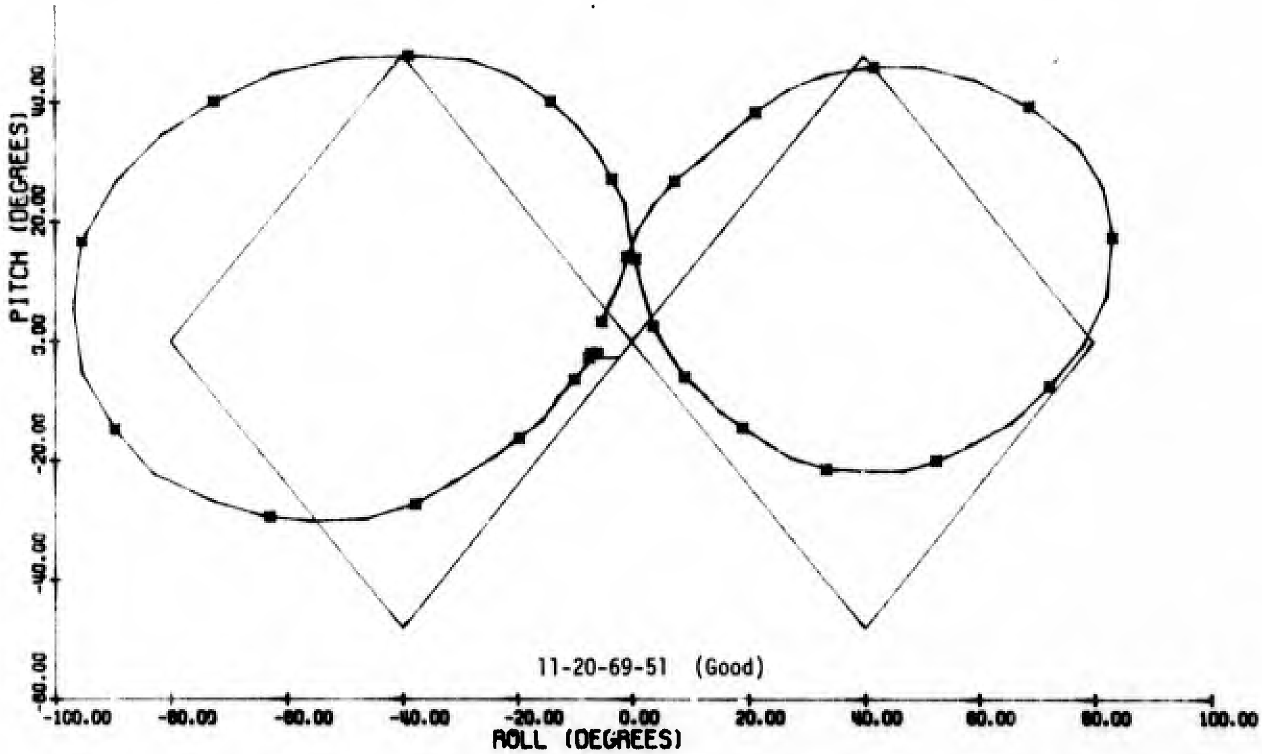
11-20-69-54 (Hi. Good)



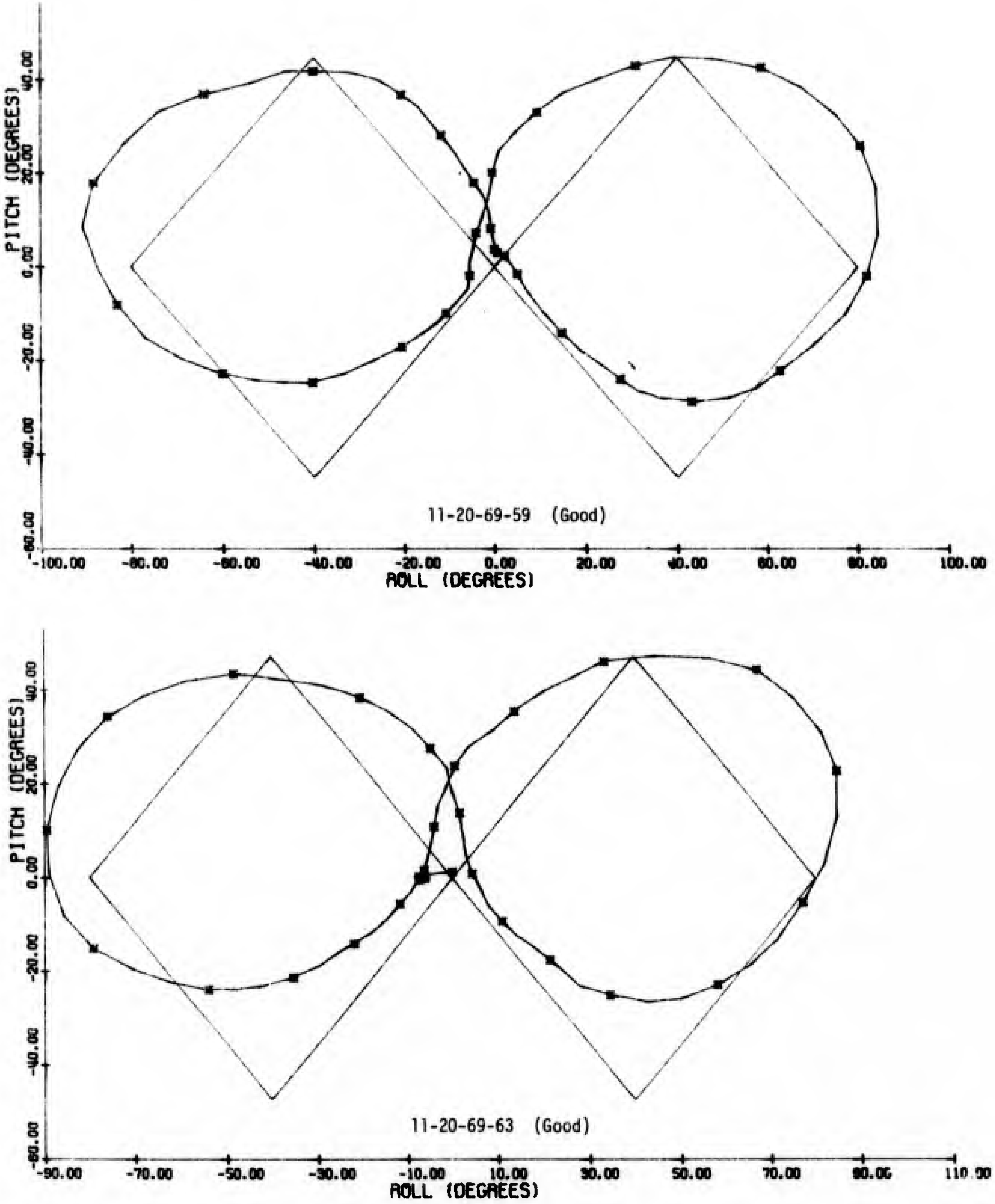
11-20-69-45 (Good)

ROLL VS. PITCH FOR LAZY 8

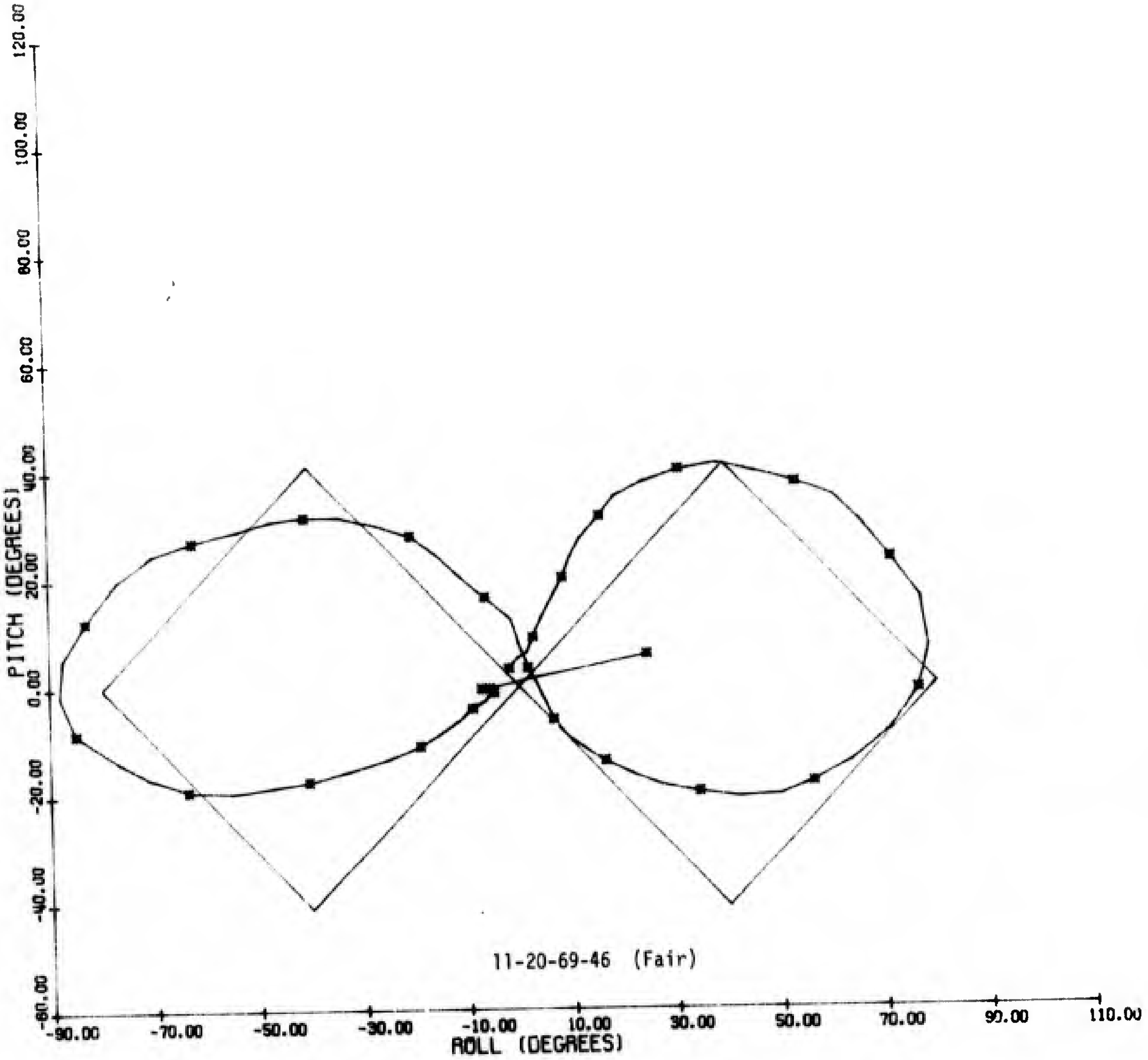




ROLL VS. PITCH FOR LAZY 8



ROLL VS. PITCH FOR LAZY 8



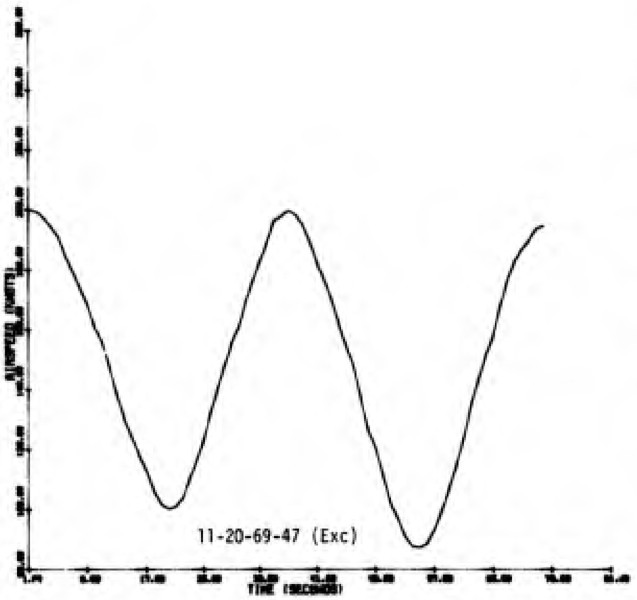
11-20-69-46 (Fair)

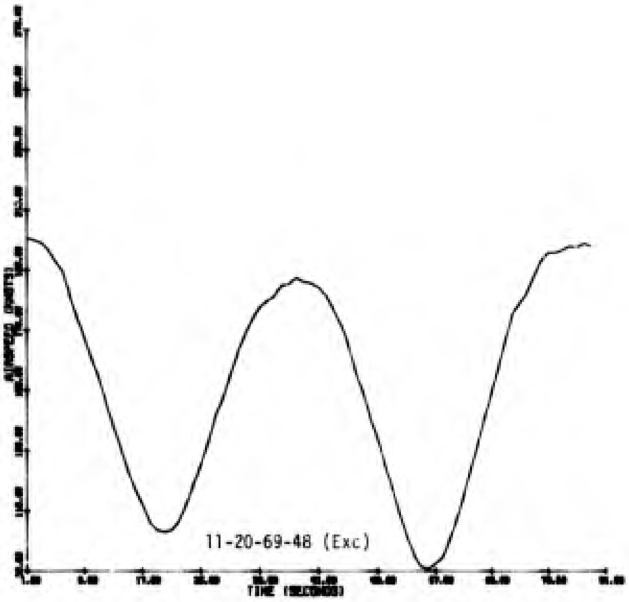
ROLL VS. PITCH FOR LAZY 8

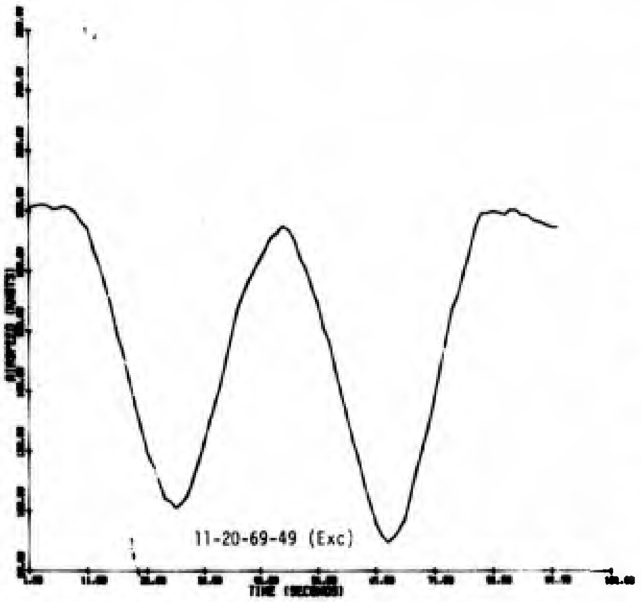
APPENDIX XII

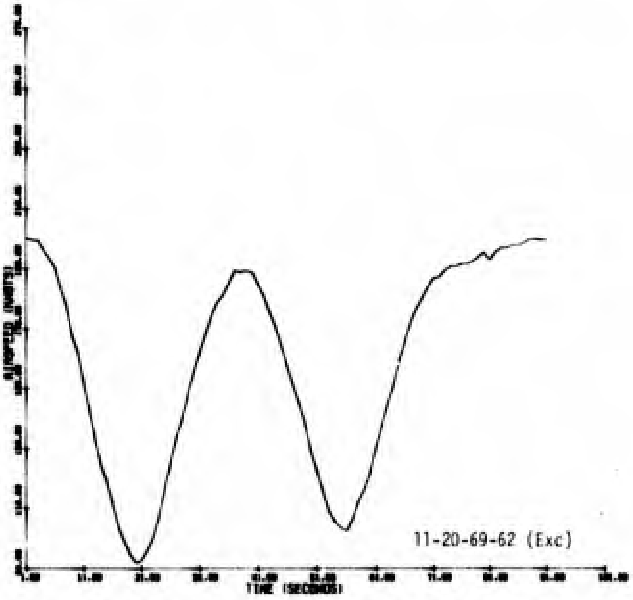
AIRSPEED PLOTS FOR REPRESENTATIVE LAZY 8 MANEUVERS

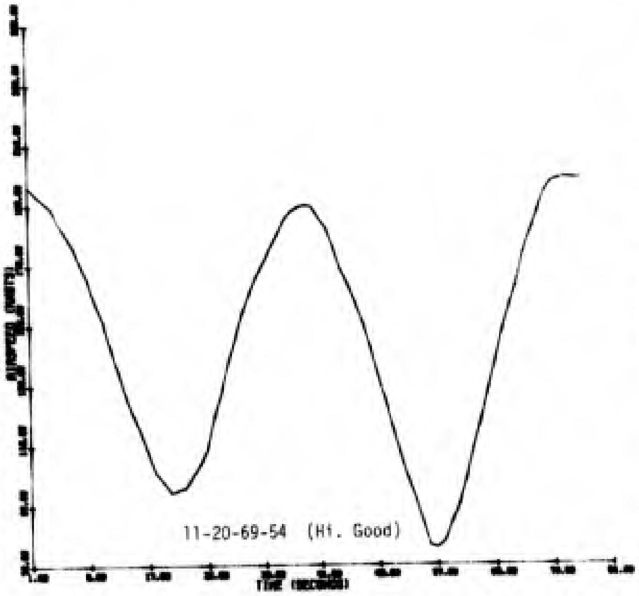
Preceding page blank

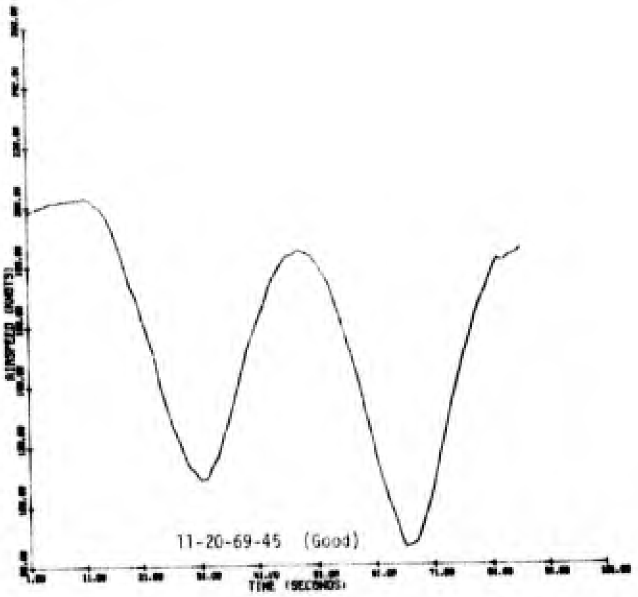

11-20-69-47 (Exc)

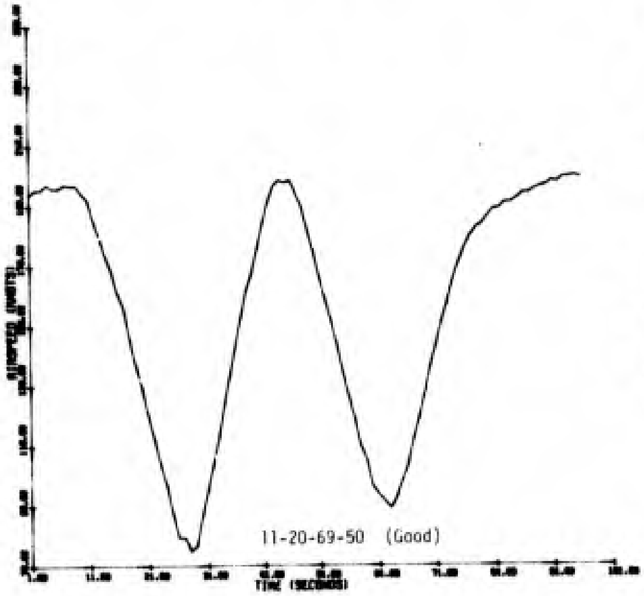

11-20-69-48 (Exc)

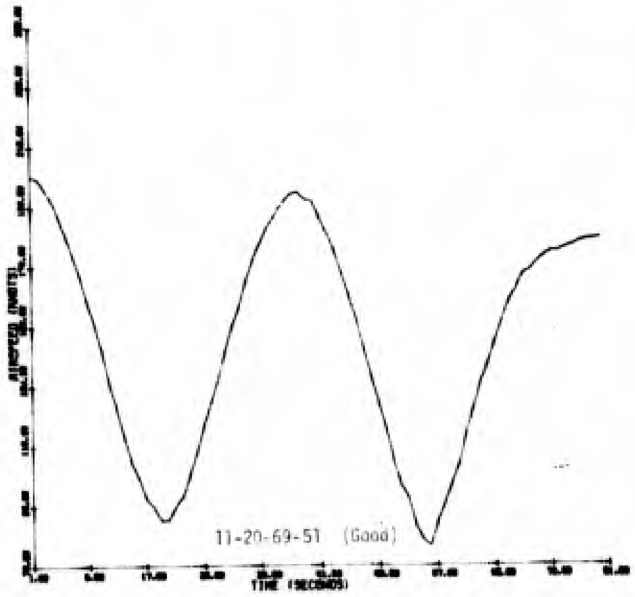

11-20-69-49 (Exc)

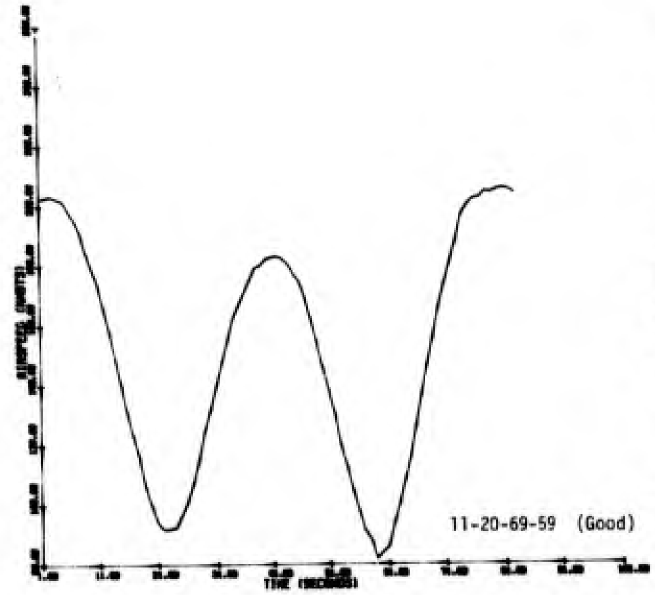

11-20-69-62 (Exc)


AIRSPEED (KNOTS)
TIME (SECONDS)
11-20-69-54 (Hi. Good)

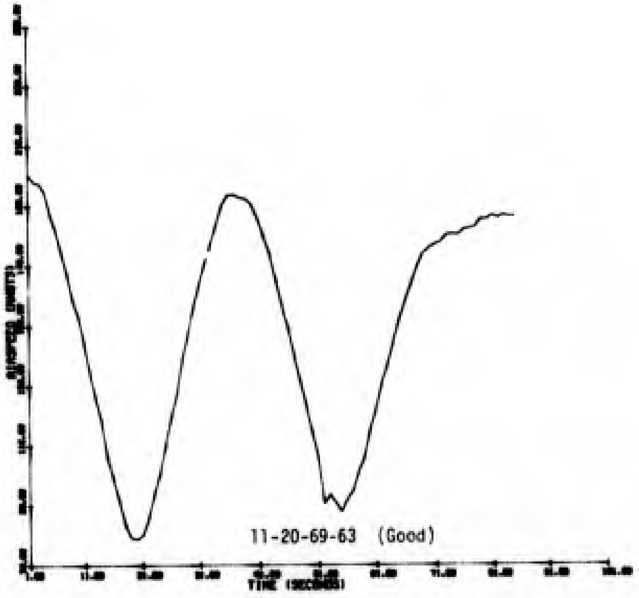

AIRSPEED (KNOTS)
TIME (SECONDS)
11-20-69-45 (Good)


AIRSPEED (KNOTS)
TIME (SECONDS)
11-20-69-50 (Good)

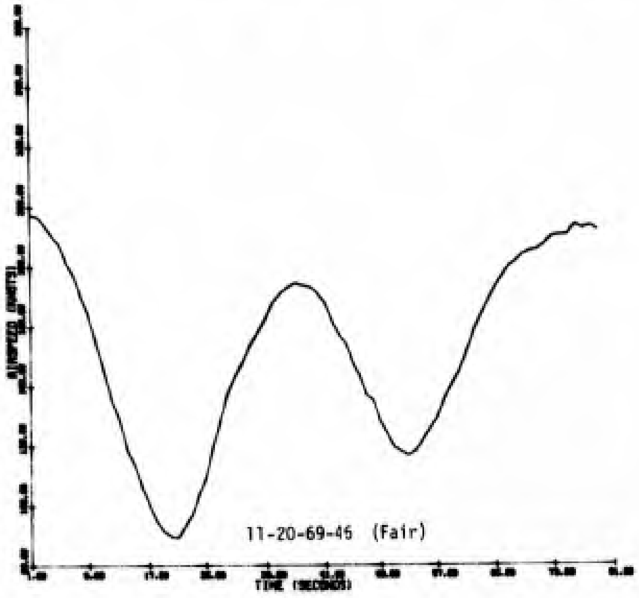

AIRSPEED (KNOTS)
TIME (SECONDS)
11-20-69-51 (Good)



11-20-69-59 (Good)



11-20-69-63 (Good)



11-20-69-46 (Fair)

APPENDIX XIII

PUNCH AND PRINT PROGRAM

PUNCH AND PRINT PROGRAM

This program prints at $\Delta t = 0.5$ and punches cards at

$$\Delta t = \begin{cases} 0.4, & \text{Barrel Roll and Others} \\ 0.5, & \text{Lazy 8} \end{cases}$$

Input CrDS:
(1) $ Setup Λ A(3) ΛΛΛΛ T37DXX, N0RING
(2) Month, Day, Year
(3) N
(4) KODE $= \begin{cases} + & \text{Lazy 8} \\ - & \\ \text{or} & \text{other maneuver} \\ 0 & \end{cases}$
(5) evno
(6) Duration

```
      KNCCP                                                                      07/15
           LAZYY8      -  EFN   SOURCE STATEMENT  -  IFN(S)  -

CPRINT MEASURE VARIABLES FOR LAZY 8 MANEUVER
      DIMENSION AR(10,1500)
      DIMENSION INM(25)
      DIMENSION A(120,9),B(12,25),EVNO(25)
      DIMENSION XCNT(25)
      ICOUNT=4
      IEV=1
      READ(5,5011)IMON,IDAY,IYR
 5011 FORMAT(3I5)
      READ (5,500) N
      READ(5,1501)(INM(I),I=1,N)
 1501 FORMAT(12I5)
      READ (5,501) (EVNO(I),I=1,N)
  601 READ (5,501) (XCNT(I),I=1,N)
 4030 CONTINUE
      ITEST=-10
    1 READ(16) ((A(I,J),I=1,120),J=1,9)
      READ(16) ((B(I,J),I=1,12),J=1,25)
      DO 20 I=1,12
      X=AMOD(B(I,18),100.0)
      IF(ITEST)9710,5,5
 9710 CONTINUE
      IF(EVNO(IEV)-X) 2,3,2
    3 IF(ITEST) 4,5,5
    4 WRITE(5,350)IMON,IDAY,IYR
      WRITE(6,300)EVNO(IEV)
      ICOUNT=4
 6751 WRITE(7,6760)IMON,IDAY,IYR,EVNO(IEV)
 6760 FORMAT(I5,I5,I5,F7.0)
 6750 CONTINUE
      XERPT=EVNO(IEV)
      L=0
      TIME=0.0
      ITEST=0
    5 IA=10*(I-1)+1
      L=L+1
 6004 CONTINUE
      IF(L-1)820,820,821
  821 IF(A(IA,6))822,826,826
  826 IF(A(IA,6)-350.)827,827,822
  827 IF(ABS(A(IA,2))-360.)9411,9411,822
 9411 IF(B(I,6))822,822,820
  822 DO 823 MOM=1,10
  823 AR(MOM,L)=AR(MOM,L-1)
      GO TO 824
  820 CONTINUE
      AR(1,L)=A(IA,2)
      AR(2,L)=A(IA,1)
      AR(3,L)=B(I,7)
 6005 AR(4,L)=B(I,6)
      AR(5,L)=A(IA,6)
      AR(6,L)=B(I,15)
      AR(7,L)=B(I,16)
      AR(8,L)=A(IA,3)
      AR(9,L)=A(IA,4)
```

```
      KNCCF                                                              07/.6.
           LAZYY8      -  EFN   SOURCE STATEMENT  -  IFN(S)  -
      AR(10,L)=B(I,9)
  824 CONTINUE
      ANL=3.14159265*AR(2,L)/180.0
      SXLR=SIN(ANL)
      CXLR=COS(ANL)
      ALTX=SXLR*AR(5,L)*6080.0/3600.0
      GS=CXLR*AR(5,L)
      TURN=ABS(AR(3,L)-AR(3,1))
      IF(ICOUNT-4) 201,200,201
  200 WRITE(6,301)TIME,AR(1,L),AR(2,L),AR(3,L),AR(4,L),AR(5,L),AR(6,L),
     1AR(7,L),AR(8,L),AR(9,L),TURN,GS,ALTX,AR(10,L)
      TIME=TIME+0.5
      ICOUNT=0
      GO TO 600
  201 ICOUNT=ICOUNT+1
      GO TO 600
    2 IF(ITEST) 20,7,7
    7 WRITE (6,7311)
 7311 FORMAT(2H X/)
      GO TO 20
 7729 CONTINUE
 6753 LYZX=L/5
      IF(INM(IEV))1520,1520,1522
 1520 NDEL=4
      LYZX=(L-1)/4+1
      WRITE(7,500)LYZX
      WRITE(7,1524) (AR(1,JC),AR(2,JC),AR(3,JC),AR(4,JC),AR(5,JC),
     1AR(10,JC),JC=1,L,NDEL)
      GO TO 700
 1524 FORMAT(F5.0,F4.0,F5.0,F7.0,F5.0,F5.1,F5.0,F4.0,F5.0,F7.0,F5.0,
     1F5.1)
 1522 NDEL=5
      LYZX=(L-1)/5+1
      WRITE(7,500)LYZX
      WRITE(7,6754)((AR(IR,JC),IR=1,5),JC=1,L,NDEL)
 6754 FORMAT(F5.0,F4.0,F5.0,F7.0,F5.0,F5.0,F4.0,F5.0,F7.0,F5.0,F5.0,
     1F4.0,F5.0,F7.0,F5.0)
 6752 CONTINUE
  700 CONTINUE
      IF(IEV-N)9,8,8
    9 IEV=IEV+1
      ITEST=-10
      L=0
  600 XXX=XCNT(IEV)
      ALL=L
      IF(ALL-XXX)20,7729,7729
   20 CONTINUE
      GO TO 1
    8 CONTINUE
  500 FORMAT(I5)
  501 FORMAT(12F5.0)
  300 FORMAT(1H0,16HLAZY 8 NUMBER   F5.0/1H /1H /56X,4HLEFT,3X,5HRIGHT,
     14X,5HLONG.,6X,4HLAT.,2X/5H TIME,4X,4HROLL,3X,5HPITCH,2X,
     27HHEADING,5X,8HALTITUDE,2X,8HAIRSPEED,3X,3HRPM,4X,3HRPM,4X,
     38HST. POS.,3X,8HST. POS.,3X,4HTURN,3X,2HGS,5X,4HALTX,5X,4HACEL/
     41H /)
```

```
     KNCCP
         LAZYY8      -   EFN   SOURCE STATEMENT  -  IFN(S)  -                07/16/

301 FCRMAT(F6.1,2X,F5.0,3X,F5.0,4X,F5.0,6X,F7.C,5X,F5.C,2X,F5.0,2X,
   1F5.0,6X,F5.1,6X,F5.1,2X,F5.0,1X,F6.0,1X,F5.0,2X,F6.2)
350 FORMAT(1H1,20X,29HDATA PRINTOUT FOR FLIGHT OF  I3,1H-I3,1H-I3/
   11H /)
    STOP
    END
```

APPENDIX XIV

SAMPLE OUTPUT OF LAZY 8
EXPERIMENTAL MEASUREMENT PROGRAM

Preceding page blank

RECORDED VALUES[1]
EVENT 47 (11-20-69)

TIME	ROLL	PITCH	HEADING	ALTITUDE	AIRSPEED
0	0	5	360	9586	200
5	-8	22	359	9940	185
10	-26	36	358	10713	156
15	-61	34	340	11536	118
20	-90	2	308	11772	101
25	-62	-26	251	11468	132
30	-29	-21	215	10677	169
35	- 7	- 3	201	10218	197
40	0	19	201	10324	182
45	21	40	218	11030	148
50	67	41	255	11806	103
55	82	2	304	12148	88
60	48	-24	344	11772	124
65	18	-17	358	10996	167
70	3	- 1	360	10465	193

---

[1] Recorded values shown here at 5 second intervals; actual print-outs showed values at 0.5 second intervals.

FLIGHT OF 11-20-69, EVNO 47

PITCH	ROLL	ARSP	ALTX
-5.00	-0.	200.00	0.
12.67	-2.80	197.05	177.89
25.33	-10.23	179.60	596.00
38.00	-42.80	134.80	1517.40
25.33	-73.74	106.14	2079.19
12.67	-83.75	100.42	2175.80
0.	-90.68	101.70	2186.00
-9.00	-88.54	105.52	2206.45
-18.00	-79.46	115.07	2158.34
-27.00	-51.00	141.75	1646.00
-18.00	-23.00	176.00	914.01
-9.00	-13.00	192.00	667.00
0.	-5.50	197.86	596.00
15.00	-0.57	187.76	646.37
30.00	9.00	162.99	1049.37
45.00	46.67	120.67	1983.33
30.00	78.37	92.63	2392.76
15.00	83.00	87.00	2557.92
0.	81.08	88.79	2557.91
-8.33	76.81	94.20	2515.37
-16.67	66.97	103.10	2469.79
-25.00	40.00	135.00	2051.00
-16.67	17.28	169.44	1387.86
-8.33	8.37	186.00	1099.56
2.00	2.00	195.00	879.00

```
     FLIGHT OF 11/20/69
     ENVO 47  (4,LEFT )
   AIRSPEED CCMPUTATIONS
NO.  ERROR
 1      0.      SUM(1-5) =  18.00
 2      0.
 3      0.      SUM(1-3) =    0.
 4   -13.00
 5    -5.00     SUM(3-5) =  18.00

    EXCURSION  TIME    RATE
 1    100.000  19.0      5.3
 2    100.000  17.0      5.9
 3    113.000  17.5      6.5
 4    108.000  18.0      6.0
```

RESULTS OF ANALYSIS: STANDARD DEVIATION AND MEAN FOR ALL GROUPS

	GROUP 1 EXC.		GROUP 2 GOOD		GROUP 3 FAIR		GROUP 4 UNSAT.		GROUP 5 RIGHT-EXC.	
ITEM	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.
MAX(1) PITCH	40.11	3.69	38.11	6.88	36.40	7.79	43.10	12.30	40.33	4.73
MIN(1) PITCH	-27.78	3.96	-25.28	5.81	-30.10	7.54	-36.30	9.17	-25.33	3.51
MAX(2) PITCH	40.89	2.89	40.22	5.06	40.10	7.23	43.60	14.67	39.33	2.08
MIN(2) PITCH	-26.00	2.35	-25.89	3.66	-30.00	7.[illegible]2	-37.00	14.22	-27.00	4.36
ROLL (MAX 1)	46.08	5.45	44.90	5.93	45.90	9.22	53.90	[illegible].26	46.06	5.85
ROLL (MIN 1)	50.66	5.30	50.89	7.04	[illegible]	[illegible]9	63.60	9.74	44.61	2.33
ROLL (MAX 2)	45.39	5.39	44.65	4.63	51.[illegible]	5.[illegible]5	63.08	5.[illegible]9	46.17	9.52
ROLL (MIN 2)	48.49	6.88	50.11	5.27	52.[illegible]7	5.[illegible]4	60.27	10.90	56.23	5.05
ARSP (MAX 1)	130.28	6.56	134.02	14.04	[illegible].54	15.[illegible]4	133.34	24.56	123.83	5.01
ARSP (MIN 1)	134.61	5.91	137.81	9.99	137.04	10.[illegible]	13[illegible].26	34.04	130.36	8.52
ARSP (MAX 2)	127.03	7.79	127.56	8.82	120.00	10.[illegible]0	123.57	27.36	134.42	8.50
ARSP (MIN 2)	132.22	4.48	133.79	8.84	130.45	8.[illegible]4	122.57	27.20	129.34	4.33
ALT (MAX 1)	1342.23	129.4	1272.97	272.03	[illegible]3.27	364.79	1259.17	479.83	1352.22	72.64
ALT (MIN 1)	1520.61	74.77	1464.10	238.34	1427.36	438.00	1349.28	623.36	1538.31	62.14
ALT (MAX 2)	1621.46	170.5	1629.91	280.36	1501.00	229.05	1309.82	629.18	1527.17	100.36
ALT (MIN 2)	1780.61	159.4	1754.33	268.91	1382.4[illegible]	169.52	1462.37	644.83	1828.4	99.94
MAX + ROLL	82.62	2.73	81.91	4.83	85.30	5.[illegible]4	101.40	12.73	84.46	4.15
MAX - ROLL	91.11	4.62	88.71	6.37	-92.40	3.[illegible]7	-108.90	12.54	-89.92	6.18
TIME HALF 1	38.5	2.76	37.81	3.25	39.90	4.[illegible]6	34.65	5.68	37.17	1.04
TIME HALF 2	40.72	5.85	39.42	5.72	33.30	7.[illegible]	28.75	4.24	43.83	8.89
TOTAL TIME	79.22	6.18	77.22	6.96	73.70	8.76	63.40	5.37	81.0	7.86
E 1	1.67	2.00	2.61	2.00	[illegible].[illegible]0	4.30	6.30	7.34	2.33	2.52
E 2	7.22	7.60	13.17	8.51	19.20	12.[illegible]1	42.60	25.16	12.0	11.53
E 3	5.56	4.39	7.44	5.95	14.50	8.[illegible]3	14.00	9.40	8.33	3.79
E 4	10.67	6.46	13.72	7.90	23.20	17.97	47.40	32.36	6.33	5.13
E 5	3.44	4.82	9.39	8.40	14.[illegible]0	10.[illegible]8	22.[illegible]0	13.01	2.33	3.21
E 6	28.56	10.97	46.33	13.16	76.70	25.66	133.10	63.75	31.33	16.20
E 7	14.44	10.04	23.22	8.95	33.70	21.[illegible]8	65.10	29.99	22.67	12.90
E 8	19.67	5.29	30.56	12.06	52.00	13.15	84.00	44.46	17.0	5.29
E 9	105.33	7.91	101.89	17.08	102.30	25.[illegible]3	111.70	47.54	109.67	12.58
E10	102.11	9.55	96.94	16.26	93.40	23.36	107.60	38.33	103.67	9.87
E11	105.78	11.46	104.61	13.44	105.40	33.[illegible]1	123.00	34.20	96.67	8.39
E12	107.00	9.81	103.33	13.85	10[illegible].[illegible]0	34.64	109.20	39.80	102.67	7.23
E13	5.13	.74	5.11	1.01	4.69	0.[illegible]4	6.34	2.52	5.67	.95
E14	5.77	.55	5.53	.93	[illegible].80	0.97	7.17	2.05	5.87	.66
E15	5.94	.58	6.06	.92	6.22	1.22	8.20	1.37	5.50	.78
E16	4.81	.89	4.90	1.12	5.[illegible]2	1.79	5.86	2.34	4.13	1.22
T 1	20.78	2.39	20.19	2.66	21.30	3.66	17.00	2.35	19.5	1.32
T 2	17.72	.87	17.61	1.64	15.50	1.[illegible]4	14.85	2.15	17.67	1.15
T 3	17.83	1.37	17.33	1.40	15.[illegible]	2.[illegible]4	14.30	2.11	17.67	1.15
T 4	22.94	5.05	22.08	5.63	19.45	6.[illegible]6	16.75	3.94	26.17	7.82

	GROUP 6 LEFT-EXC.		GROUP 7 RIGHT-GOOD		GROUP 8 LEFT-GOOD		GROUP 9 RIGHT-FAIR		GROUP 10 LEFT-FAIR	
ITEM	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.
MAX(1) PITCH	40.00	.58	39.33	8.48	37.50	6.77	31.67	8.14	30.43	7.28
MIN(1) PITCH	-29.00	5.85	-21.83	4.26	-27.00	5.55	-22.00	1.73	-31.57	5.22
MAX(2) PITCH	41.67	3.08	39.67	6.09	40.00	4.74	44.00	10.44	33.43	5.53
MIN(2) PITCH	-25.50	0.55	-27.17	3.54	-25.25	3.70	-31.67	11.08	-29.29	6.29
ROLL (MAX 1)	46.09	.92	45.41	3.99	44.50	6.55	39.22	3.51	50.82	7.76
ROLL (MIN 1)	53.68	3.15	44.28	4.20	54.20	5.72	48.17	3.97	[illegible]	[illegible]
ROLL (MAX 2)	45.00	2.12	45.10	3.57	44.43	5.22	45.61	7.21	53.86	3.20
ROLL (MIN 2)	44.62	3.42	55.10	2.71	47.61	4.66	54.31	4.56	51.71	6.28
ARSP (MAX 1)	133.51	4.62	124.80	12.46	138.64	12.92	137.56	16.85	134.32	15.99
ARSP (MIN 1)	136.74	2.25	132.61	9.66	140.40	9.48	145.42	13.21	133.45	16.10
ARSP (MAX 2)	123.33	4.16	132.21	9.67	125.25	7.76	125.83	10.65	127.64	9.06
ARSP (MIN 2)	135.56	4.13	133.96	9.35	[illegible]	9.00	125.17	12.01	132.50	7.43
ALT (MAX 1)	1337.23	156.84	1344.26	223.49	1237.32	295.90	1004.67	330.52	1329.54	356.39
ALT (MIN 1)	1511.76	84.26	1498.33	168.40	1446.99	271.93	1130.17	443.87	1553.05	398.25
ALT (MAX 2)	1668.61	185.75	1527.63	271.32	1681.05	281.98	1373.44	204.58	1555.57	228.99
ALT (MIN 2)	1756.71	186.07	1721.93	289.34	1770.52	269.70	1627.92	69.45	1564.51	200.44
MAX + ROLL	82.00	1.55	81.12	2.73	82.58	5.43	80.00	2.65	89.00	5.92
MAX - ROLL	-91.83	4.12	88.55	5.78	-89.42	7.08	-91.57	3.79	-92.71	3.73
TIME HALF 1	44.17	3.93	36.33	1.89	41.83	4.12	37.83	1.04	40.79	5.01
TIME HALF 2	35.25	3.42	43.00	5.55	34.33	4.85	41.50	10.48	30.50	3.61
TOTAL TIME	79.42	5.66	79.33	6.52	76.17	7.20	79.33	9.93	71.29	7.71
E 1	1.33	1.55	1.67	1.51	3.09	2.11	[illegible]	3.21	6.00	5.23
E 2	4.83	4.01	15.33	8.82	12.08	[illegible]	11.67	5.43	21.57	14.51
E 3	4.17	4.26	7.83	6.91	7.25	5.74	10.67	12.66	15.43	7.53
E 4	12.83	6.27	13.50	5.68	13.81	9.04	37.67	19.09	17.00	14.61
E 5	4.00	5.65	7.67	8.21	10.25	8.72	10.00	6.08	16.86	11.80
E 6	27.17	8.98	46.00	14.13	46.50	13.30	76.33	19.26	76.86	28.47
E 7	10.33	5.32	24.83	4.26	22.42	10.56	23.67	11.06	47.00	24.44
E 8	21.00	5.22	29.00	15.02	31.33	10.97	51.33	11.06	49.29	13.76
E 9	103.17	4.45	109.00	15.32	93.33	17.40	89.33	18.50	107.86	27.69
E10	101.33	10.23	102.	18.56	94.17	15.07	83.67	8.21	97.57	27.75
E11	110.33	10.37	99.00	18.21	107.42	10.13	117.00	50.71	100.43	27.59
E12	109.17	10.78	99.17	10.46	105.42	15.25	121.00	38.94	99.29	33.60
E13	4.37	0.52	5.75	.86	4.79	0.76	4.75	1.12	4.57	0.81
E14	5.72	0.53	5.95	1.10	5.32	0.79	5.18	0.17	6.14	1.04
E15	6.16	0.74	5.67	.92	6.25	0.58	5.03	1.99	6.31	0.94
E16	5.15	0.49	3.95	.60	5.38	1.03	5.28	2.79	5.76	1.46
T 1	21.42	2.33	19.00	1.55	20.79	2.94	19.00	1.80	23.00	3.70
T 2	17.75	0.82	17.33	1.57	17.75	1.73	16.17	1.04	15.54	1.89
T 3	17.92	1.56	17.33	.86	17.33	1.64	18.83	2.93	15.71	1.85
T 4	21.33	2.44	25.67	5.19	20.29	5.13	25.33	9.78	16.93	2.01

	GROUP 11 RIGHT-UNSAT.		GROUP 12 LEFT-UNSAT.		GROUP 13 RIGHT		GROUP 14 LEFT		GROUP 15 ALL	
ITEM	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.
MAX(1) PITCH	50.50	7.78	41.25	12.39	39.50	8.56	39.06	8.01	39.19	8.18
MIN(1) PITCH	-37.00	4.24	-33.38	10.23	-24.77	5.29	-31.64	8.03	-29.50	8.17
MAX(2) PITCH	60.50	7.76	45.53	15.00	43.50	9.77	41.57	8.43	42.11	8.73
MIN(2) PITCH	-55.00	7.07	-32.70	11.71	-32.07	11.43	-27.91	7.18	-29.15	6.75
ROLL (MAX 1)	59.42	4.12	58.47	5.75	45.22	7.09	49.56	5.53	47.57	5.41
ROLL (MIN 1)	53.25	3.54	53.04	7.93	46.43	4.78	[illegible]	8.51	53.71	9.72
ROLL (MAX 2)	64.50	4.95	62.75	6.00	44.21	8.75	50.97	8.93	50.17	8.87
ROLL (MIN 2)	77.25	7.42	57.27	9.75	57.62	7.01	50.29	7.42	52.47	9.31
ARSP (MAX 1)	105.67	1.55	140.01	26.17	124.77	11.99	137.23	16.97	133.51	17.00
ARSP (MIN 1)	105.25	3.13	142.04	34.92	131.39	15.73	136.66	15.93	136.50	16.06
ARSP (MAX 2)	99.67	6.60	129.48	26.04	126.88	15.27	126.00	14.70	125.27	14.71
ARSP (MIN 2)	99.33	10.37	123.37	27.27	125.24	14.43	132.15	14.44	130.59	14.54
ALT (MAX 1)	1629.25	23.69	1166.65	497.06	1314.75	272.73	1257.91	341.11	1274.85	320.42
ALT (MIN 1)	1724.25	96.17	1233.34	671.77	1460.23	264.57	1435.29	409.08	1442.72	373.47
ALT (MAX 2)	1673.00	67.48	1219.02	678.79	1515.76	213.72	1540.19	423.91	1532.76	371.47
ALT (MIN 2)	1802.00	104.65	1377.46	701.32	1735.01	202.11	1629.02	411.78	1660.77	366.37
MAX + ROLL	91.50	4.36	103.86	12.94	82.21	4.96	89.00	11.40	87.22	10.25
MAX - ROLL	-119.50	14.35	-106.25	11.42	-94.14	12.41	-94.54	9.85	-94.49	10.55
TIME HALF 1	38.25	1.06	33.75	6.05	37.34	2.02	39.09	5.83	39.19	5.10
TIME HALF 2	31.25	1.77	28.13	4.35	40.72	7.16	32.16	4.94	34.73	6.87
TOTAL TIME	69.50	2.83	61.98	4.76	78.29	7.48	72.08	4.88	73.93	8.89
E 1	4.50	3.54	7.00	8.12	2.79	2.46	4.33	4.13	3.67	4.55
E 2	59.50	19.09	38.38	26.94	20.57	19.34	19.15	19.42	19.57	19.08
E 3	21.50	3.54	12.13	9.58	10.59	5.32	9.21	7.85	9.27	7.92
E 4	75.00	19.70	40.50	21.92	22.93	25.78	20.79	20.67	22.22	22.15
E 5	25.00	6.49	27.00	14.33	9.50	9.44	13.36	11.98	12.21	11.33
E 6	183.50	16.26	120.00	64.86	59.29	33.27	67.24	46.21	67.33	49.28
E 7	95.50	12.02	57.50	30.93	32.86	23.06	32.09	25.98	32.22	24.96
E 8	121.50	31.82	74.63	43.51	43.92	27.78	43.76	29.93	44.40	32.05
E 9	155.00	22.63	100.93	46.51	111.70	24.70	101.45	27.13	104.72	25.58
E10	138.00	22.63	100.00	35.55	103.79	21.31	97.51	22.92	99.45	23.17
E11	153.50	16.26	115.38	40.07	110.14	20.79	106.38	25.94	103.91	25.86
E12	150.00	11.31	99.00	37.74	111.86	25.10	107.24	22.25	105.61	25.25
E13	7.84	1.01	6.22	2.73	5.82	1.27	6.12	1.58	[illegible]	1.52
E14	5.74	0.45	6.78	2.12	6.15	1.33	5.92	1.34	5.99	1.33
E15	9.33	1.39	7.92	1.95	6.24	1.71	6.64	1.35	[illegible]	1.45
E16	2.57	0.63	6.44	3.04	4.94	2.06	5.67	1.75	5.45	1.85
T 1	19.75	0.35	16.31	2.73	19.21	1.74	20.29	3.76	19.97	3.25
T 2	15.75	1.77	14.63	2.26	16.94	1.45	16.55	2.20	16.66	2.00
T 3	16.50	0.71	14.38	2.15	17.61	1.36	16.38	2.20	15.74	2.09
T 4	17.50	0.	16.56	4.44	24.54	6.59	18.25	4.39	20.55	5.70

APPENDIX XV

SAMPLE OUTPUT OF BARREL ROLL EXPERIMENTAL MEASUREMENT PROGRAM

Preceding page blank

```
                                 BAFFEL ROLL MEASURES

           MO-DA-YR                          EVNO     13.                           DIR-RATING
            7-31-70                                                                 -10    3

NO.          DESCRIPTION                                          MEASURE

  1          SYMMETRY:                  QTRS. 1,4                   5.80          .57962791E+01
  2                                     QTRS. 2,3                   1.10          .10979987E+01
  3                                     HLVS. 1,2                   3.10          .31048217E+01
  4          CIRCLE:                       HALF 1                   1.46          .14614650E+01
  5                                        HALF 2                   1.19          .11868706E+01
  6                                           ALL                    .95          .95460536E+00
  7          REG. COEFS. AND CORREL.          R-A                 -12.00         -.11997213E+02
  8                                             B                   -.01         -.14023494E-01
  9                                             R                   -.19         -.18987461E+00
 10          A-ALL MANEUVER                  FR-A                   6.45          .64458838E+01
 11                                             B                    .00          .42831953E-02
 12                                             R                    .15          .14804101E+00
 13                                           G-A                   2.25          .22475610E+01
 14                                             B                   -.00         -.12860062E-02
 15                                             R                   -.15         -.15130202E+00
 16          B-ROLL > 45                      R-A                 -20.35         -.20350909E+02
 17                                             B                    .00          .48071433E-02
 18                                             R                    .05          .53653977E-01
 19                                          FR-A                   7.15          .71533664E+01
 20                                             B                    .00          .26970781E-02
 21                                             R                    .04          .40266814E-01
 22                                           G-A                   2.69          .26945579E+01
 23                                             B                   -.01         -.60983011E-02
 24                                             R                   -.47         -.47196496E+00
 25          MAX G                         HALF 1                   3.60          .36000000E+01
 26                                        HALF 2                   4.10          .41000000E+01
 27          MIN G                                                   .20          .20000000E+00
 28          ROLL AT MAX PITCH                                     55.00          .55000000E+02
 29          ROLL AT MIN PITCH                                     81.00          .81000000E+02
 30          MAX ROLL RATE                                          2.92          .29166667E+01
 31          MIN ROLL RATE, ROLL > 20                             -29.58         -.29583333E+02
 32          MAX PITCH RATE                                        10.21          .10208333E+02
 33          MIN PITCH RATE, ROLL > 20                            -11.67         -.11666667E+02
 34          TIME                                     ALL          24.40          .24400000E+02
 35                                        HALF 1                  12.00          .12000000E+02
 36                                        HALF 2                  12.40          .12400000E+02
```

SUMMARY PRINT-OUT

```
              MO-DA-YR               RUNNO   13.               DIR-RATING
              6-16-70                                            10  10

                            ROLL         PITCH                     HEADING     ALTITUDE      AIRSPEED
 ROLL        PITCH          RATE         RATE         Z*           EXCURSION   EXCURSION     EXCURSION
   0          14.0          7.08         5.11         99.0         0.          0.            0.
  10          22.0          6.04         5.21         1.57          1.00        134.00       -7.00
  20          27.6          13.5         4.94         1.16          2.00        320.14       -16.0
  30          30.2          10.9         2.37         -.267         2.00        407.60       -23.6
  40          32.0          13.3         .764         -1.72         1.67        534.33       -28.3
  50          32.0          15.2         .222         -4.18        0.           668.00       -37.0
  60          31.2          13.4         -2.42        -6.94        -5.40        795.20       -39.6
  70          29.2          11.4         -3.54        -10.4        -18.2        926.75       -44.5
  80          26.0          9.73         -3.54        -14.6        -45.0        1002.0       -50.0
  90          21.2          12.0         -5.37        -19.8        -86.6        1129.4       -56.4
 100          16.6          18.7         -7.68        -23.8        -113.        1177.4       -57.2
 110          12.7          19.1         -7.41        -25.4        -122.        1236.0       -59.4
 120          9.00          22.5         -8.54        -24.6        -125.        1280.7       -58.7
 130          5.20          25.9         -8.06        -22.1        -126.        1256.1       -60.8
 140          2.73          26.4         -6.44        -18.1        -127.        1257.6       -59.5
 150          .200          26.4         -6.98        -13.7        -129.        1249.6       -57.4
 160          -2.64         26.1         -7.48        -9.00        -130.        1236.0       -56.5
 170          -5.67         22.4         -8.22        -4.12        -131.        1236.0       -54.9
 180          -12.5         0.04         -8.75        1.86         -130.        1202.5       -50.0
-170          -20.4         23.7         -9.17        .766         -130.        1116.2       -44.2
-160          -23.6         27.4         -9.38        -1.31        -130.        1084.5       -42.5
-150          -27.3         28.6         -10.2        -2.39        -128.        1038.5       -38.8
-140          -30.9         30.4         -9.78        -2.59        -124.        991.85       -33.2
-130          -33.3         31.3         -8.68        -3.01        -119.        960.67       -28.8
-120          -36.7         35.6         -7.95        -1.87        -109.        877.33       -26.3
-110          -38.1         34.5         -5.34        -1.80        -99.6        831.31       -23.2
-100          -39.3         30.5         -3.08        -1.44        -88.2        772.00       -20.7
 -90          -40.3         24.1         -2.19        -.700        -71.9        671.70       -18.2
 -80          -41.0         25.0         -.648        .252         -56.7        591.10       -11.9
 -70          -40.7         25.1         2.06         .707         -46.3        527.80       -6.10
 -60          -39.4         24.6         4.55         .703         -38.2        394.10       -2.80
 -50          -36.9         21.1         6.85         .132         -32.1        275.87       .375
 -40          -32.9         16.6         8.39         -1.02        -26.9        186.14       4.57
 -30          -26.9         16.2         10.1         -2.68        -23.4        -9.4286      8.43
 -20          -20.0         10.8         10.2         -3.36        -22.0        -134.00      13.0
 -10          -12.0         9.06         6.67         -2.63        -20.0        -317.00      19.0
  -1          0.            -2.38        0.           99.0         -19.0        -551.50      17.5
```

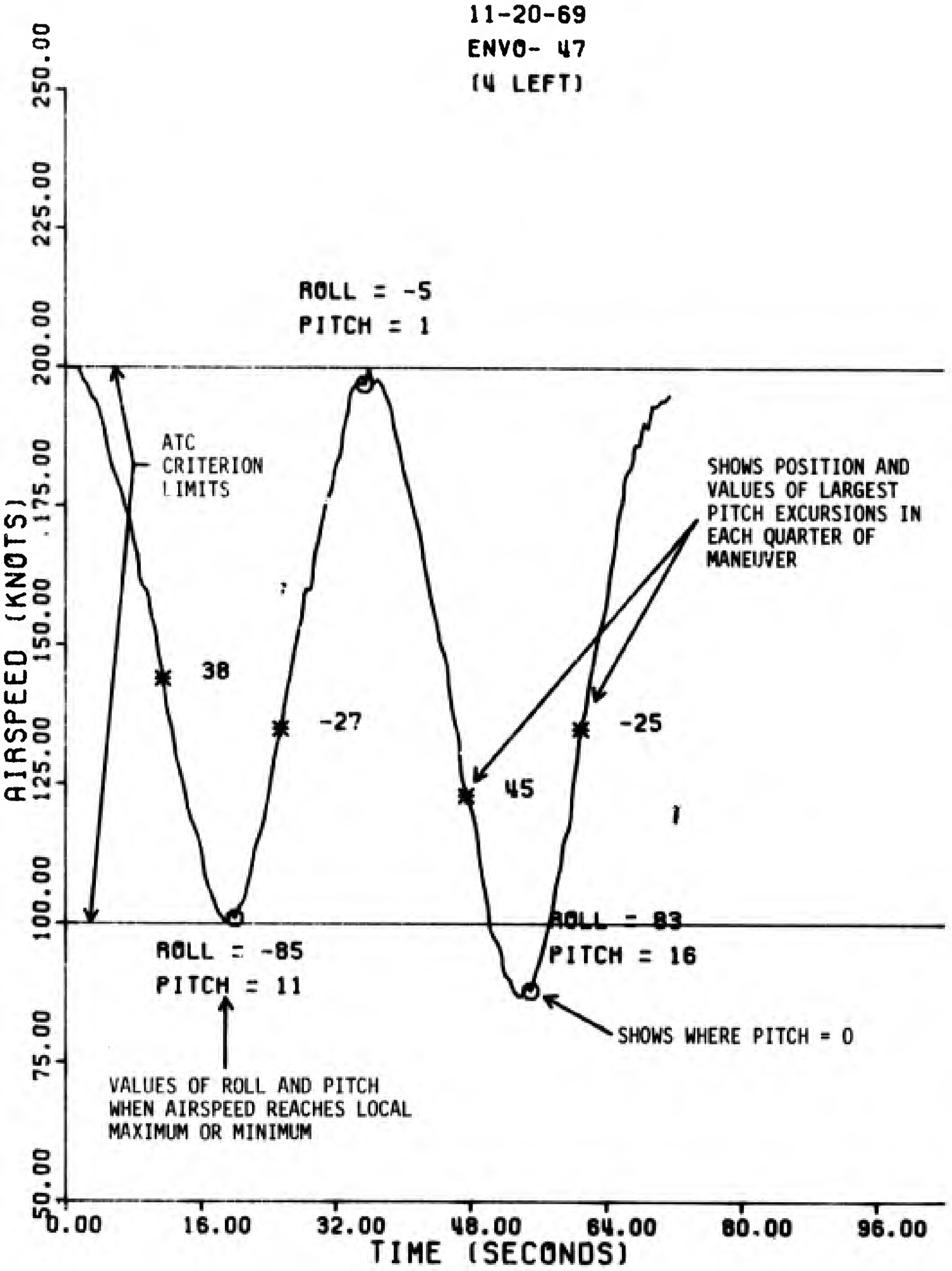
APPENDIX XVI

DEBRIEFING PLOTS FOR FOUR LAZY 8 PERFORMANCES

Preceding page blank

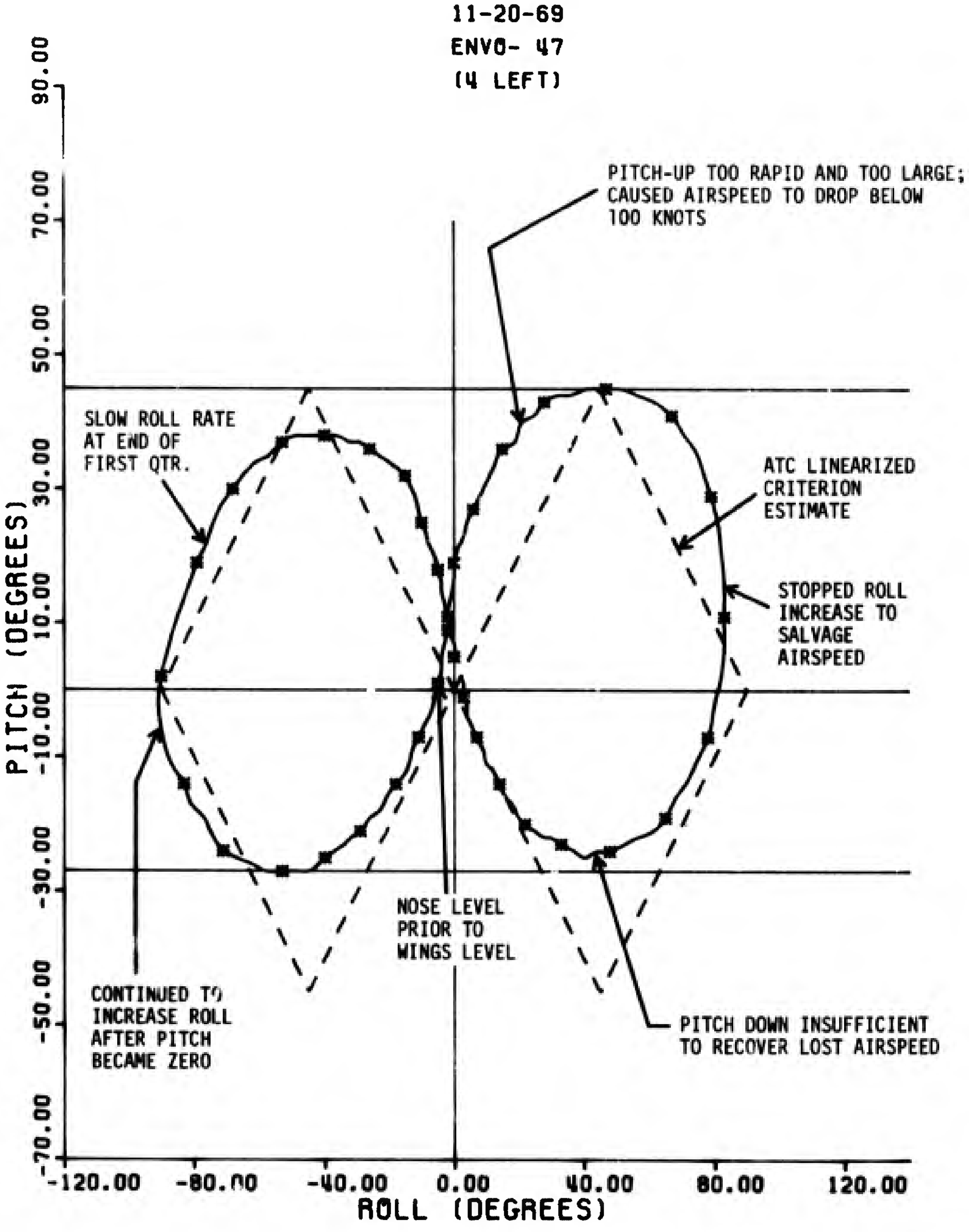
LAZY 8

IP Rating: Excellent
Direction: Left



LAZY 8

IP Rating: Excellent
Direction: Left



PITCH-UP TOO RAPID AND TOO LARGE; CAUSED AIRSPEED TO DROP BELOW 100 KNOTS

SLOW ROLL RATE AT END OF FIRST QTR.

ATC LINEARIZED CRITERION ESTIMATE

STOPPED ROLL INCREASE TO SALVAGE AIRSPEED

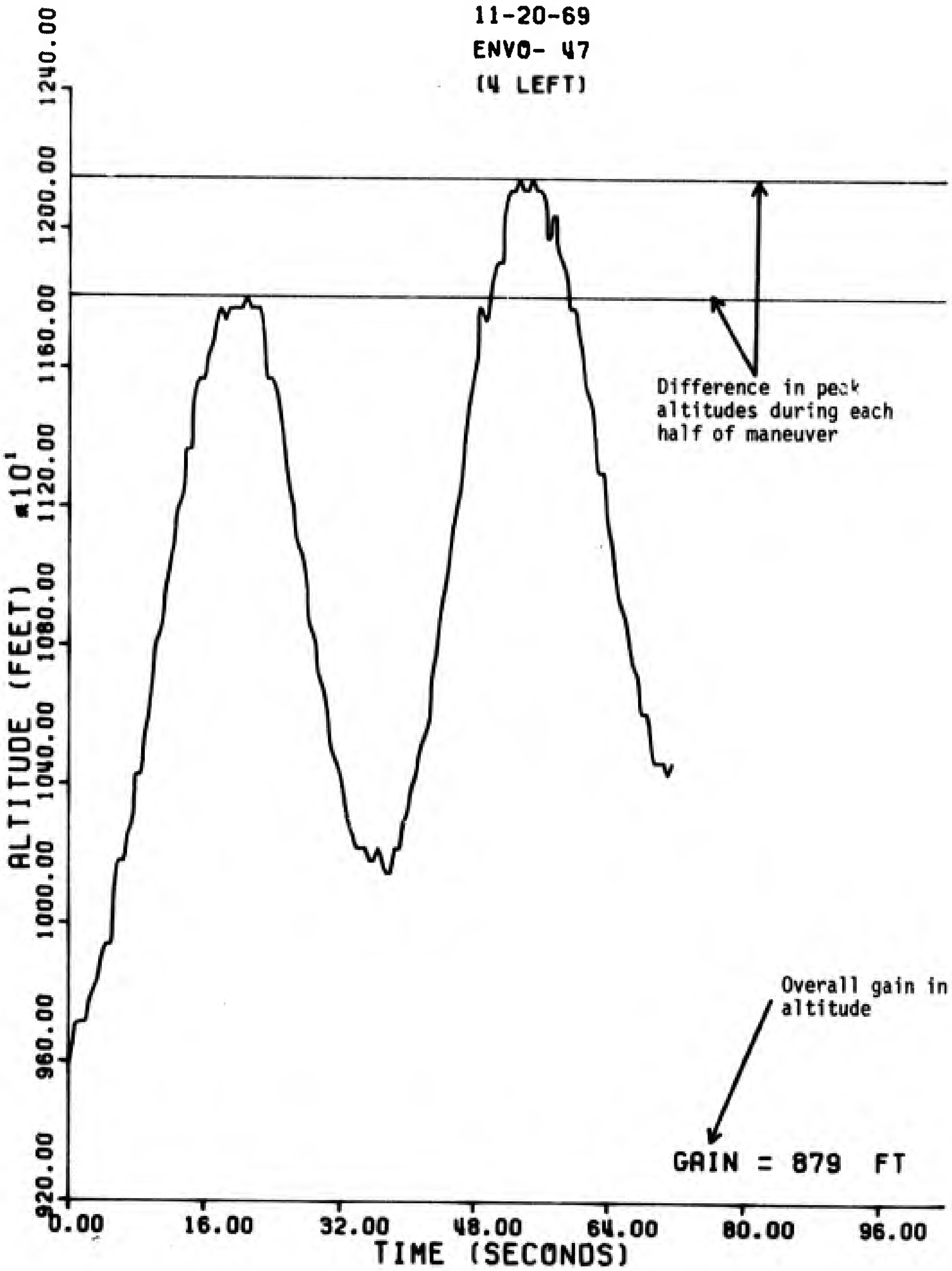
NOSE LEVEL PRIOR TO WINGS LEVEL

CONTINUED TO INCREASE ROLL AFTER PITCH BECAME ZERO

PITCH DOWN INSUFFICIENT TO RECOVER LOST AIRSPEED

LAZY 8

IP Rating: Excellent
Direction: Left

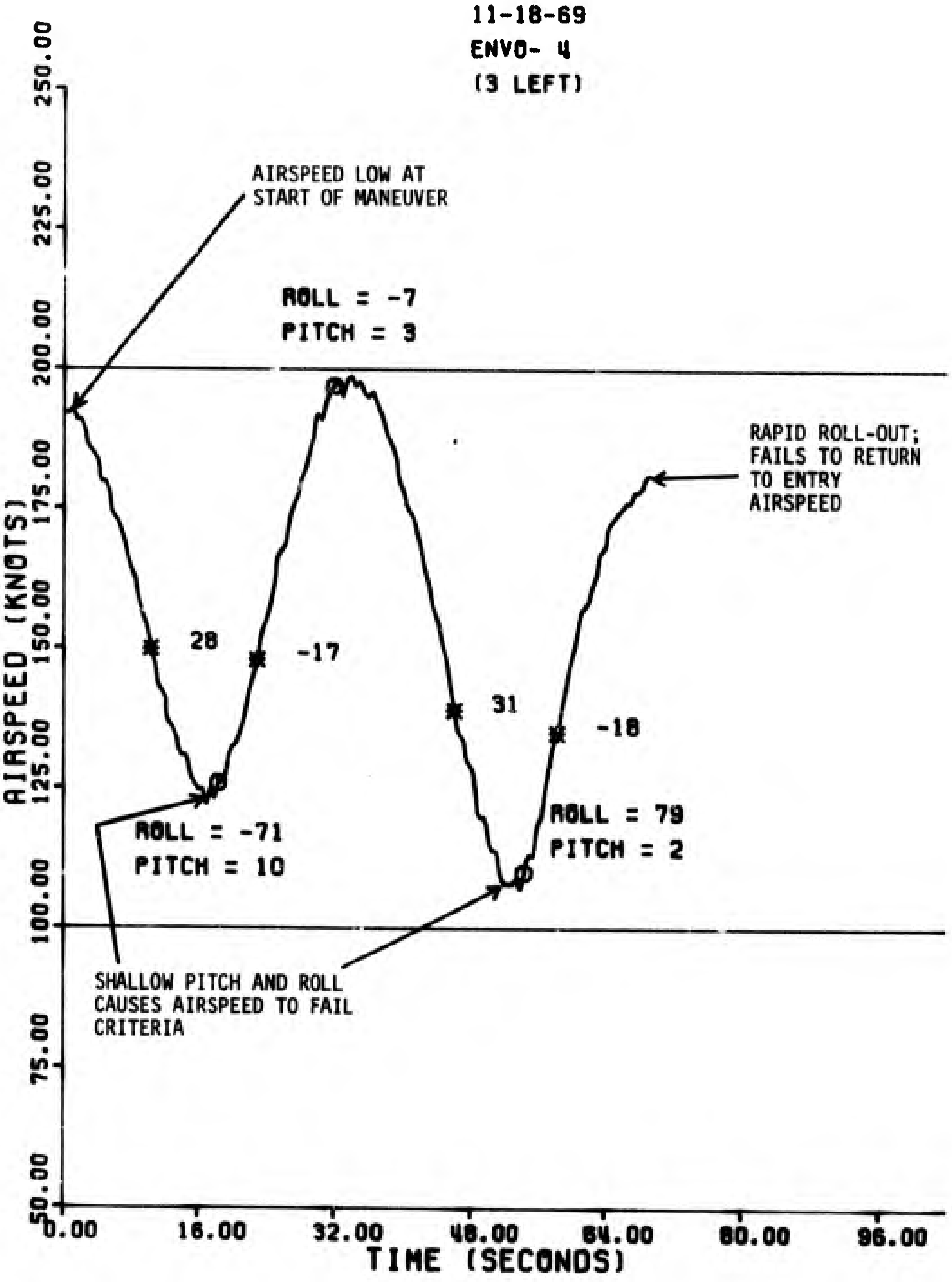


Difference in peak altitudes during each half of maneuver

Overall gain in altitude

LAZY 8

IP Rating: Good
Direction: Left



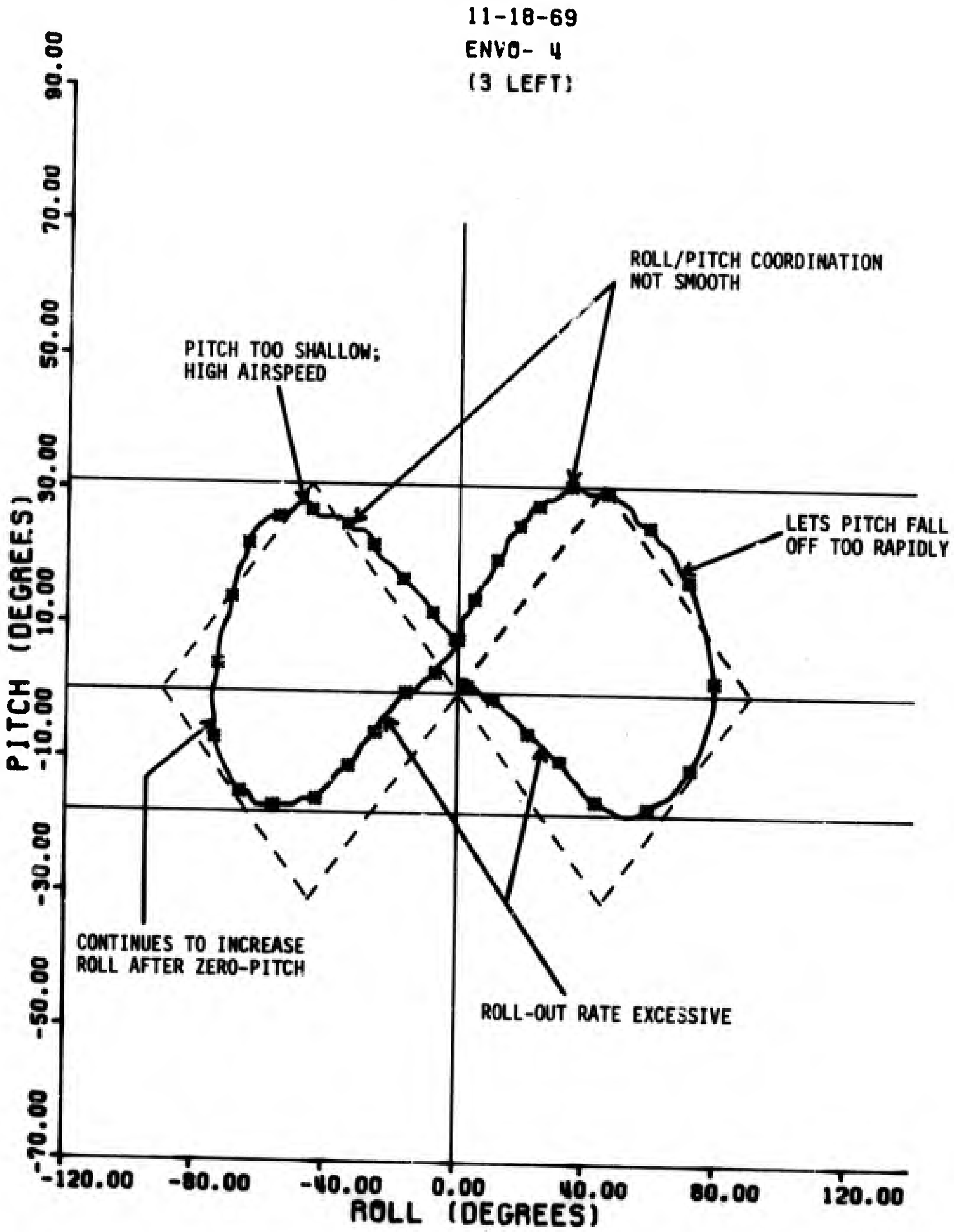
AIRSPEED LOW AT START OF MANEUVER

RAPID ROLL-OUT; FAILS TO RETURN TO ENTRY AIRSPEED

SHALLOW PITCH AND ROLL CAUSES AIRSPEED TO FAIL CRITERIA

LAZY 8

IP Rating: Good
DIRECTION: Left



11-18-69
ENVO- 4
(3 LEFT)

ROLL/PITCH COORDINATION NOT SMOOTH

PITCH TOO SHALLOW; HIGH AIRSPEED

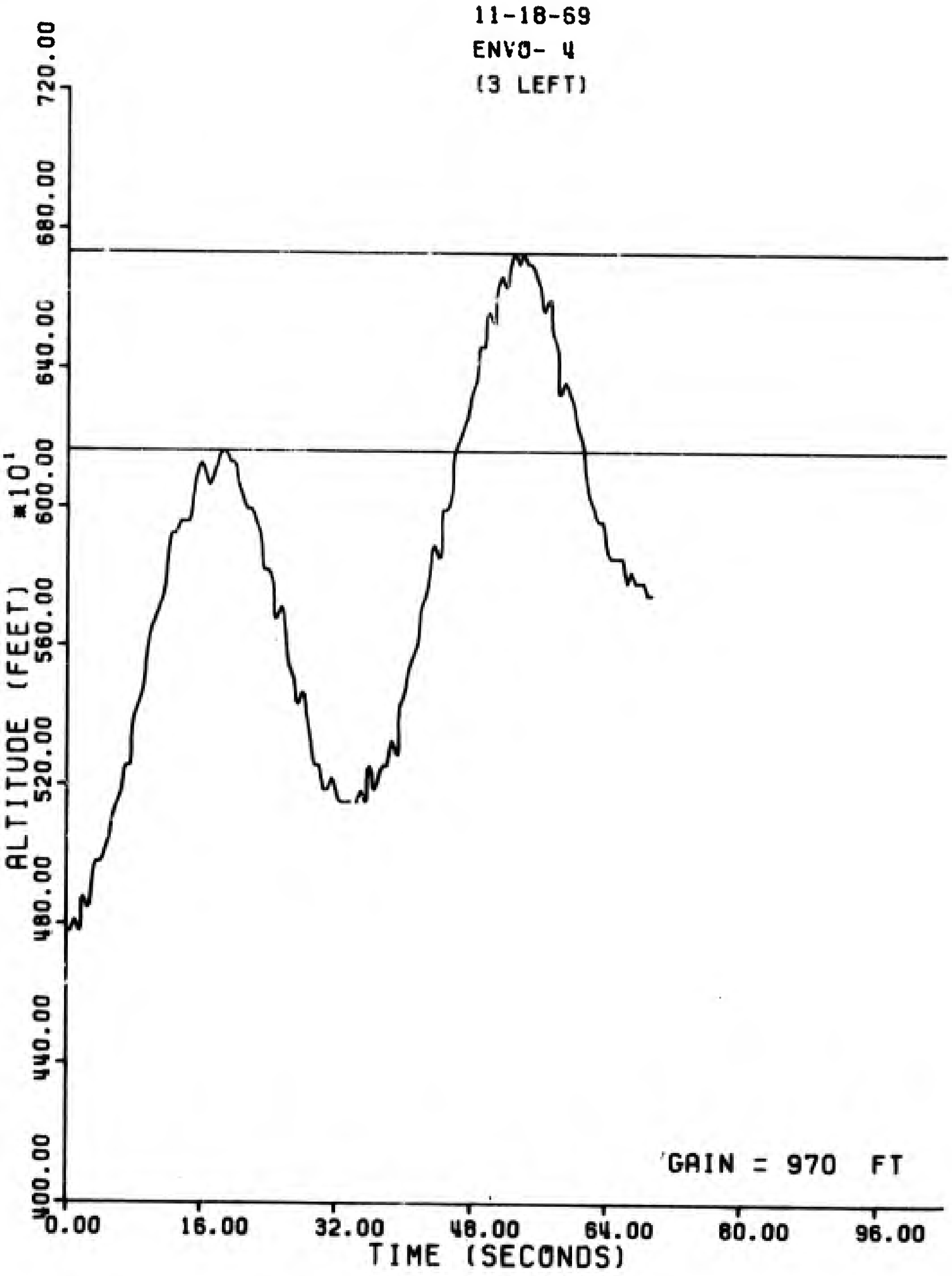
LETS PITCH FALL OFF TOO RAPIDLY

CONTINUES TO INCREASE ROLL AFTER ZERO-PITCH

ROLL-OUT RATE EXCESSIVE

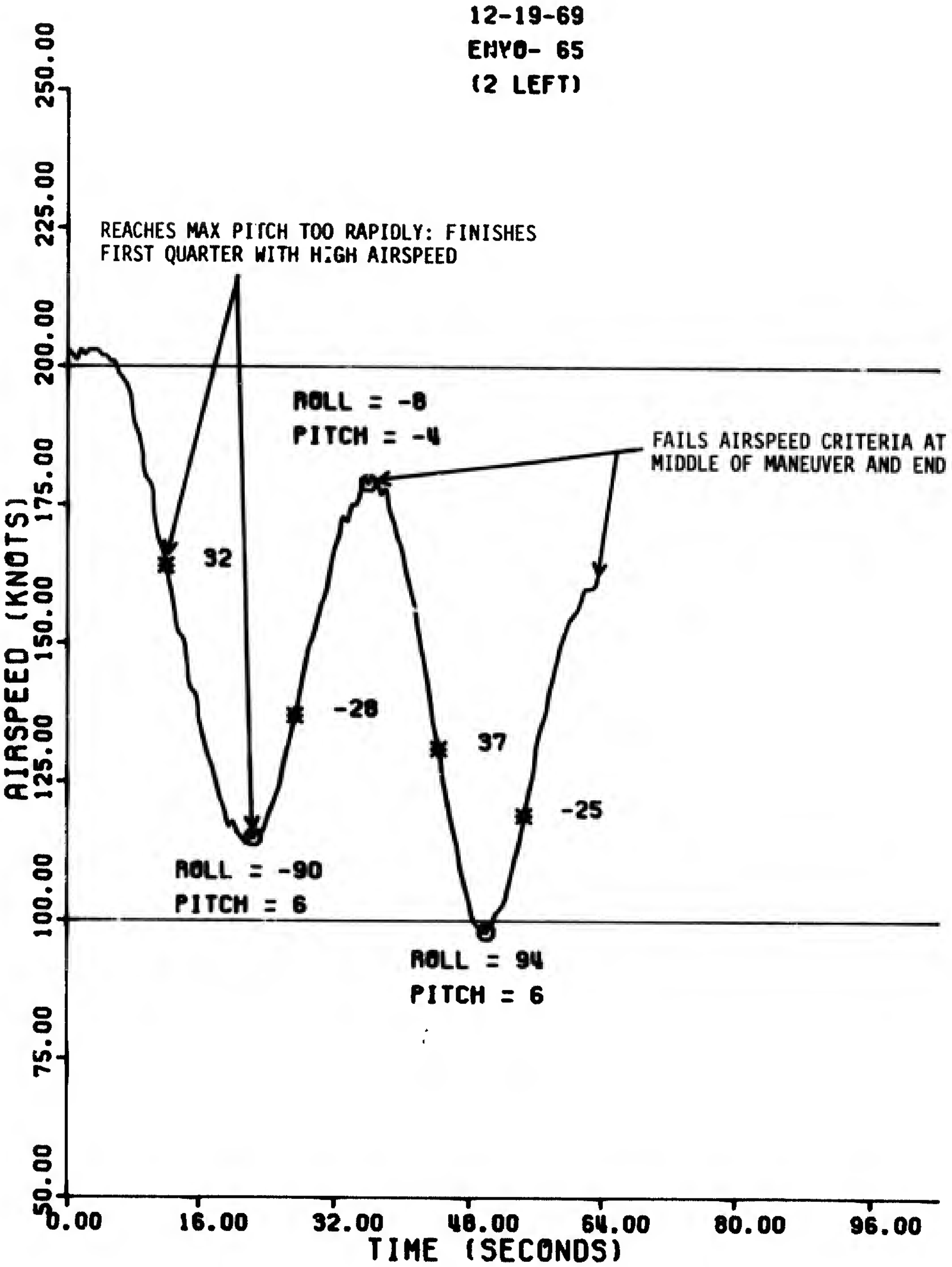
LAZY 8

IP Rating: Good
Direction: Left



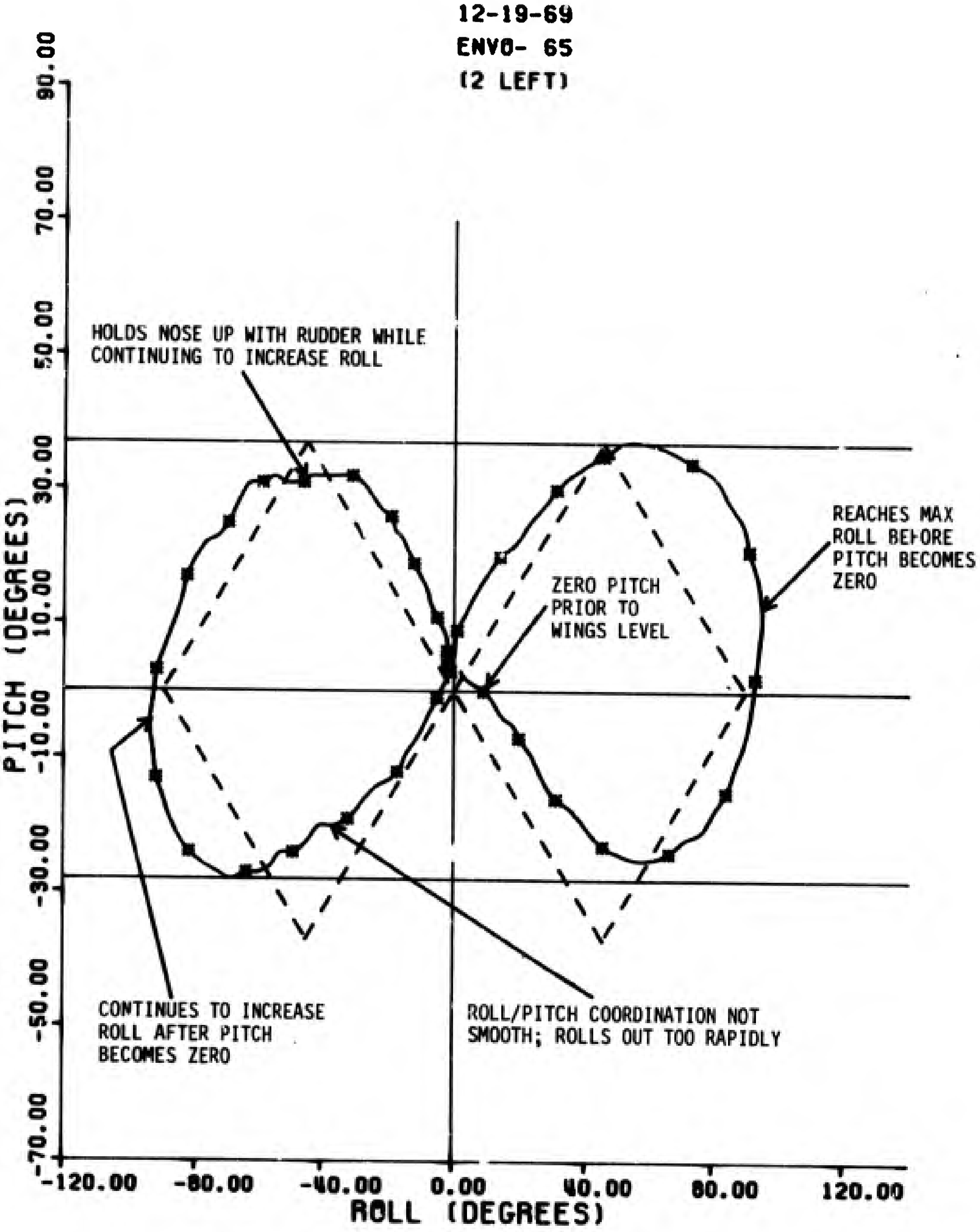
LAZY 8

IP Rating: Fair
Direction: Left



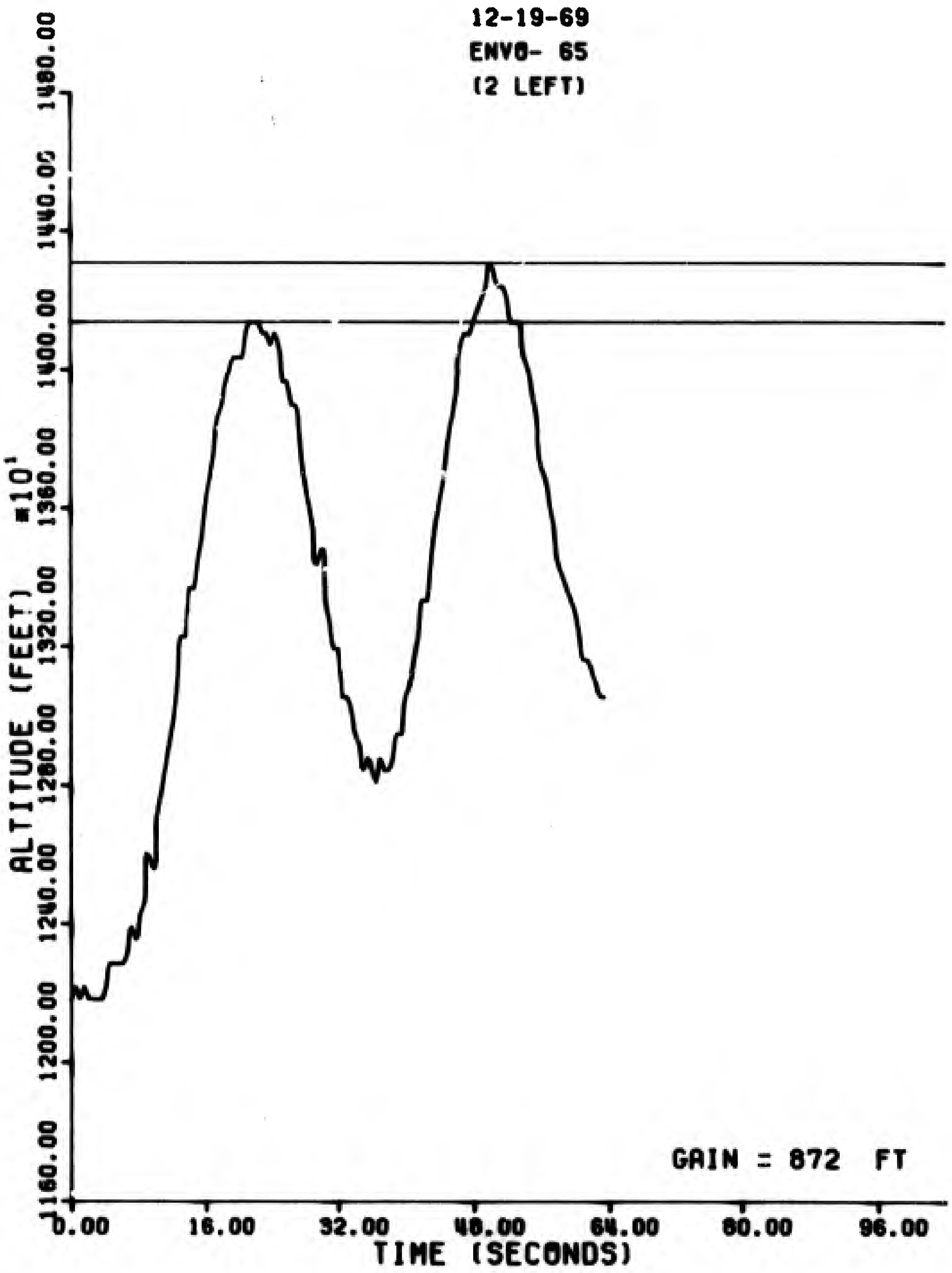
LAZY 8

IP Rating: Fair
Direction: Left



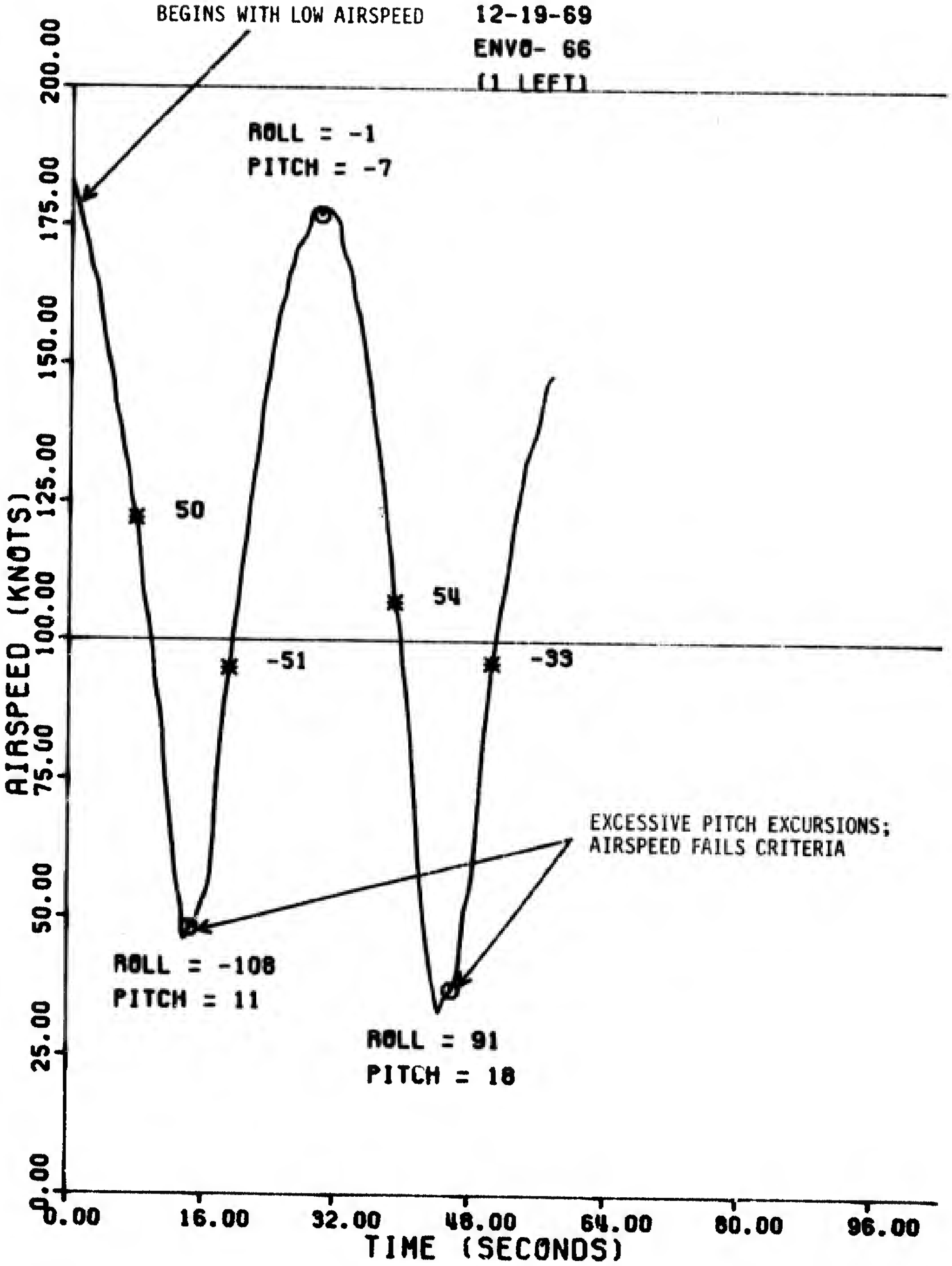
LAZY 8

IP Rating: Fair
Direction: Left



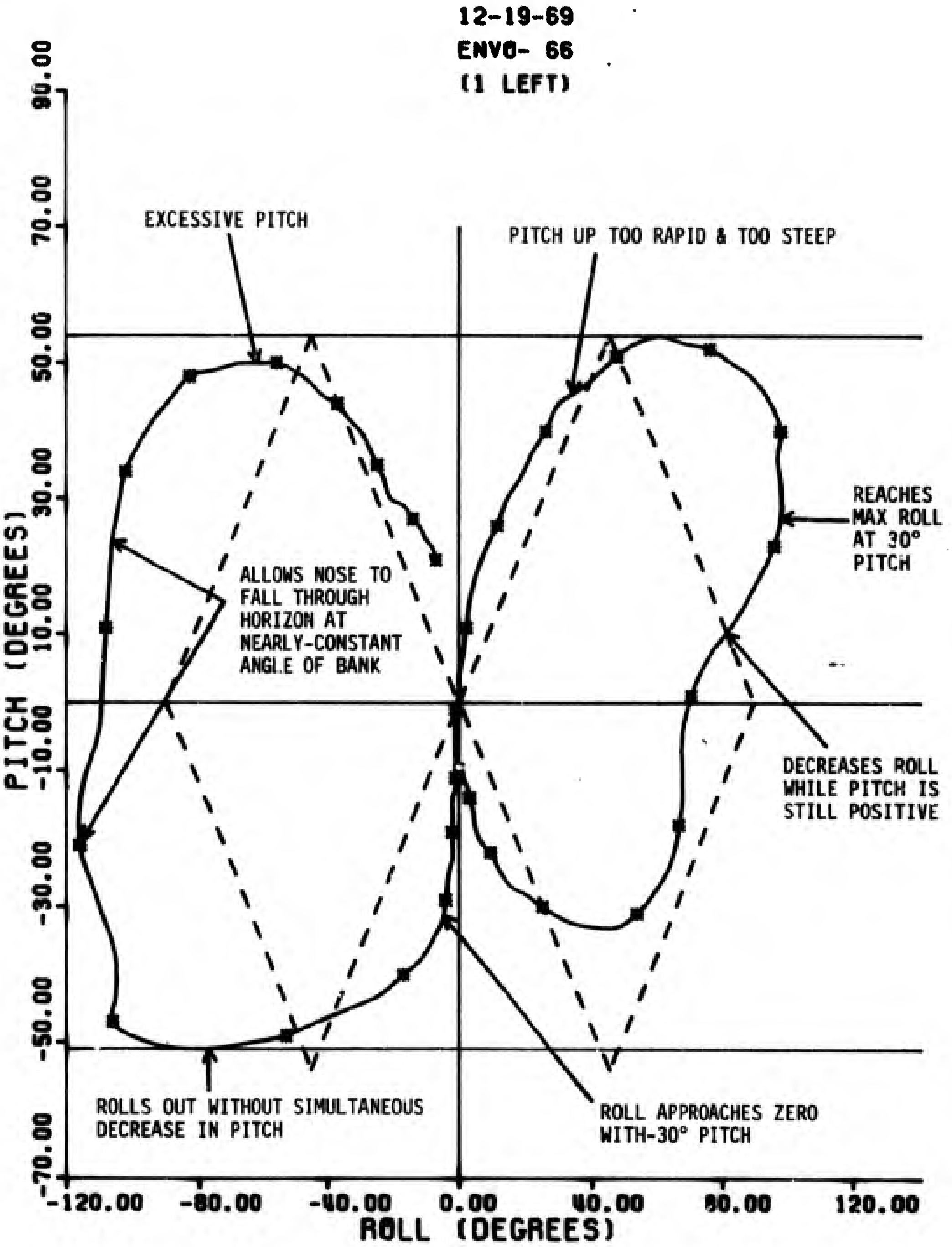
LAZY 8

IP Rating: Unsatisfactory
Direction: Left



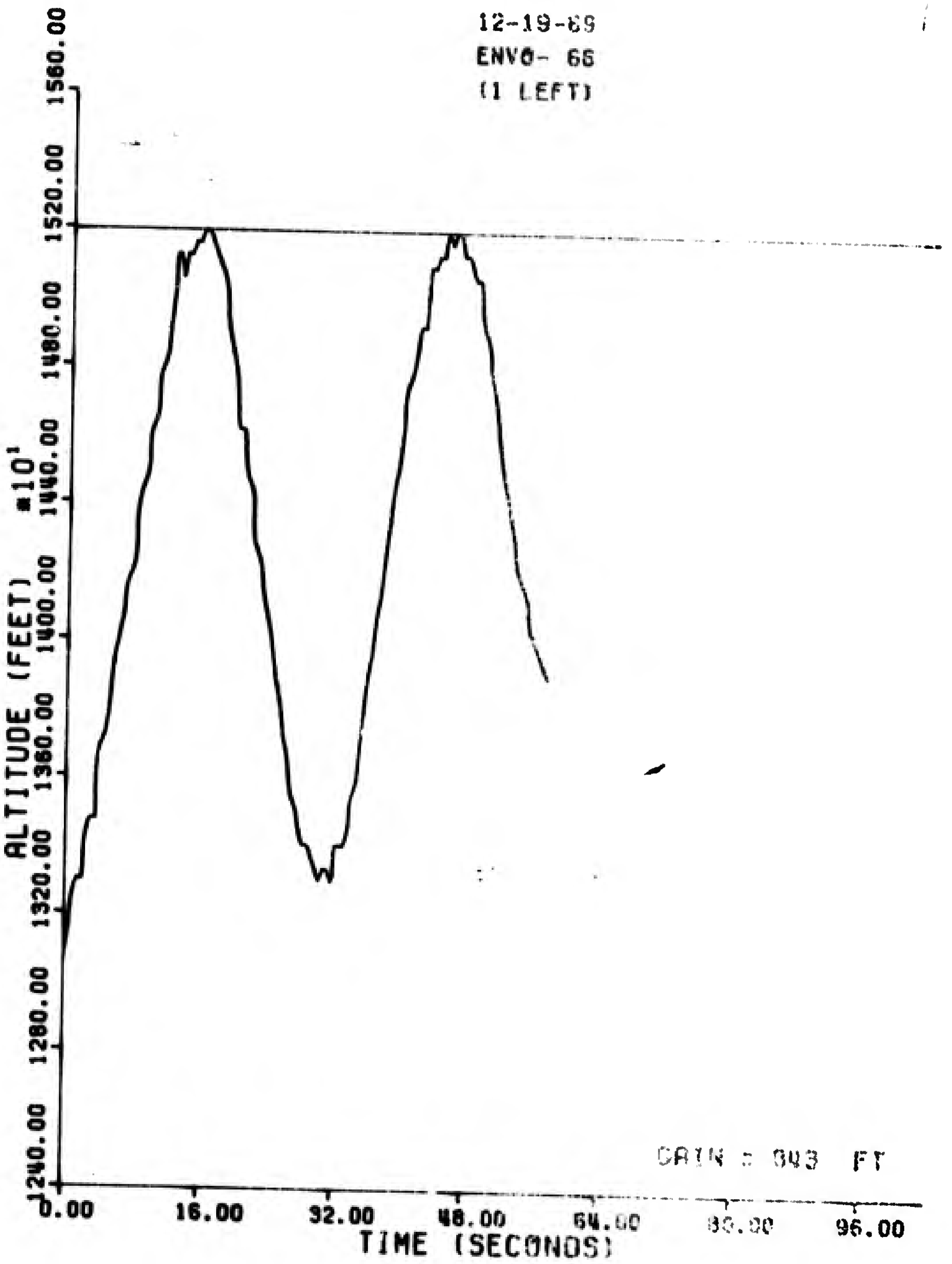
LAZY 8

IP Rating: Unsatisfactory
Direction: Left



LAZY 8

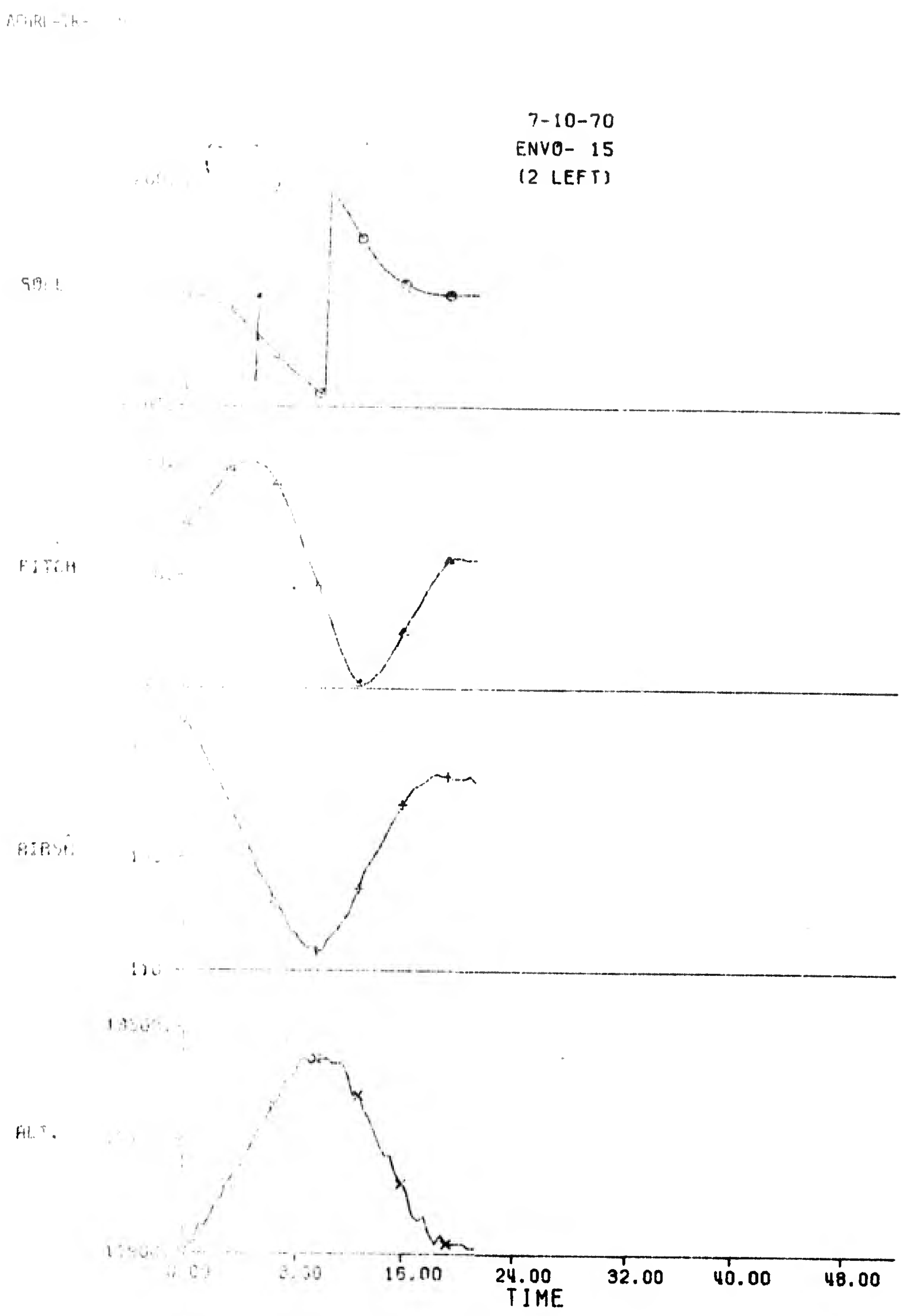
IP Rating: Unsatisfactory
Direction: Left



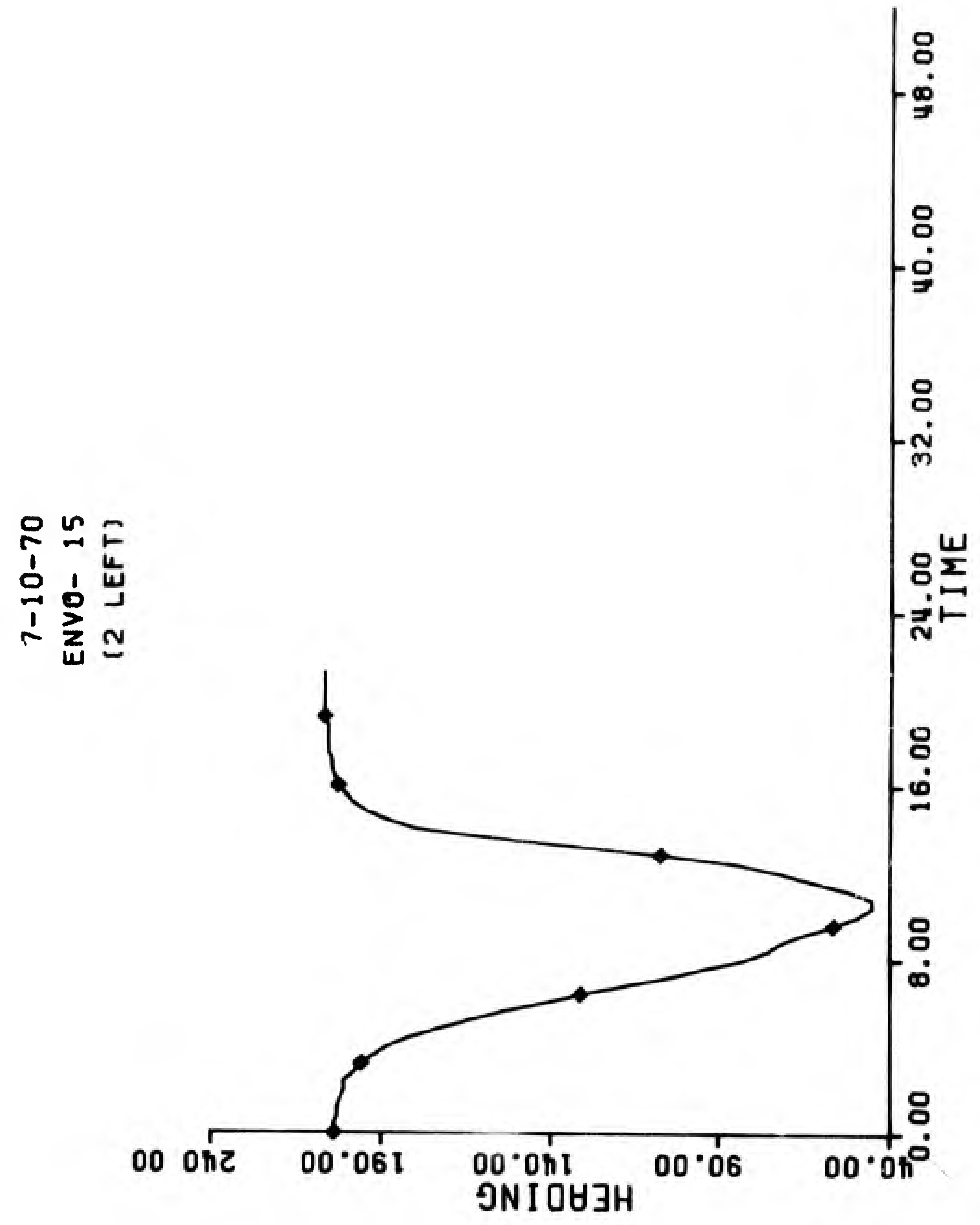
APPENDIX XVII

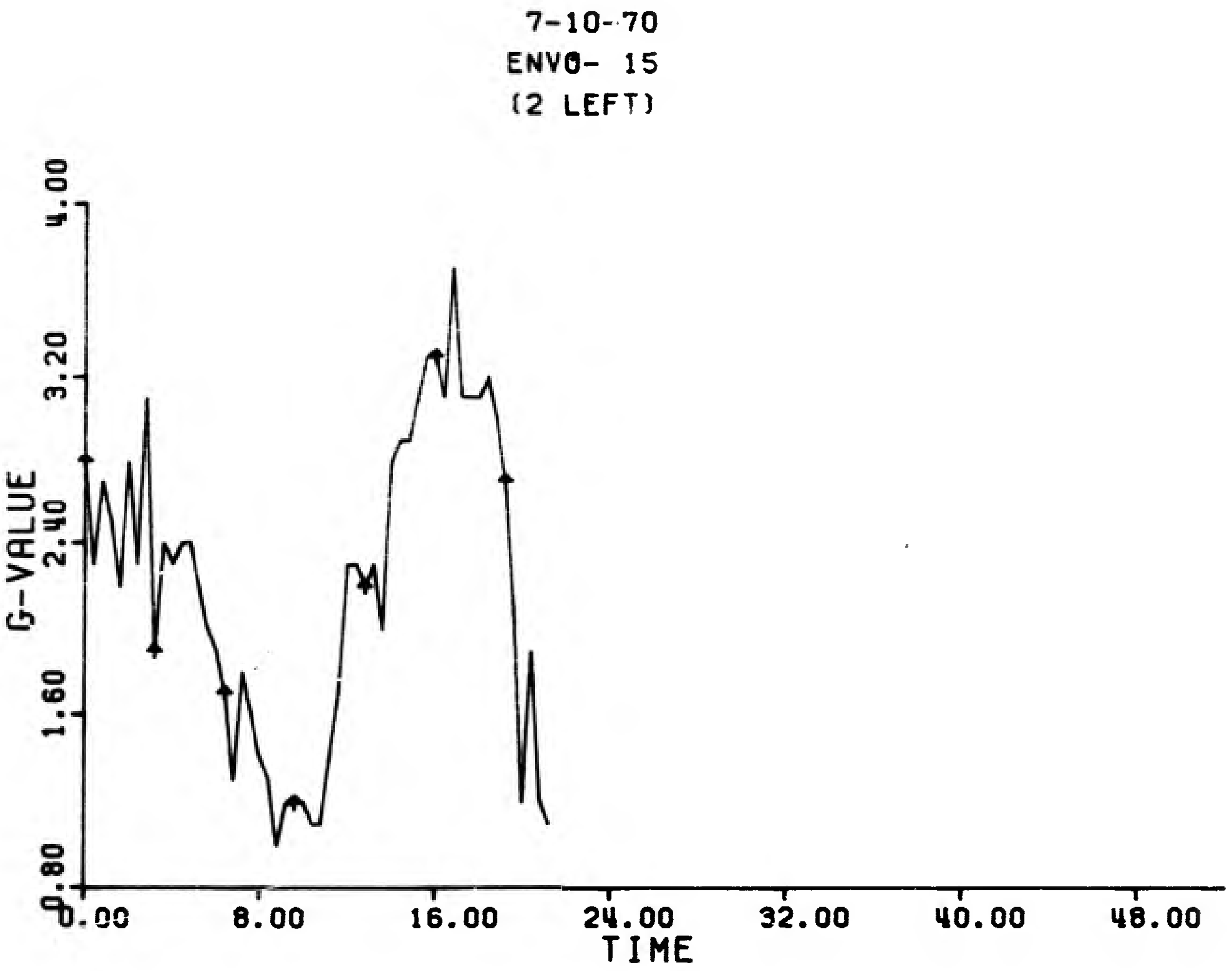
DEBRIEFING PLOTS FOR TWO BARREL ROLL PERFORMANCES

Preceding page blank

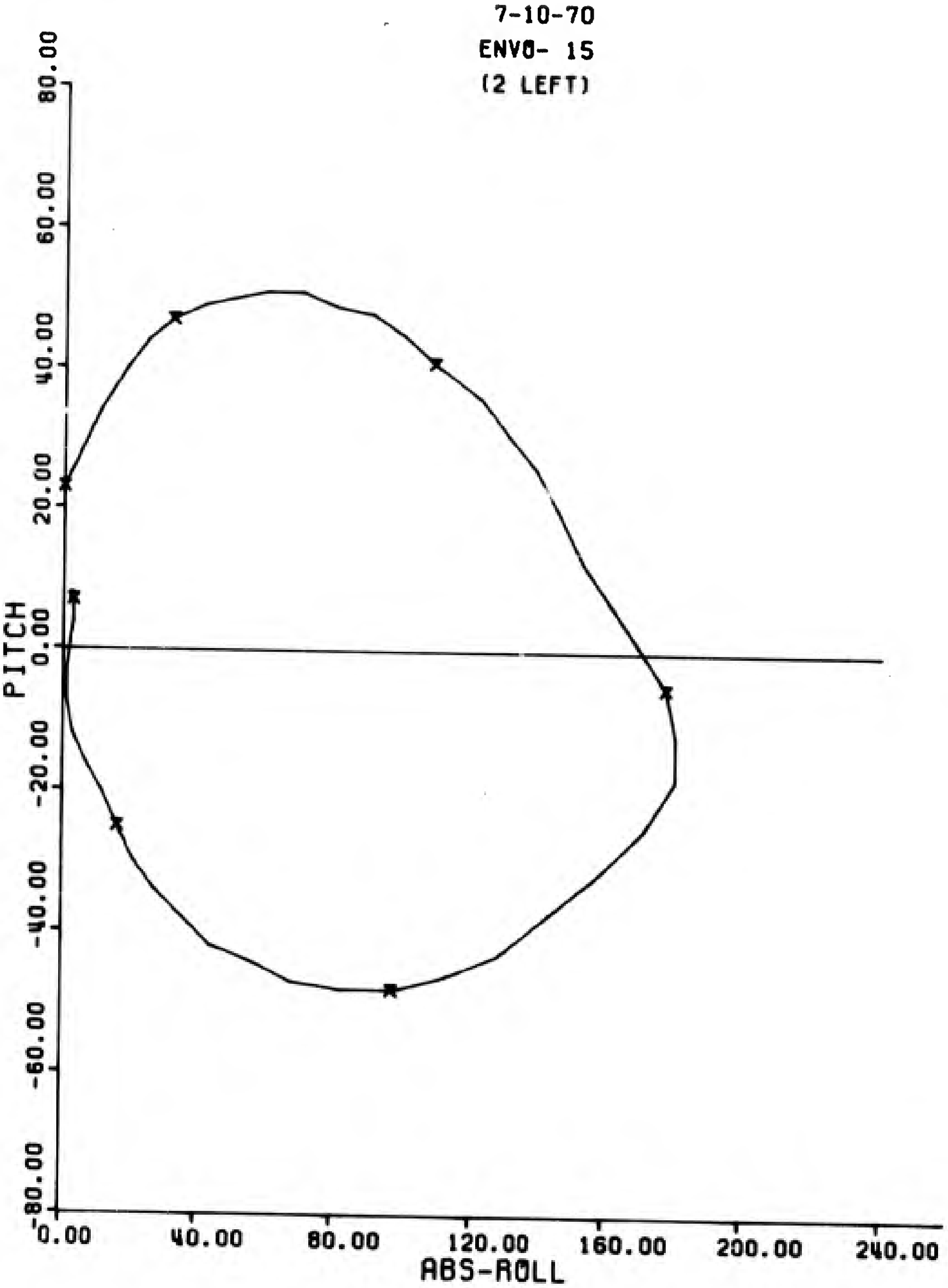


7-10-70
ENVO- 15
(2 LEFT)

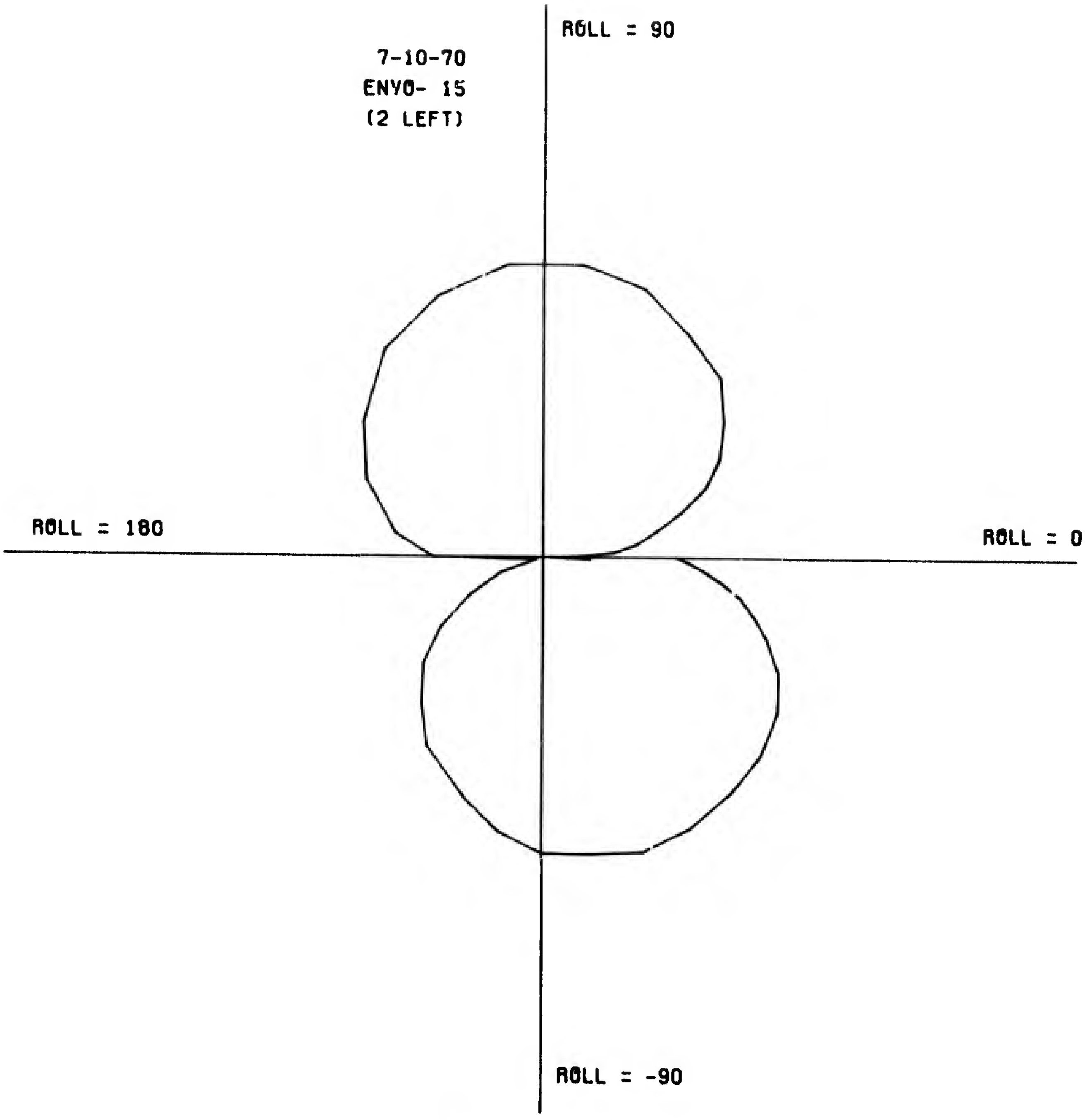

7-10-70
ENV0- 15
(2 LEFT)
HEADING
40.00
90.00
140.00
190.00
240.00
TIME
0.00
8.00
16.00
24.00
32.00
40.00
48.00



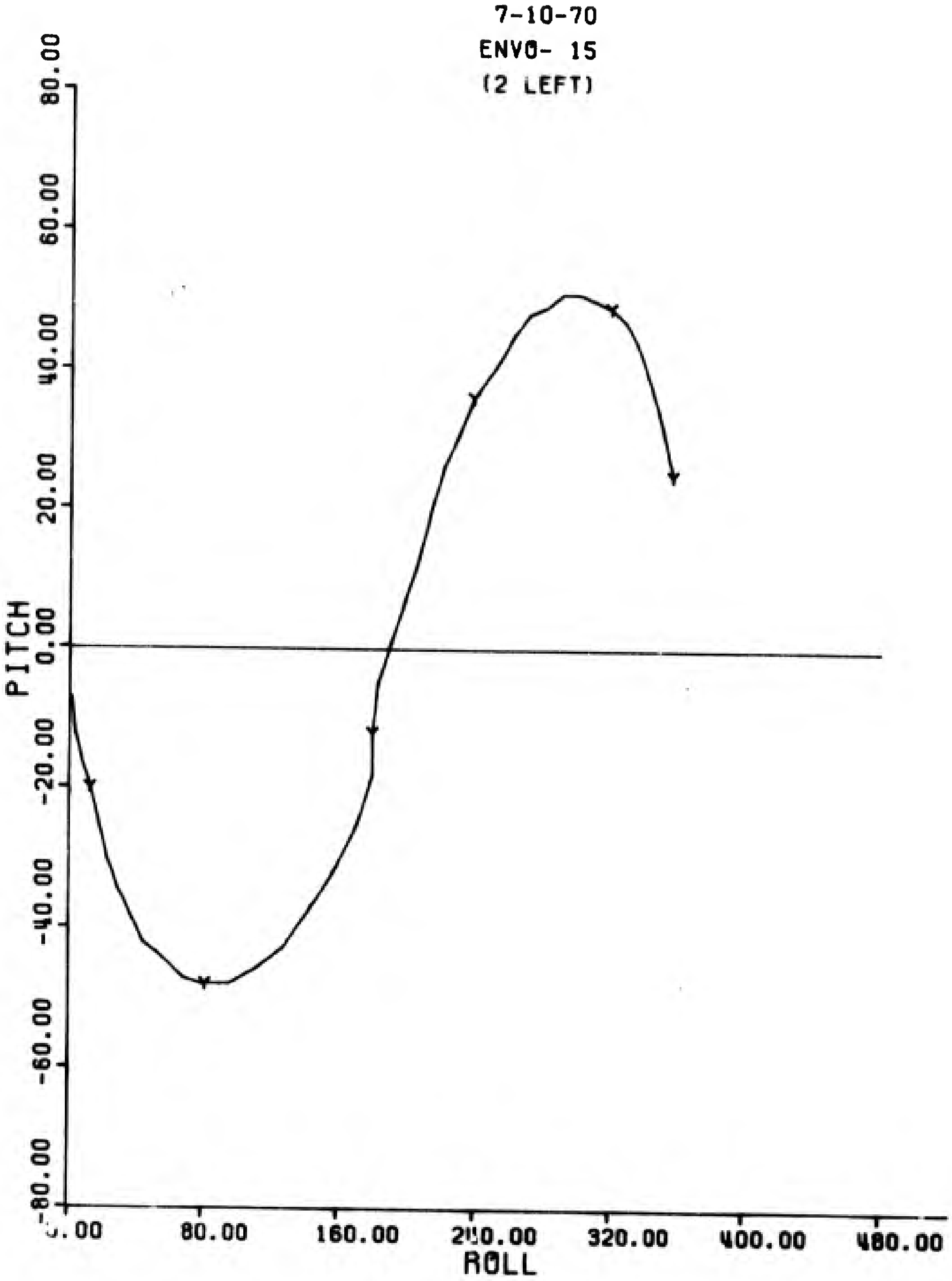
7-10-70
ENVO- 15
(2 LEFT)

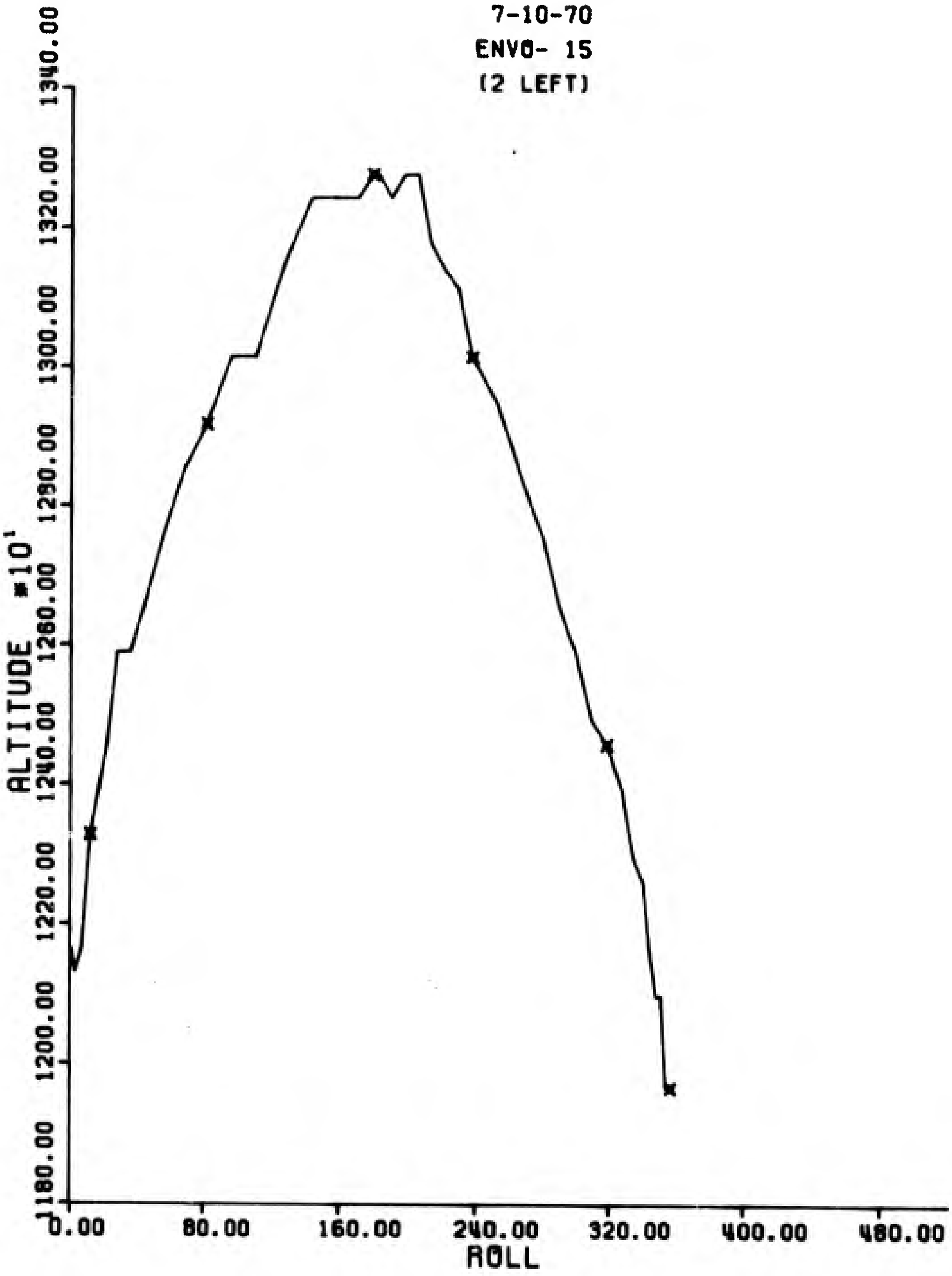


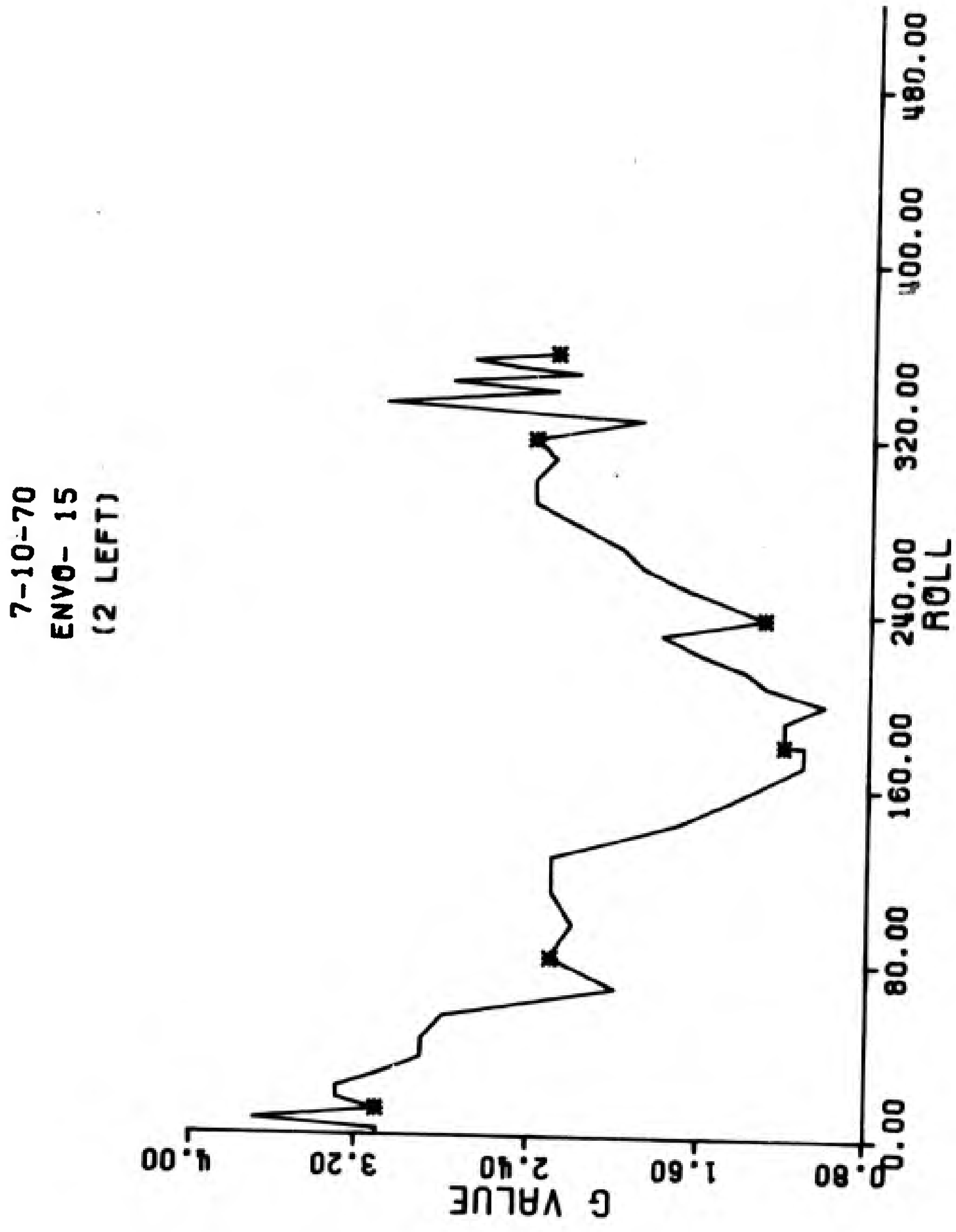
7-10-70
ENV0- 15
(2 LEFT)



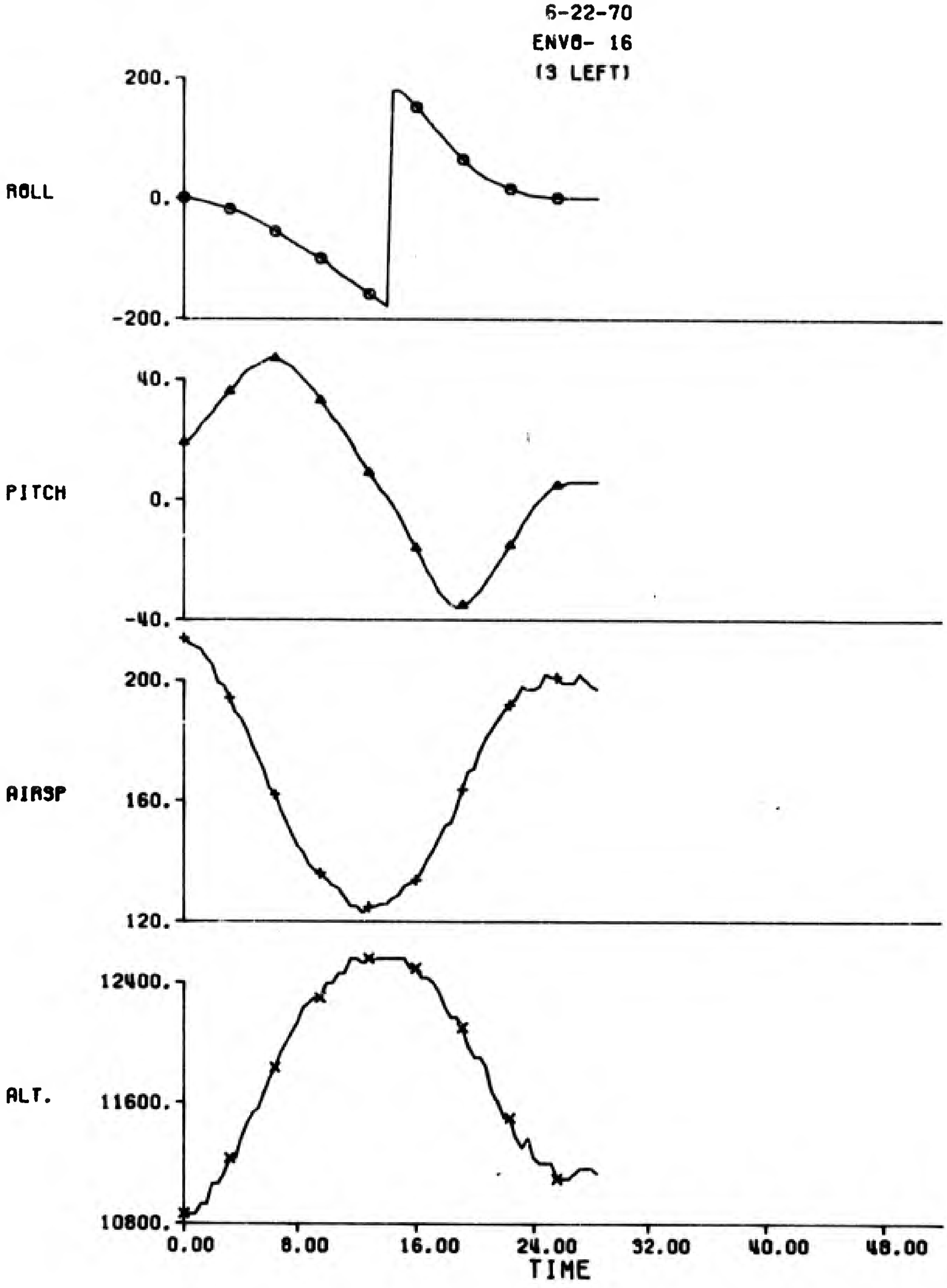
ROLL-PITCH PLOT

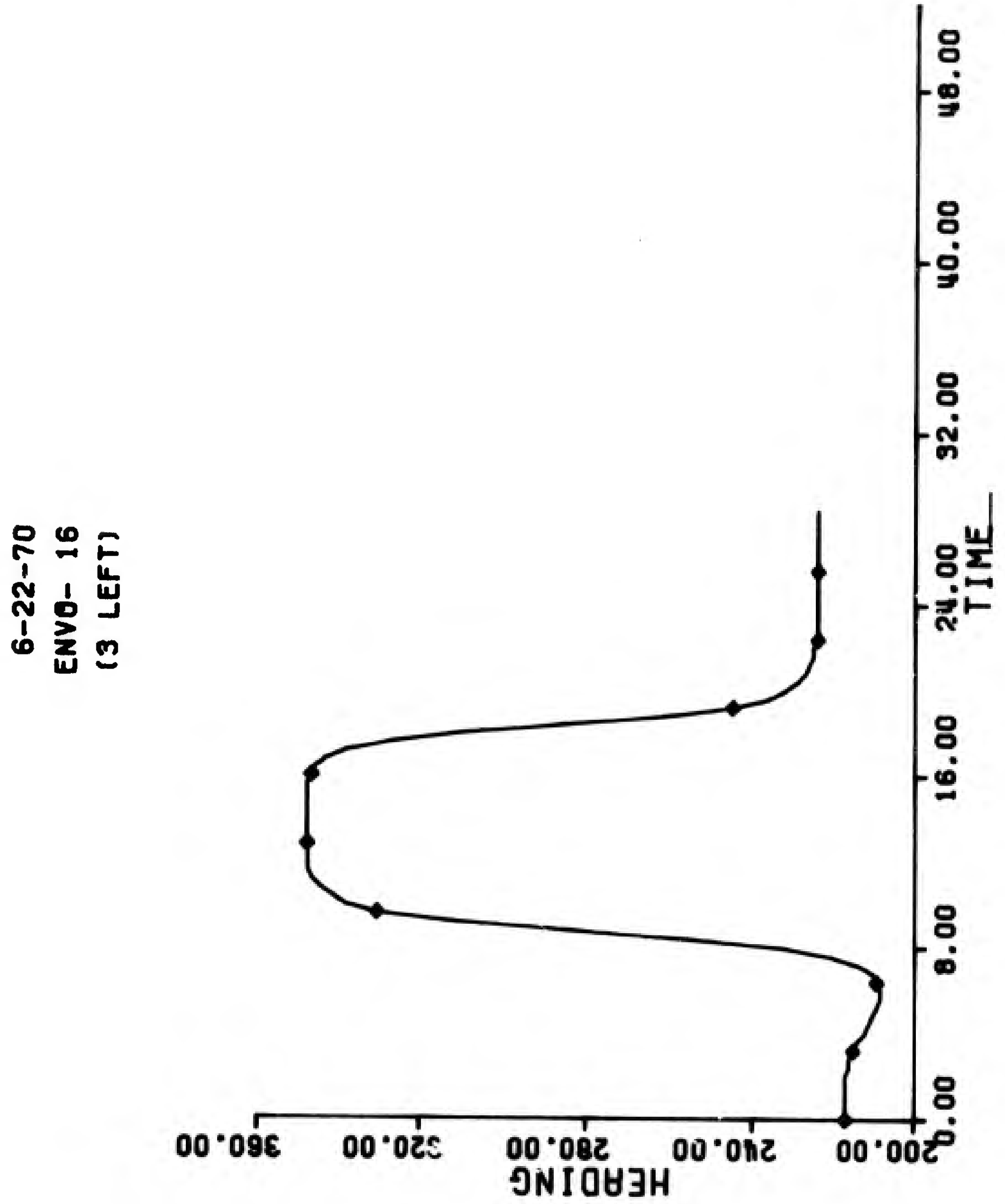

7-10-70
ENVO- 15
(2 LEFT)
PITCH
80.00
60.00
40.00
20.00
0.00
-20.00
-40.00
-60.00
-80.00
0.00
80.00
160.00
240.00
320.00
400.00
480.00
ROLL


7-10-70
ENVO- 15
(2 LEFT)
ALTITUDE *10¹
1180.00
1200.00
1220.00
1240.00
1260.00
1280.00
1300.00
1320.00
1340.00
0.00
80.00
160.00
240.00
320.00
400.00
480.00
ROLL

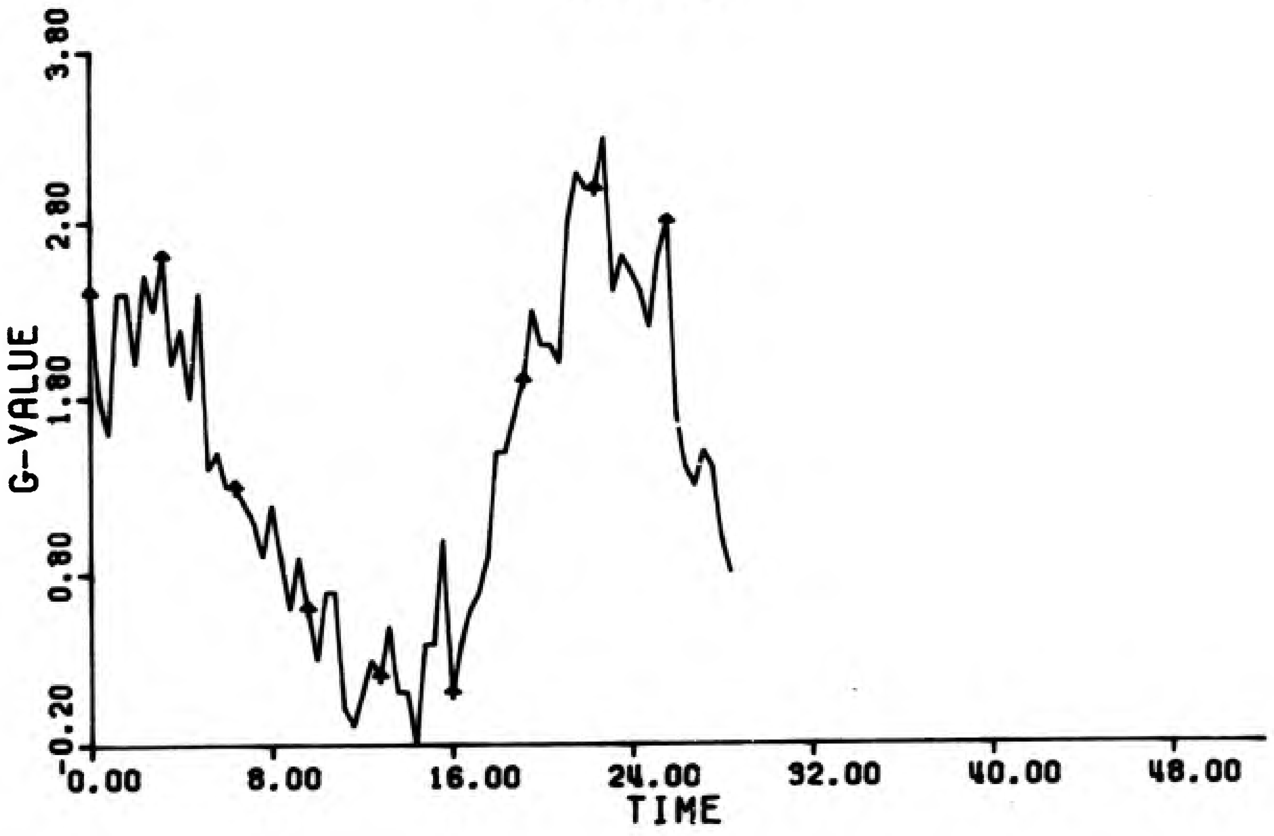


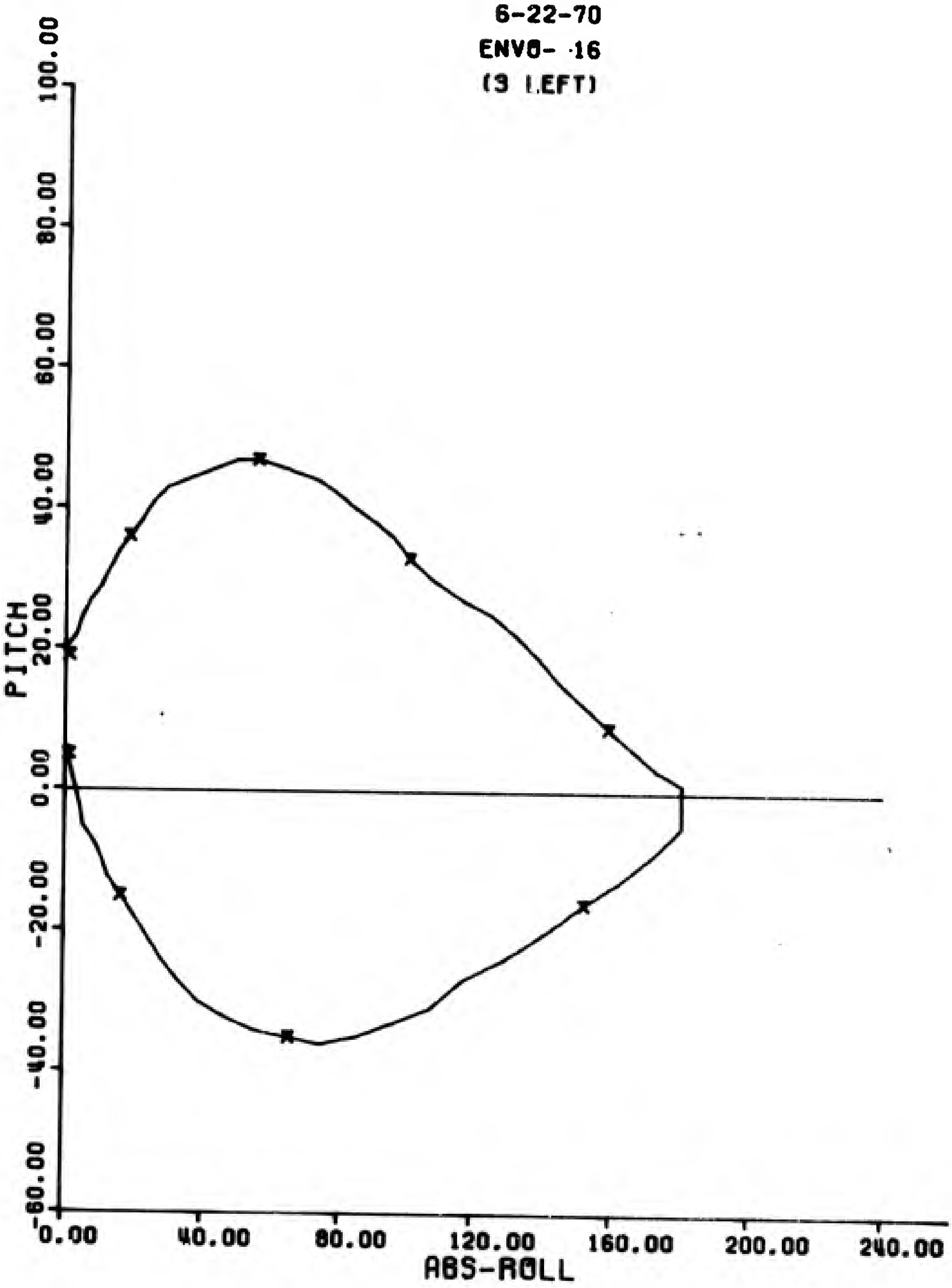
7-10-70
ENVO- 15
(2 LEFT)


6-22-70
ENV8- 16
(3 LEFT)
ROLL
200.
0.
-200.
PITCH
40.
0.
-40.
AIRSP
200.
160.
120.
ALT.
12400.
11600.
10800.
0.00
8.00
16.00
24.00
32.00
40.00
48.00
TIME

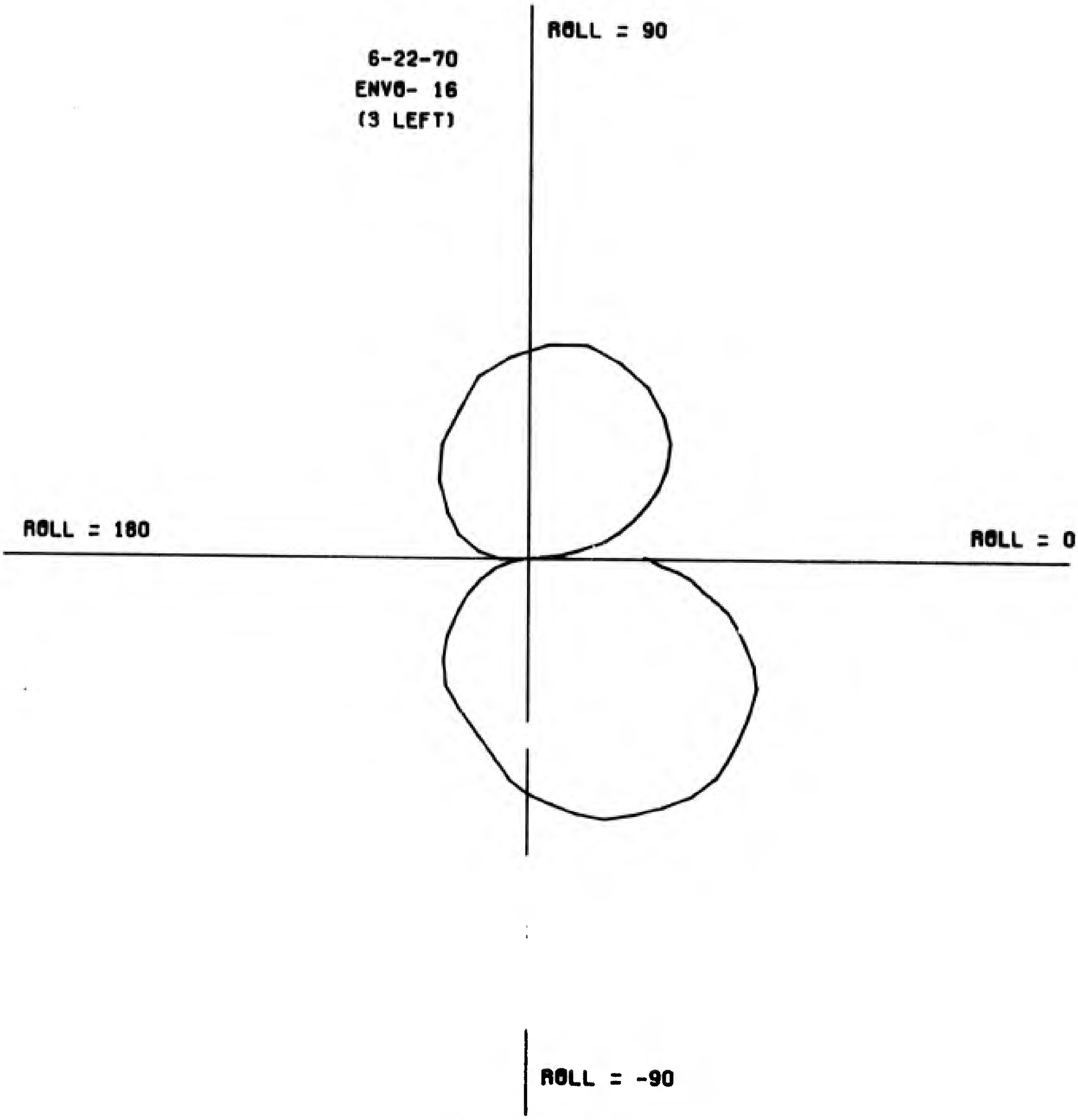

6-22-70
ENVO- 16
(3 LEFT)
TIME
0.00
8.00
16.00
24.00
32.00
40.00
48.00
HEADING
200.00
240.00
280.00
320.00
360.00

6-22-70
ENVG- 16
(3 LEFT)

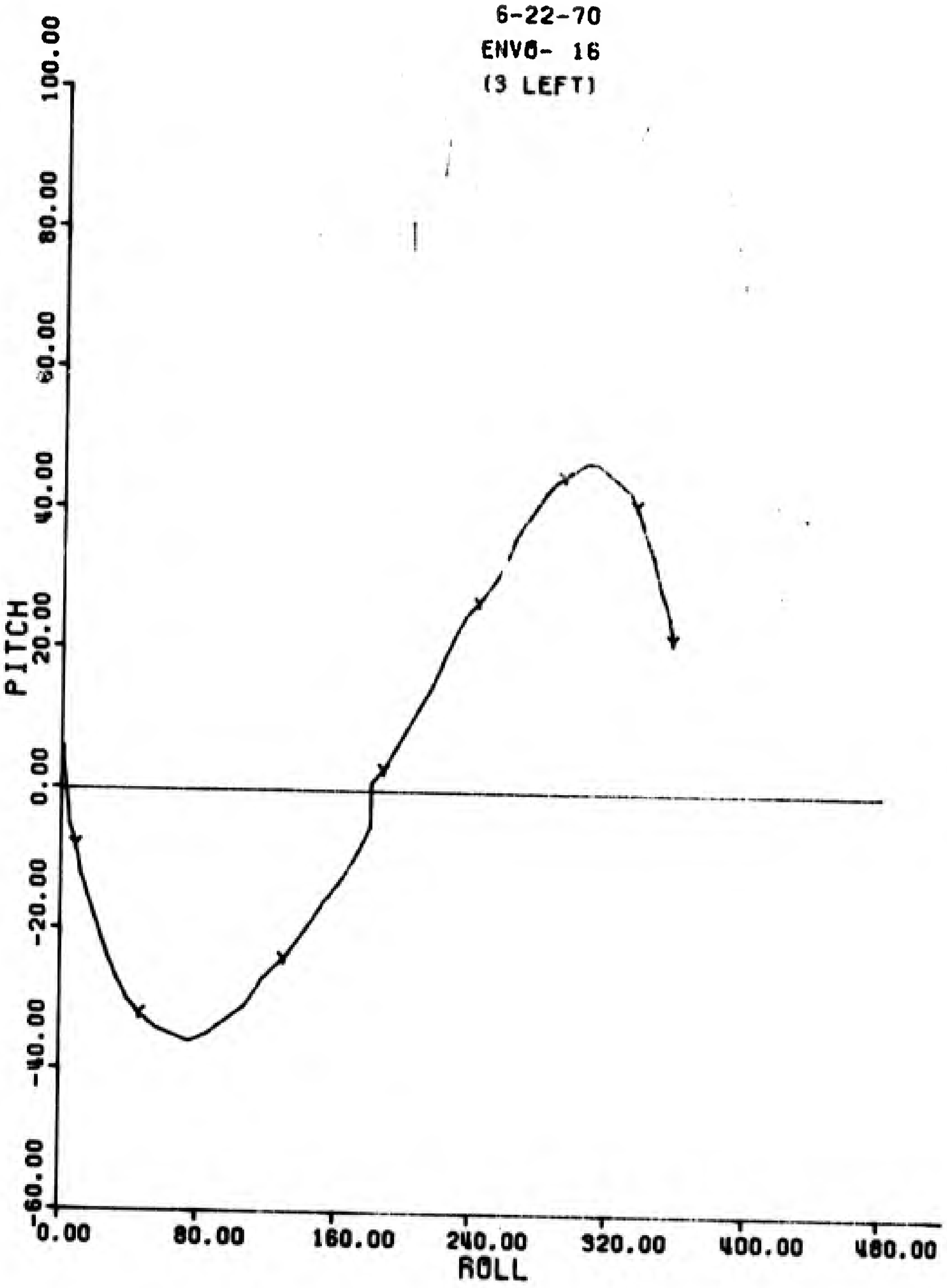


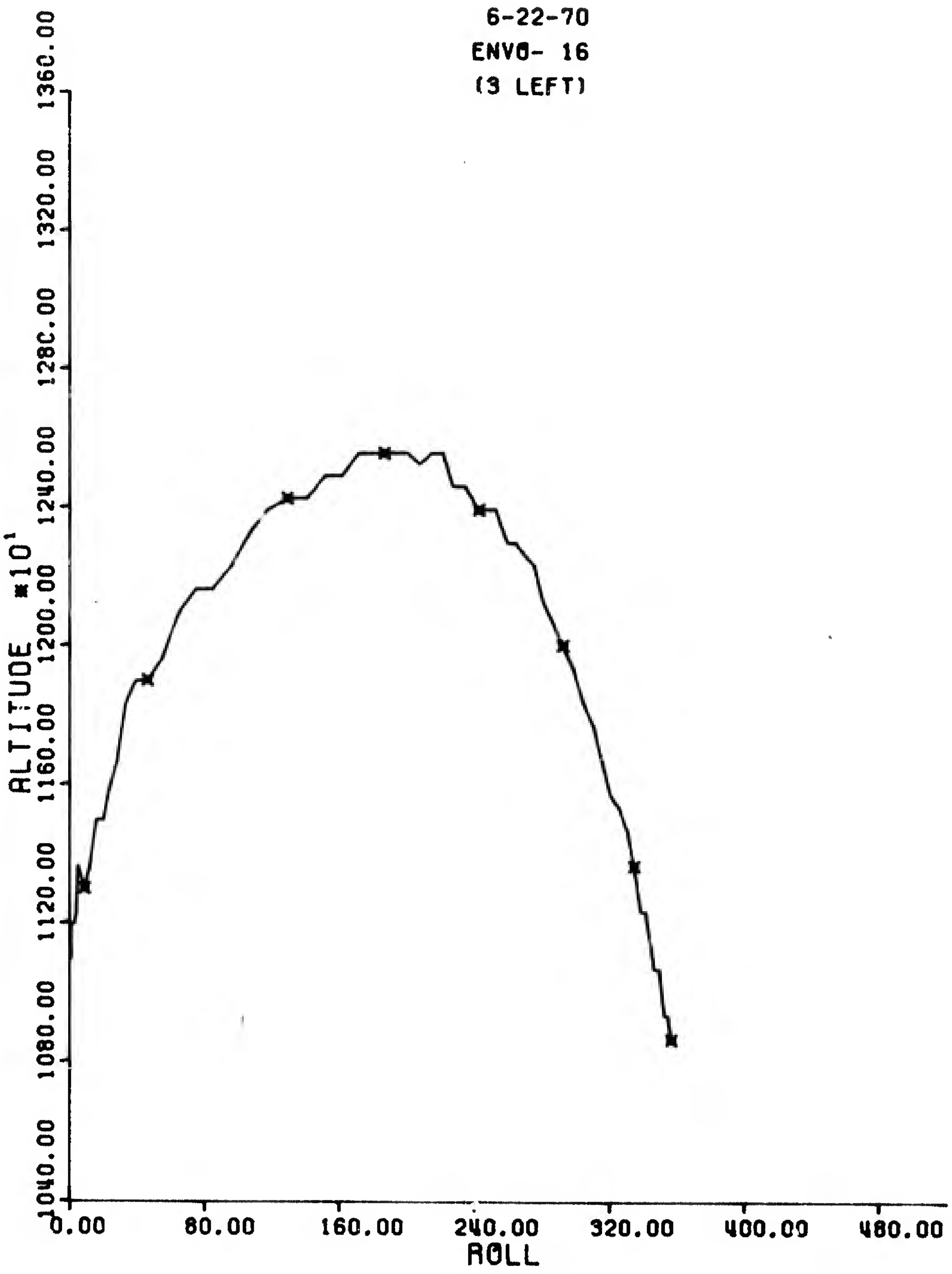


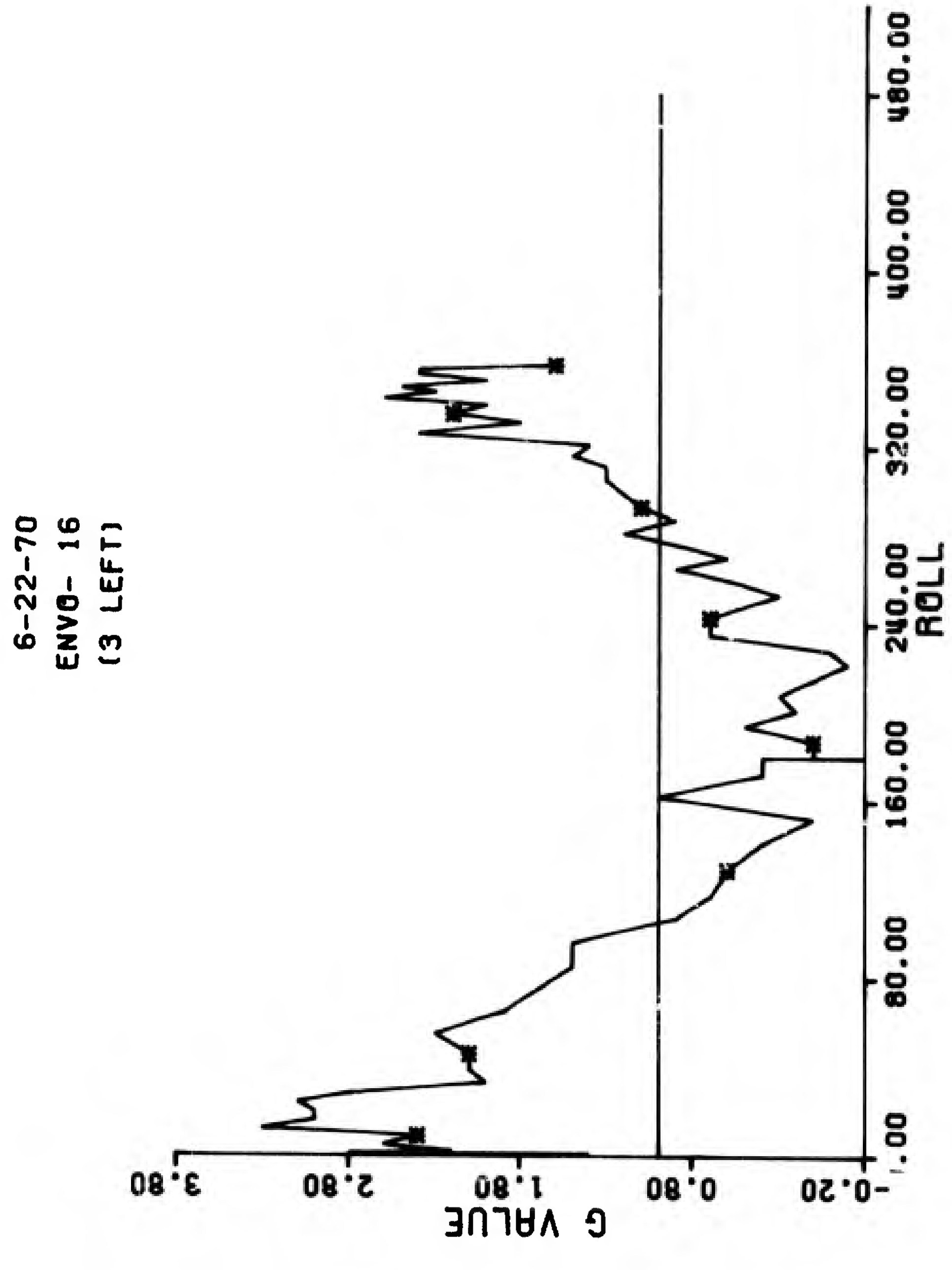
6-22-70
ENV8- 16
(3 LEFT)



ROLL-PITCH PLOT


6-22-70
ENV0- 16
(3 LEFT)
PITCH
100.00
80.00
60.00
40.00
20.00
0.00
-20.00
-40.00
-60.00
ROLL
0.00
80.00
160.00
240.00
320.00
400.00
480.00


6-22-70
ENV0- 16
(3 LEFT)
ALTITUDE *10¹
1360.00
1320.00
1280.00
1240.00
1200.00
1160.00
1120.00
1080.00
1040.00
0.00
80.00
160.00
240.00
320.00
400.00
480.00
ROLL


6-22-70
ENVG- 16
(3 LEFT)
G VALUE
3.80
2.80
1.80
0.80
-0.20
.00
80.00
160.00
240.00
320.00
400.00
480.00
ROLL

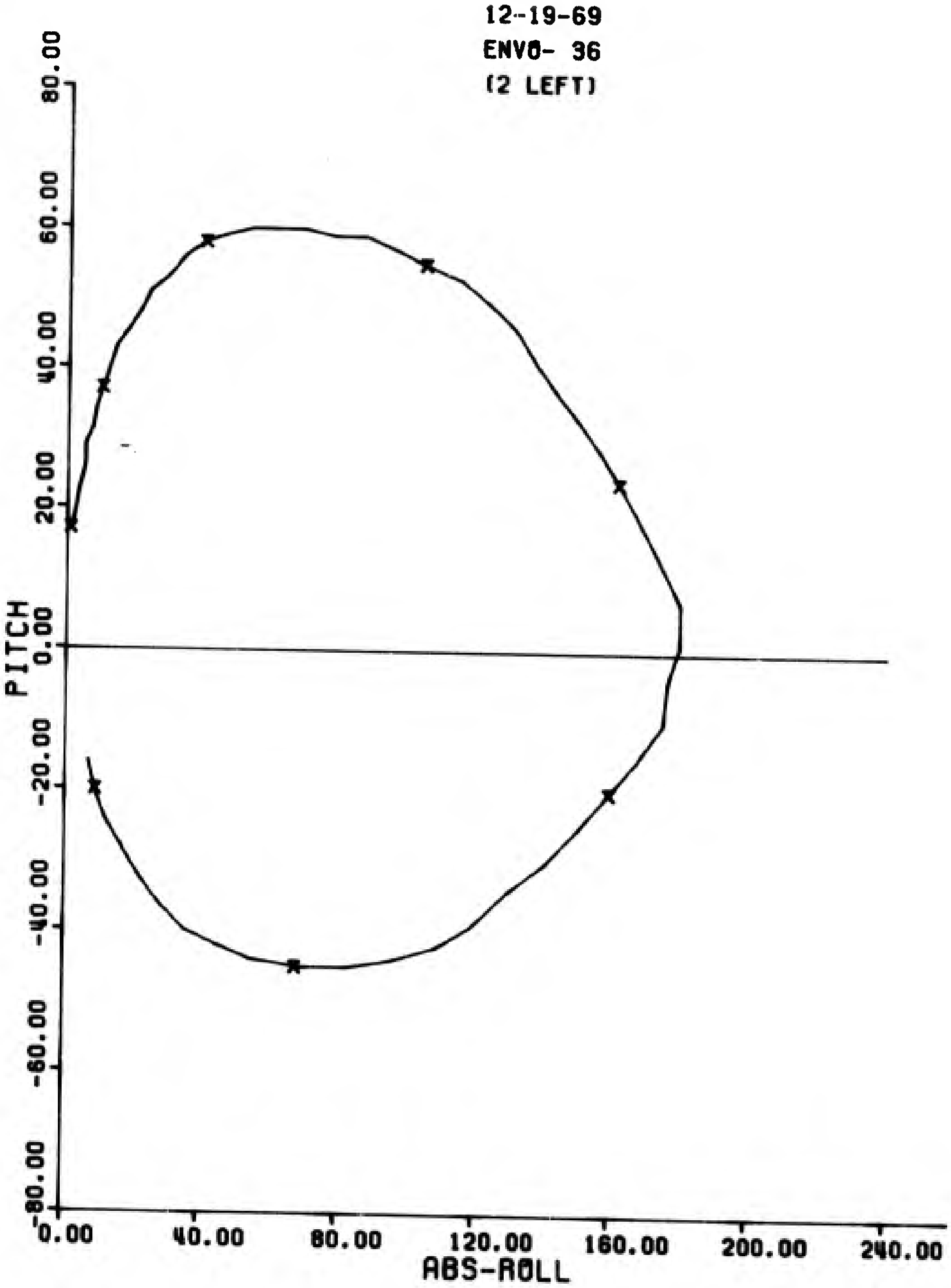
APPENDIX XVIII

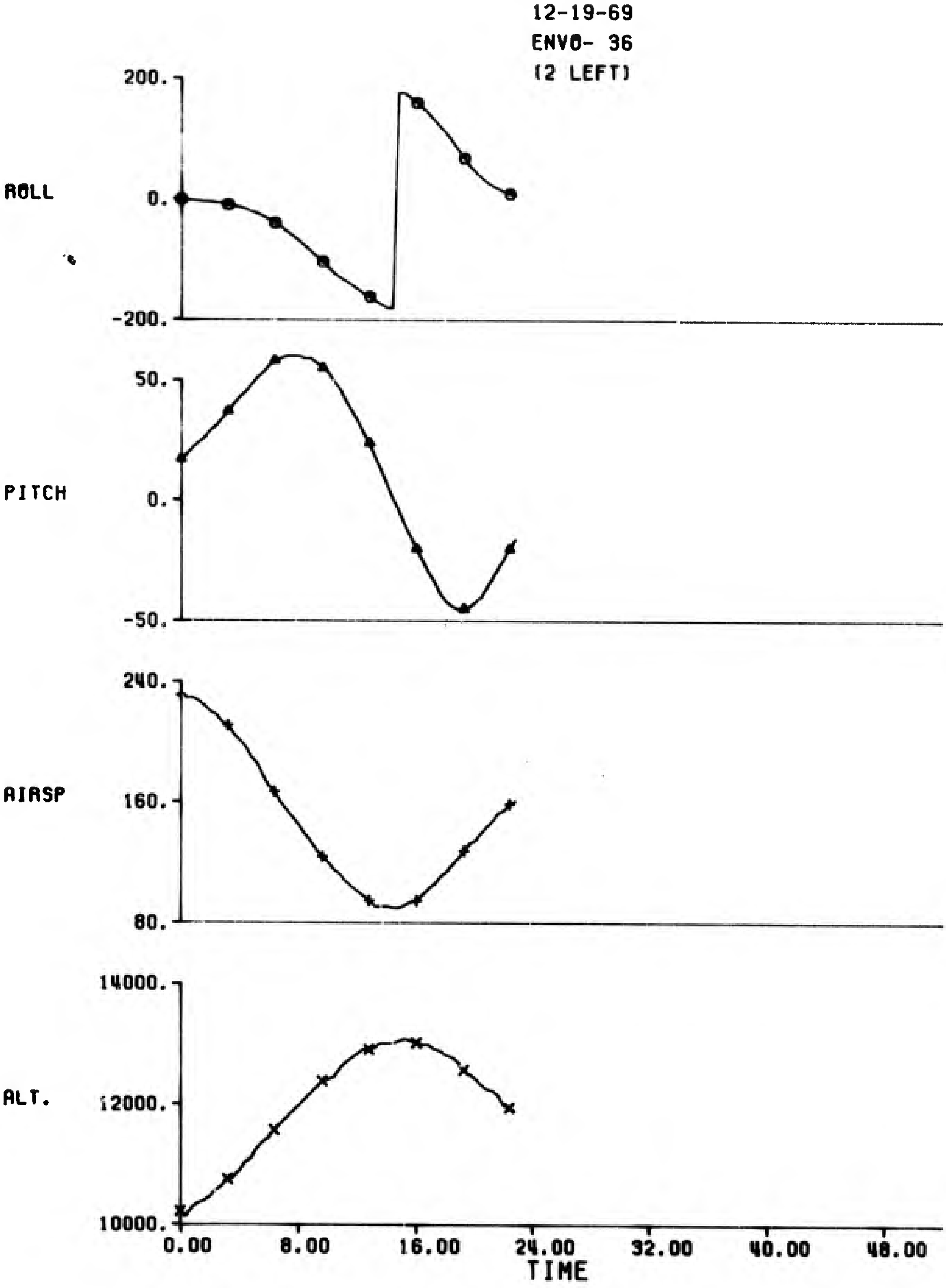
REPRESENTATIVE BARREL ROLL PLOTS

Preceding page blank

(PILOT'S COMMENTS)

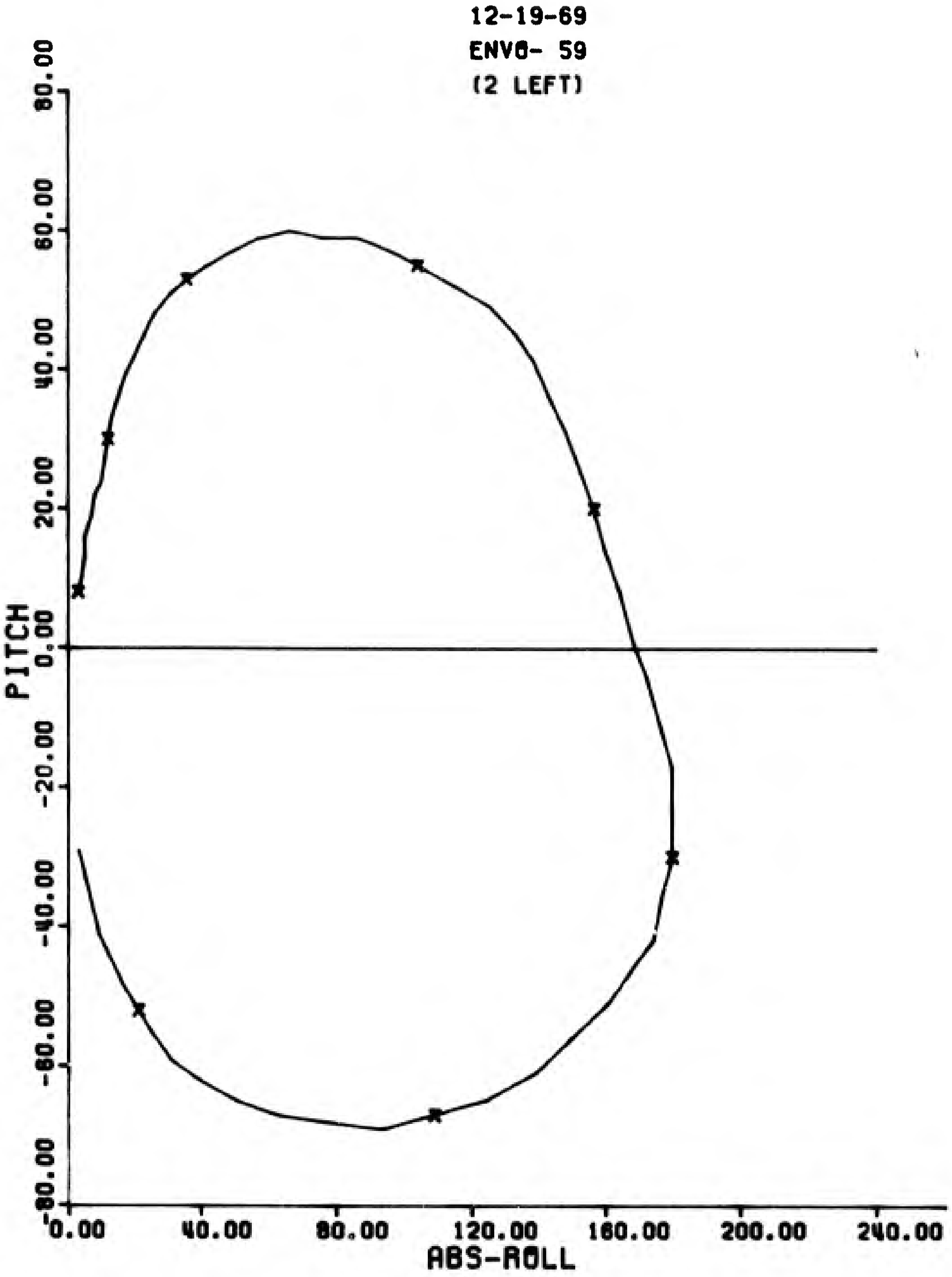
"This will be Barrel Roll No. 1, Event 36. The trouble in barrel rolls is essentially the same troubles as we have in lazy 8's. Student enters with the nose low, gets the proper parameters, starts his turn off, turns back up, is through straight and level flight with bank still in. Way too much pitch during this half of the maneuver. Not enough back pressure, too much bank. He is not very far off the point to the other side, rolls back up and is back to straight and level flight near his original point; however, if the whole maneuver were shifted up, that would be a fair maneuver."

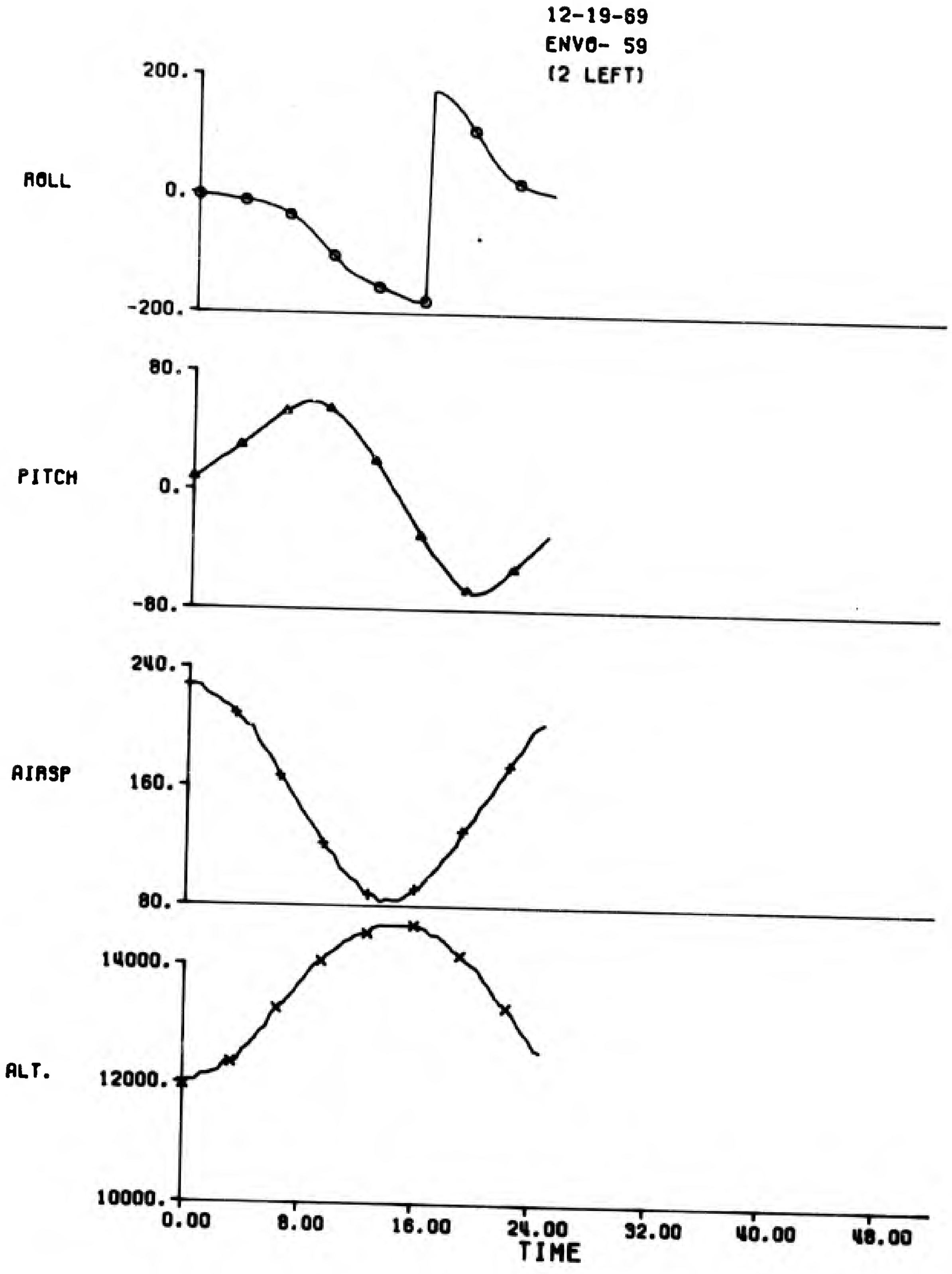

12-19-69
ENV0- 36
(2 LEFT)
PITCH
80.00
60.00
40.00
20.00
0.00
-20.00
-40.00
-60.00
-80.00
0.00
40.00
80.00
120.00
160.00
200.00
240.00
ABS-ROLL


12-19-69
ENV0- 36
(2 LEFT)
ROLL
200.
0.
-200.
PITCH
50.
0.
-50.
AIRSP
240.
160.
80.
ALT.
14000.
12000.
10000.
0.00
8.00
16.00
24.00
32.00
40.00
48.00
TIME

(PILOT'S COMMENTS)

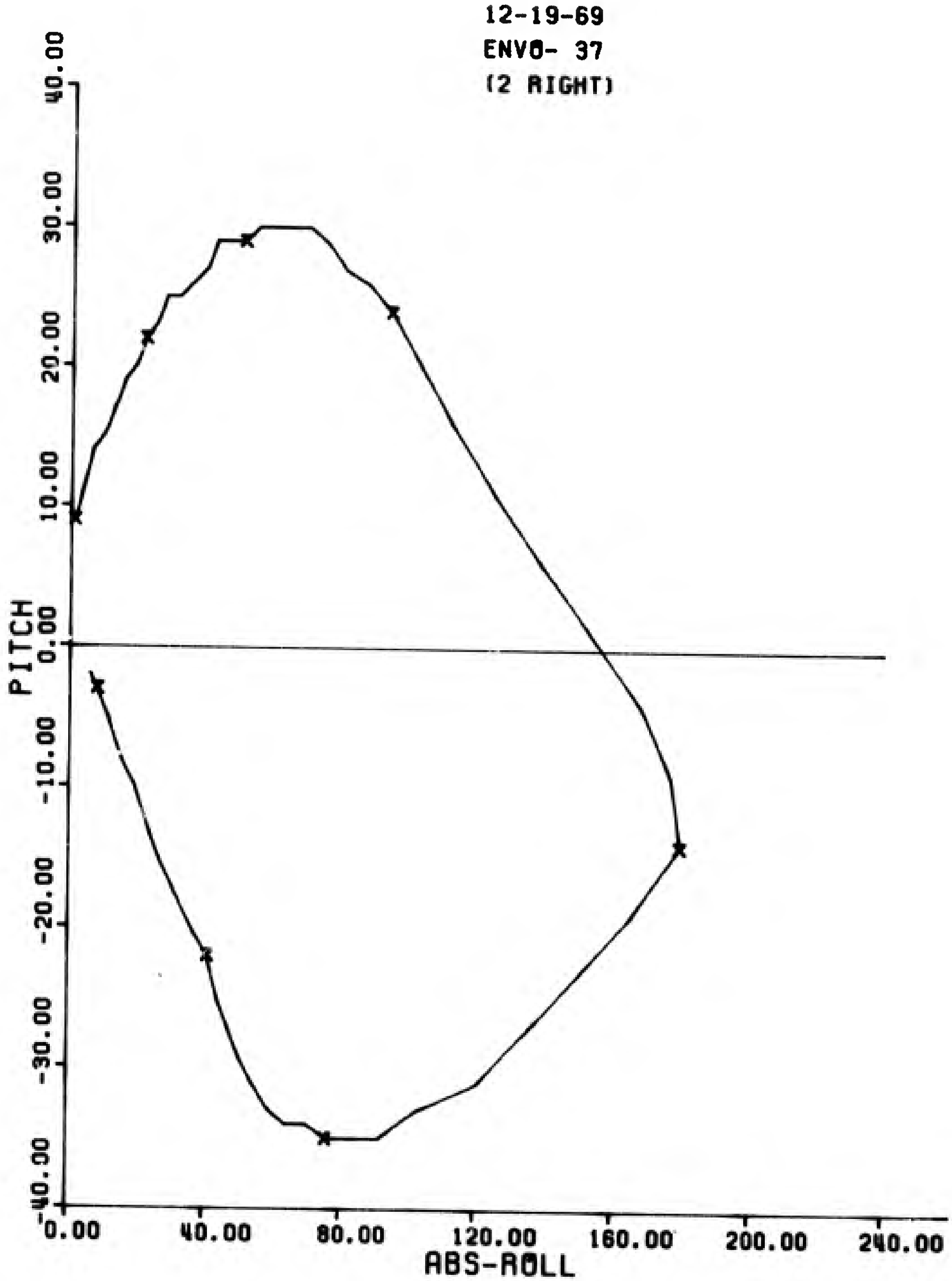
"Barrel Roll No. 6, event No. 59. The nose is below the point. Turn off. Our reference point about 20-30°. Begin the maneuver itself. This time, something that is fairly common for students to do is not to make allowance for the change of airspeed in the rate of roll that is required. Here I am not changing the aileron pressures; as a result the rate of roll is slowing down, and as we come out of the bottom of the maneuver the rate of roll increases and we wind up making a bigger maneuver than we should have and kind of dishing out at the bottom and that would have been a fair maneuver."

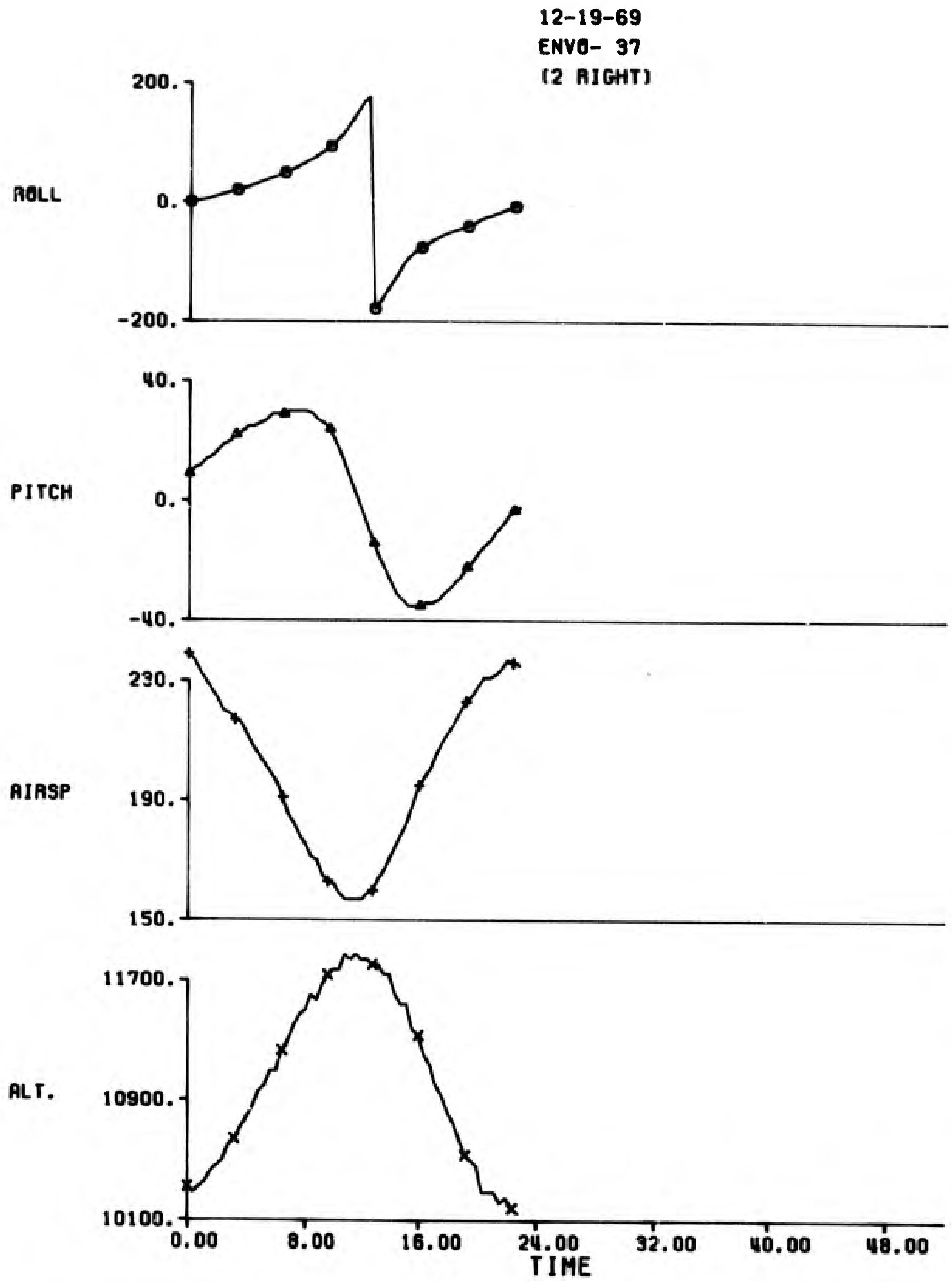

12-19-69
ENV6- 59
(2 LEFT)
PITCH
80.00
60.00
40.00
20.00
0.00
-20.00
-40.00
-60.00
-80.00
0.00
40.00
80.00
120.00
160.00
200.00
240.00
ABS-ROLL


12-19-69
ENVO- 59
(2 LEFT)
ROLL
200.
0.
-200.
PITCH
80.
0.
-80.
AIRSP
240.
160.
80.
ALT.
14000.
12000.
10000.
0.00
8.00
16.00
24.00
32.00
40.00
48.00
TIME

(PILOT'S COMMENTS)

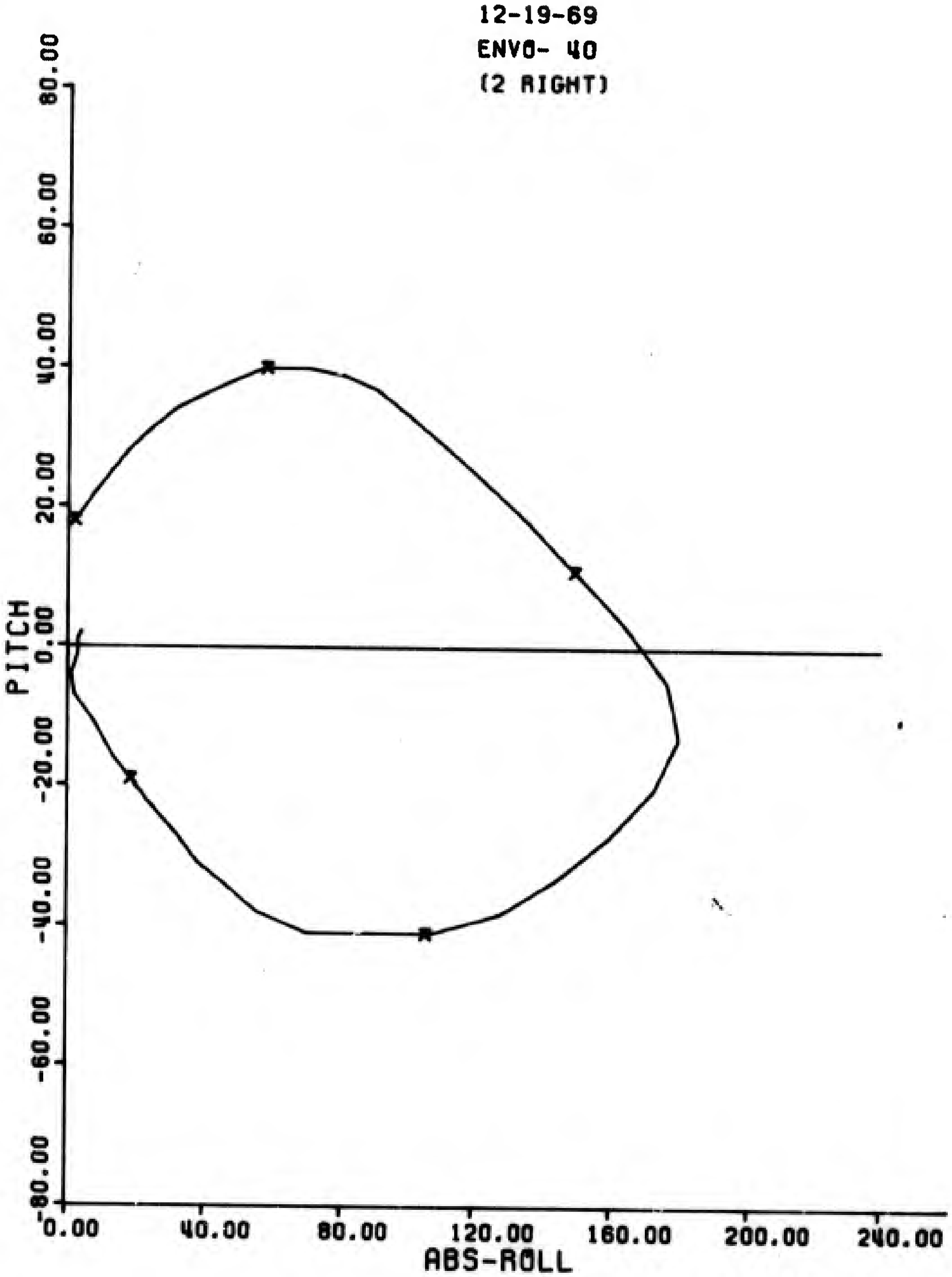
"This will be barrel roll 2, event No. 37. This one again has the nose below the point, turns off a given distance, comes through straight and level flight. Gets a pretty fair start of the thing, not enough back pressure during the first part, consequently the first half of the maneuver is flattened out; he has to roll much too rapidly to get his nose through at the proper attitude. He continues to roll too fast and winds up flattening out the bottom part of the maneuver. He has basic idea that he is flattening it out too much."

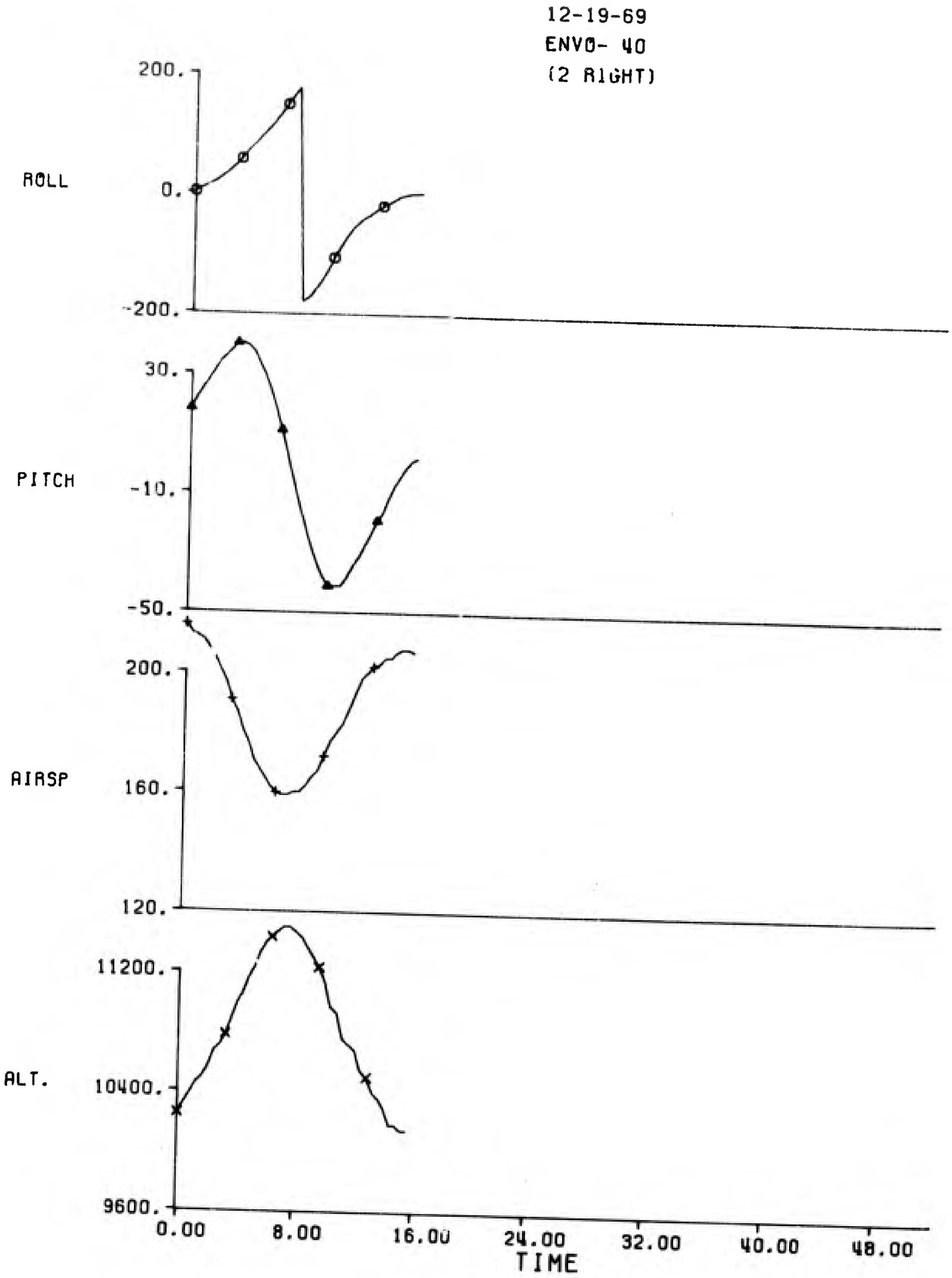

12-19-69
ENV0- 37
(2 RIGHT)
PITCH
40.00
30.00
20.00
10.00
0.00
-10.00
-20.00
-30.00
-40.00
0.00
40.00
80.00
120.00
160.00
200.00
240.00
ABS-ROLL


12-19-69
ENVO- 37
(2 RIGHT)
ROLL
200.
0.
-200.
PITCH
40.
0.
-40.
AIRSP
230.
190.
150.
ALT.
11700.
10900.
10100.
0.00
8.00
16.00
24.00
32.00
40.00
48.00
TIME

(PILOT'S COMMENTS)

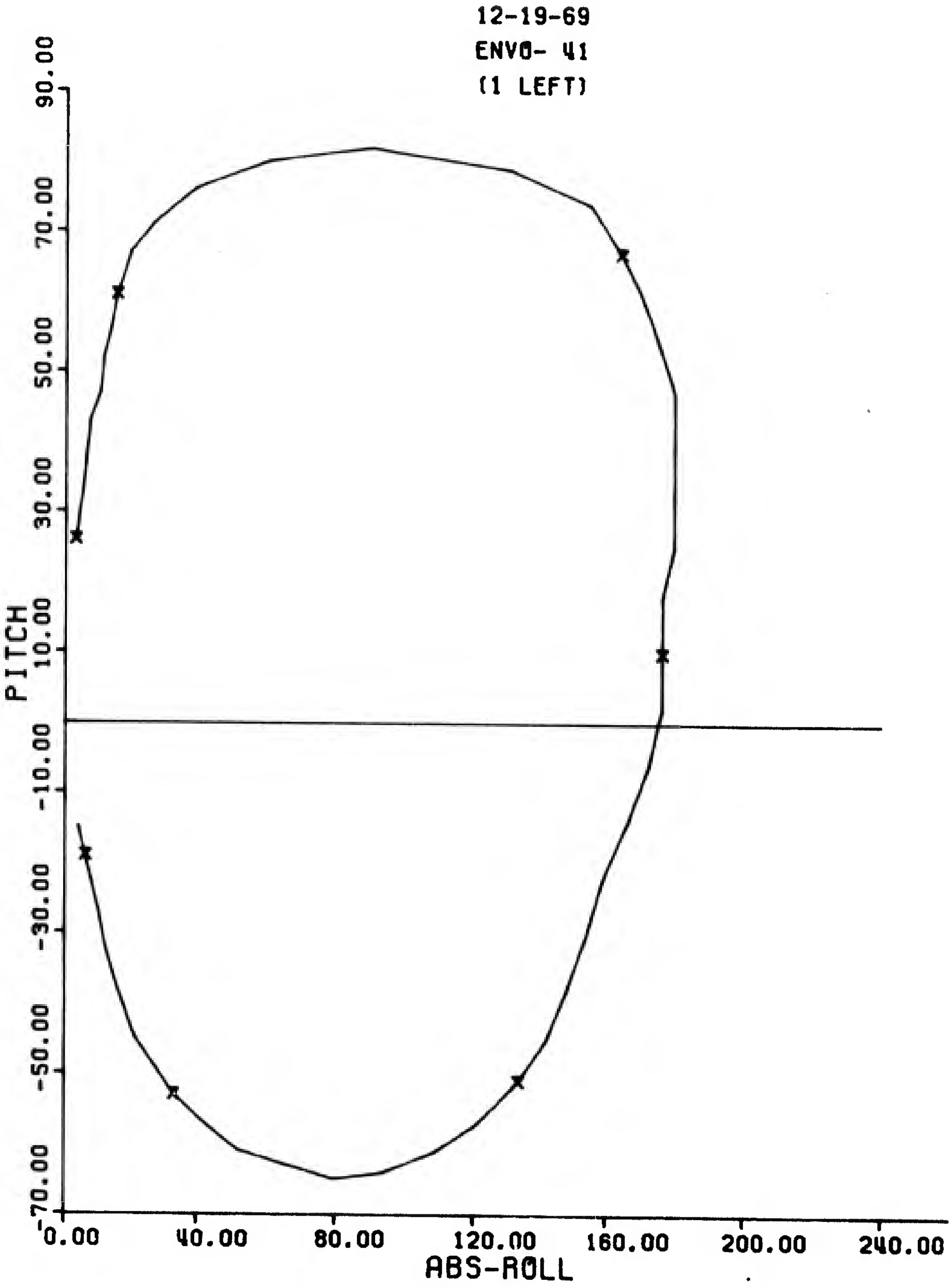
"Barrel roll 5, event No. 40. Nose below the point coming up on our entry airspeed; in this one again you have got the real tiger flying the airplane. Basically a little too aggressive with it. He is pretty smooth with the controls. But he flies a very tight, very aggressive barrel roll which is fine as far as aggressiveness goes but it does not quite look like a barrel roll is supposed to look, and that would be a fair maneuver."

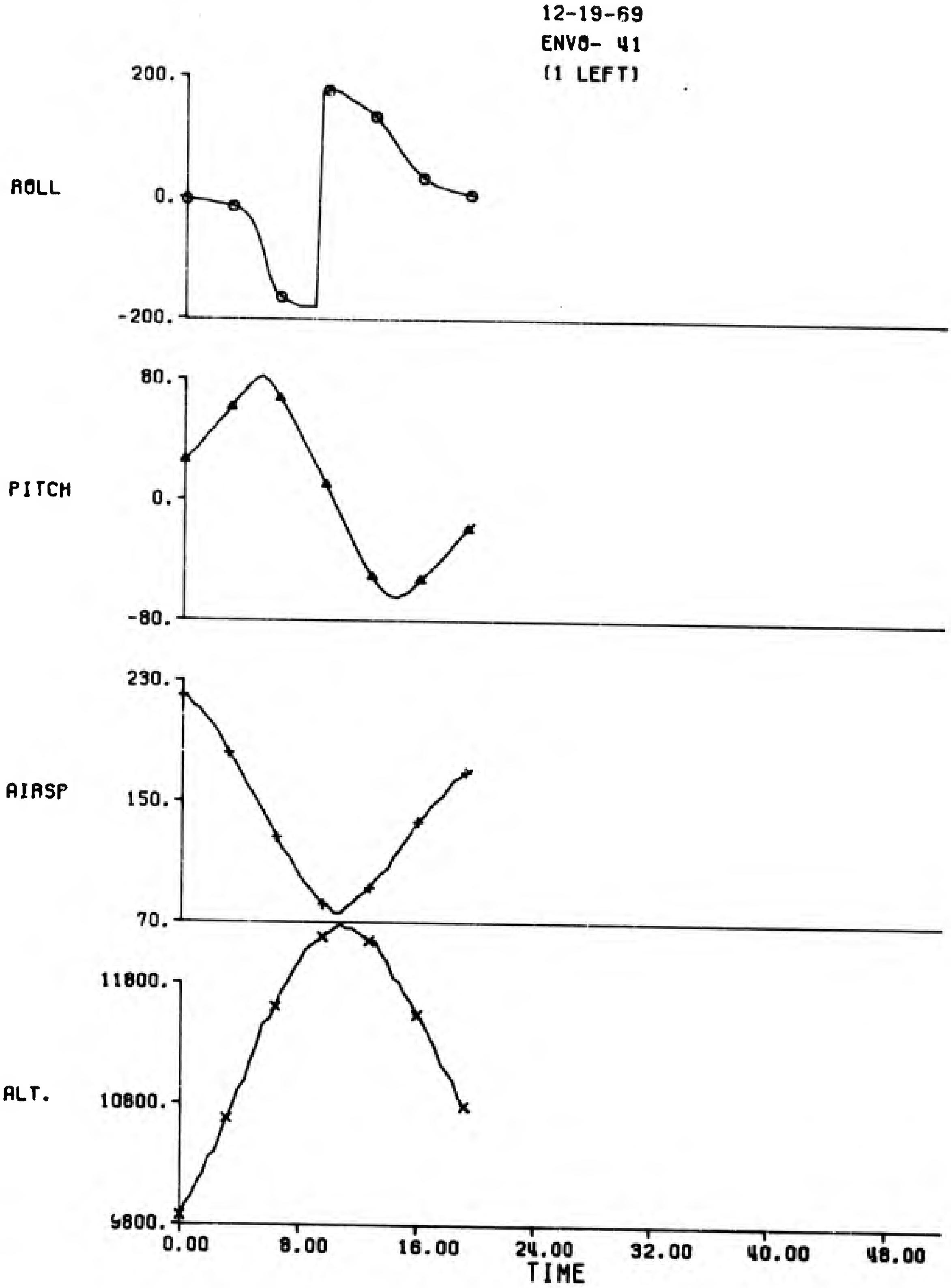

12-19-69
ENV0- 40
(2 RIGHT)
PITCH
80.00
60.00
40.00
20.00
0.00
-20.00
-40.00
-60.00
-80.00
0.00
40.00
80.00
120.00
160.00
200.00
240.00
ABS-ROLL


12-19-69
ENVO- 40
(2 RIGHT)
ROLL
200.
0.
-200.
PITCH
30.
-10.
-50.
AIRSP
200.
160.
120.
ALT.
11200.
10400.
9600.
0.00
8.00
16.00
24.00
32.00
40.00
48.00
TIME

(PILOT'S COMMENTS)

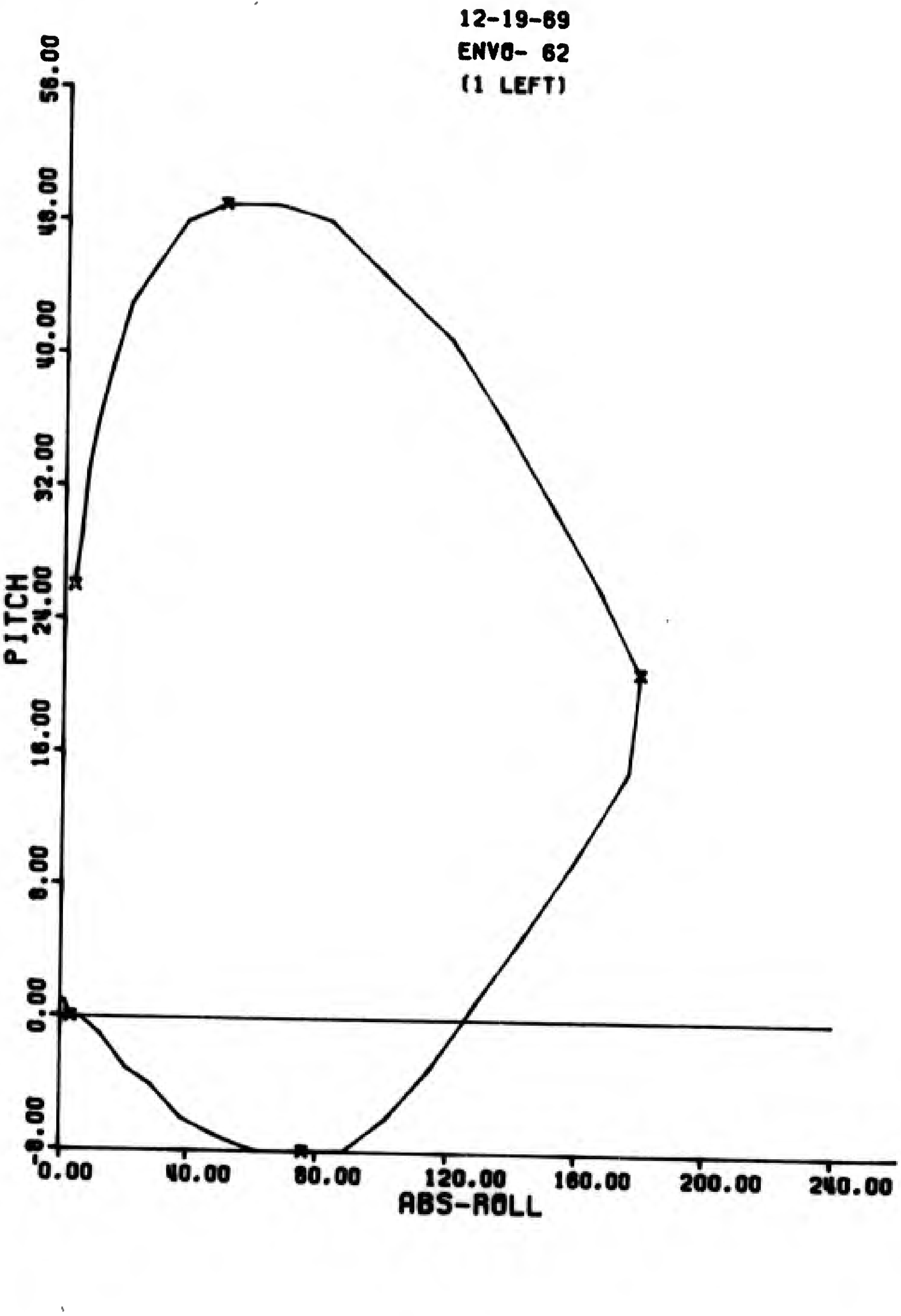
"Nose below the point entering, turns off much too far, back through not in straight and level flight, essentially winds up flying a loop around his point. The nose is much too far off the point; a little bit of burble on the top and we are back up. However we are about 60 or 70° off our point, and that would be an unsatisfactory maneuver also."

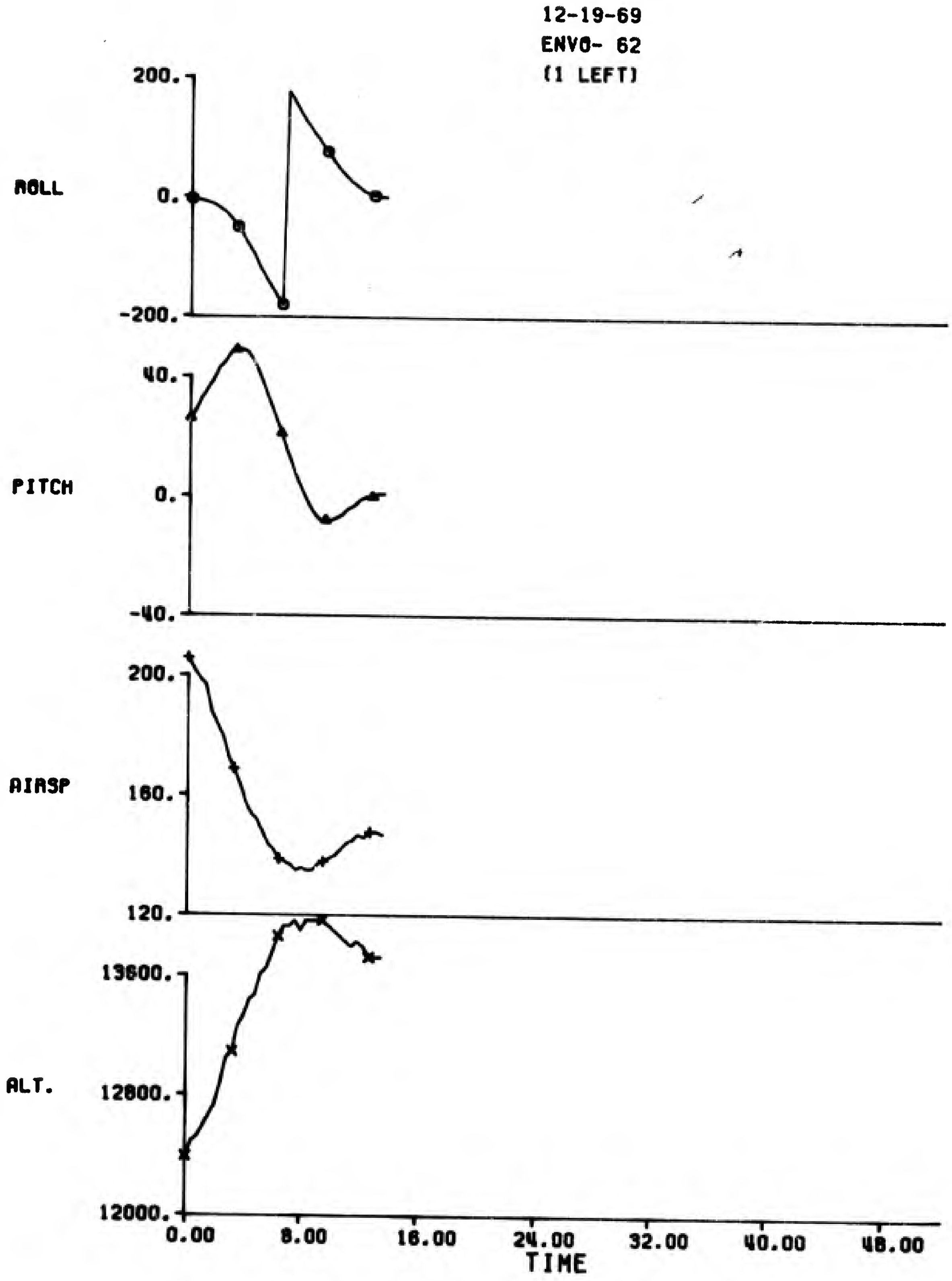

12-19-69
ENV0- 41
(1 LEFT)
PITCH
90.00
70.00
50.00
30.00
10.00
-10.00
-30.00
-50.00
-70.00
0.00
40.00
80.00
120.00
160.00
200.00
240.00
ABS-ROLL


12-19-69
ENVO- 41
(1 LEFT)
ROLL
200.
0.
-200.
PITCH
80.
0.
-80.
AIRSP
230.
150.
70.
ALT.
11800.
10800.
9800.
0.00
8.00
16.00
24.00
32.00
40.00
48.00
TIME

(PILOT'S COMMENTS)

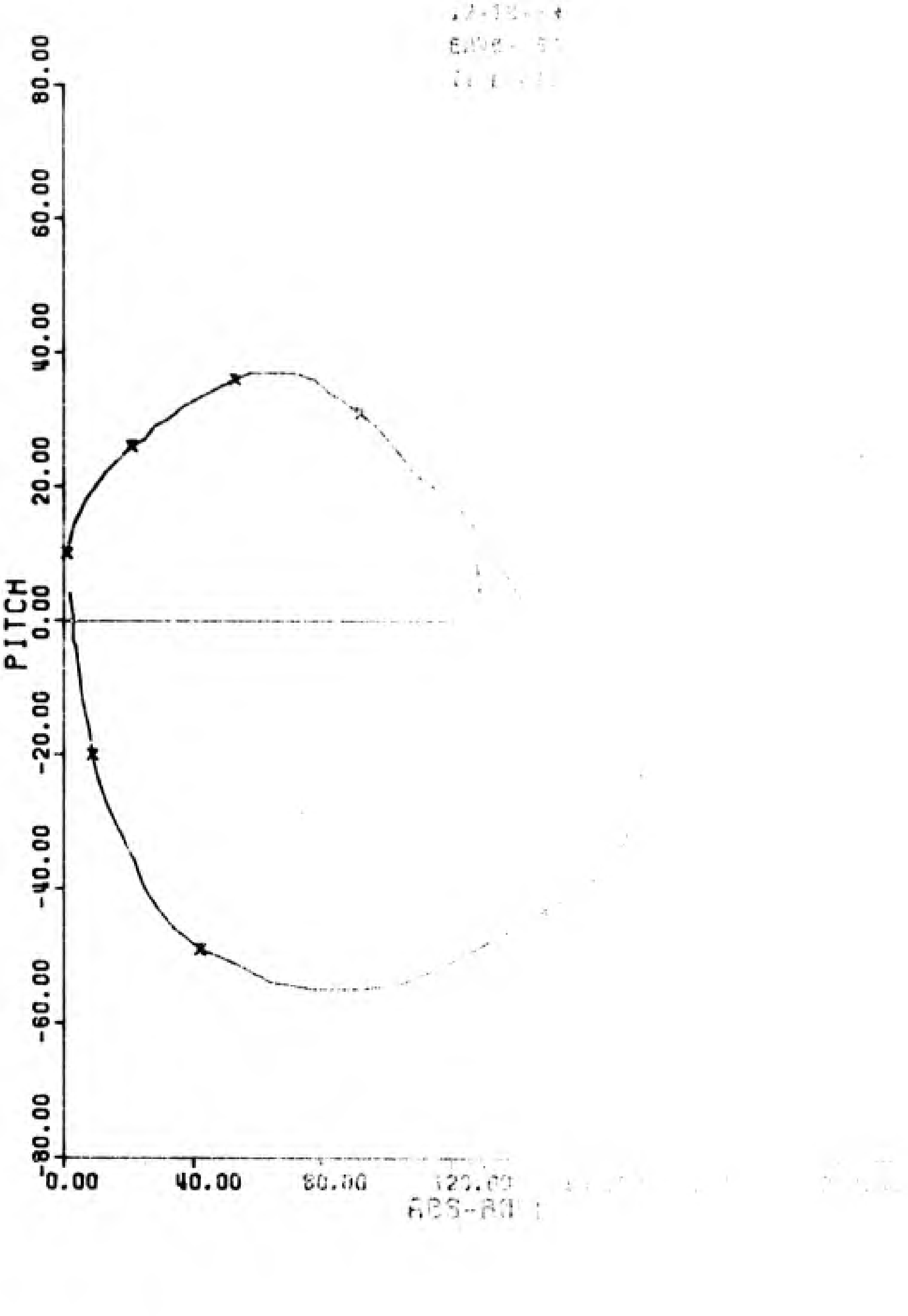
"Turn back around to the west. This will be barrel roll No. 9, event No. 62. This is the student who makes a reasonably good entry for the maneuver. Rolls the nose around his point, turns off, and then starts to roll initially with way too much back pressure and then just rolls easing up on the back pressure. As a result the nose never quite gets back to the horizon at all and you wind up at the original entry point. However, you have never descended at all and never made the lower part of the maneuver look anything like it's supposed to look. That would have been an unsatisfactory."

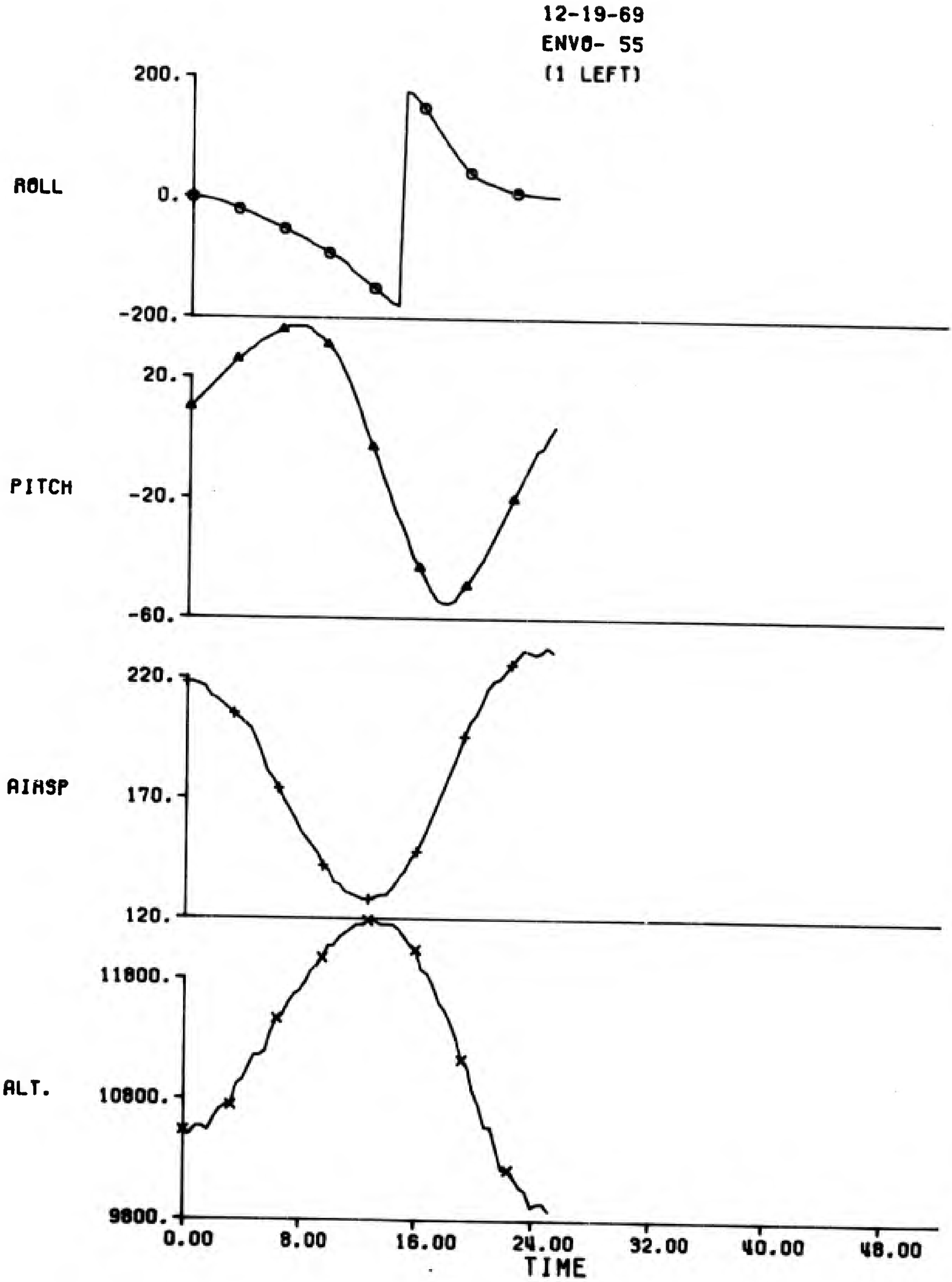

12-19-69
ENV0- 62
(1 LEFT)
PITCH
56.00
48.00
40.00
32.00
24.00
16.00
8.00
0.00
-8.00
ABS-ROLL
0.00
40.00
80.00
120.00
160.00
200.00
240.00


12-19-69
ENVO- 62
(1 LEFT)
ROLL
200.
0.
-200.
PITCH
40.
0.
-40.
AIRSP
200.
160.
120.
ALT.
13600.
12800.
12000.
0.00
8.00
16.00
24.00
32.00
40.00
48.00
TIME

(PILOT'S COMMENTS)

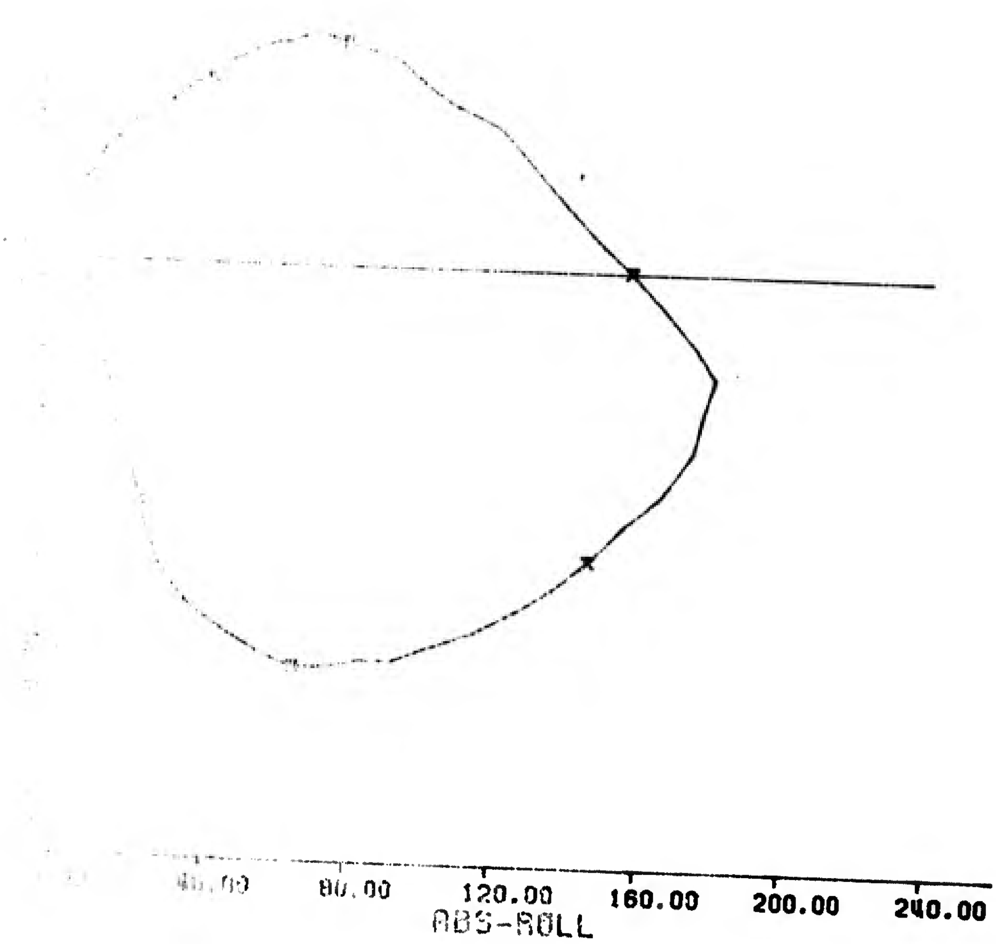
"This will be event No. 55, barrel roll 3. The nose is below the point. A lot of times when the student knows the maneuver he will turn off the point, do a pretty good job, look away for a minute and lose his reference point so that he winds up coming way over beyond the point coming through level flight with the bank indication, and because of this the nose comes well down below normal. He has to use a little higher rate of roll to come out at the bottom. Little more g's than necessary, way dished out. And that would have been an unsatisfactory barrel roll. Turn around and work back up toward the northwest momentarily."


80.00
60.00
40.00
20.00
0.00
-20.00
-40.00
-60.00
-80.00
PITCH
0.00
40.00
80.00
120.00

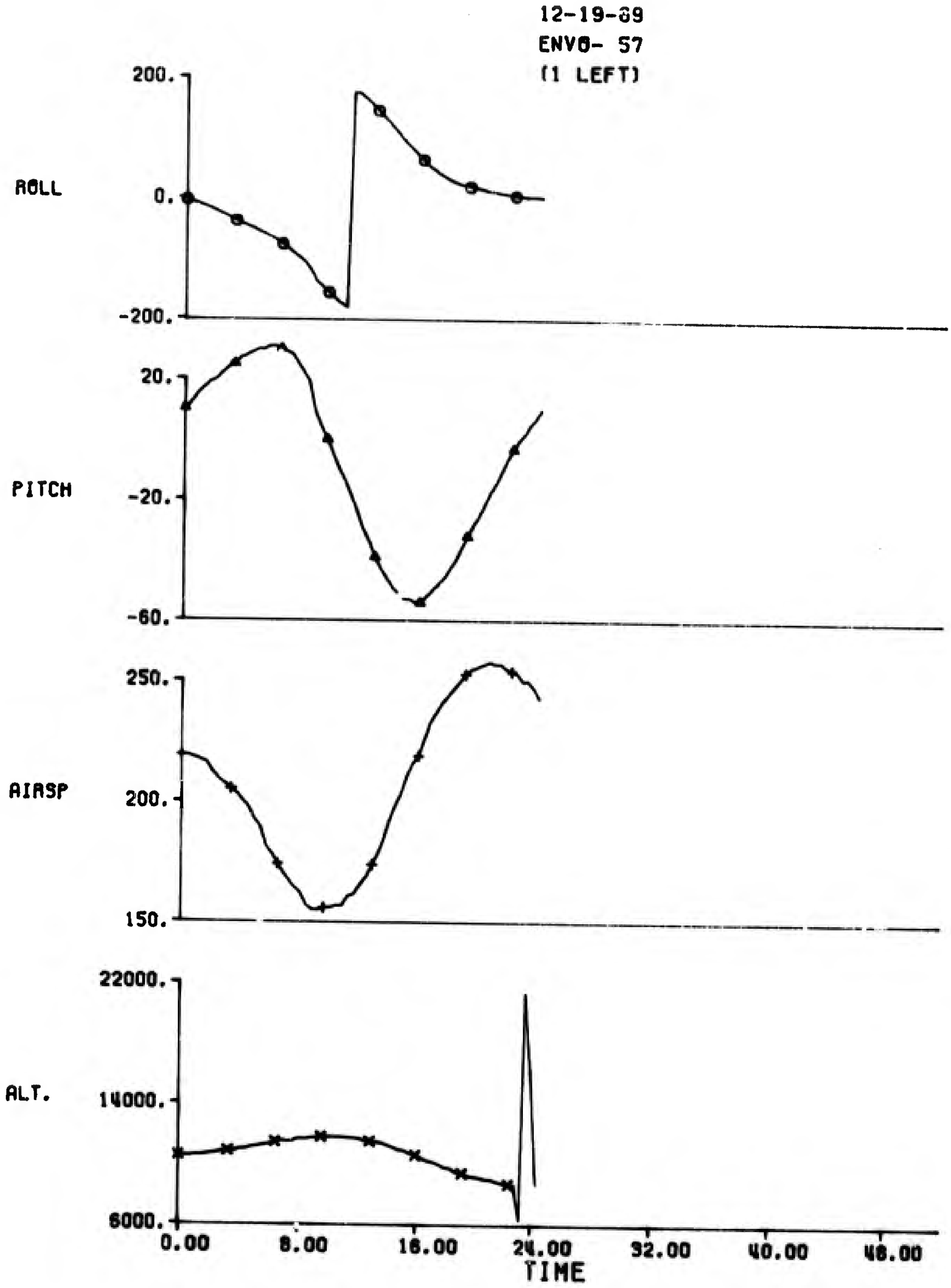

12-19-69
ENV0- 55
(1 LEFT)
ROLL
200.
0.
-200.
PITCH
20.
-20.
-60.
AIRSP
220.
170.
120.
ALT.
11800.
10800.
9800.
0.00
8.00
16.00
24.00
32.00
40.00
48.00
TIME

(PILOT'S COMMENTS)

"This will be barrel roll No. 5, event 57. Nose below the point, off. This time he rolls much too fast to start with. He is flattening out the maneuver much too much across the top. The nose is off the far side about as far as it should be, however, in here he is not rolling off nearly fast enough and 9 times out of 10 cases, he will wind up what we consider to be a high speed dive recovery. That would have been unsatisfactory."

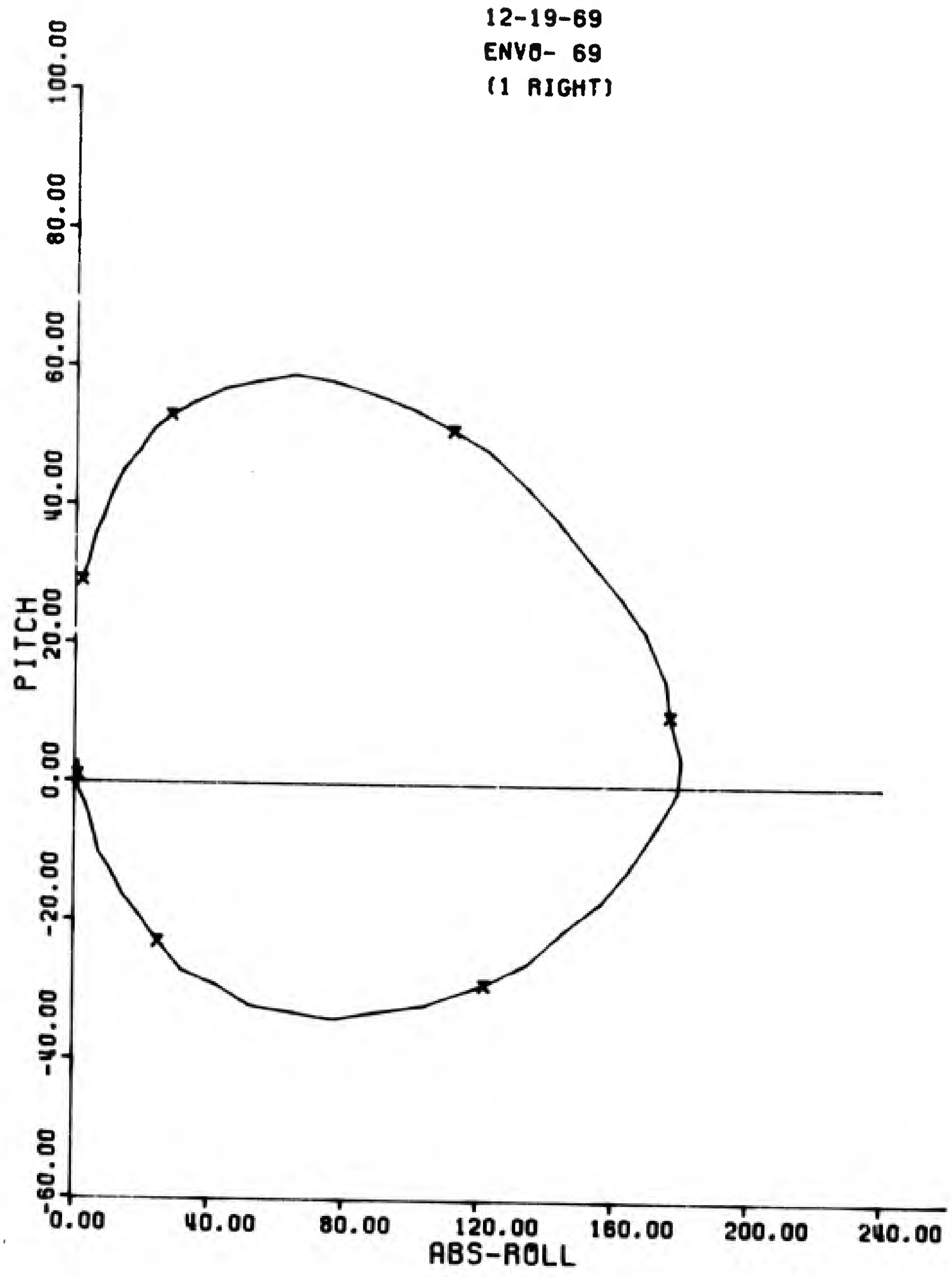


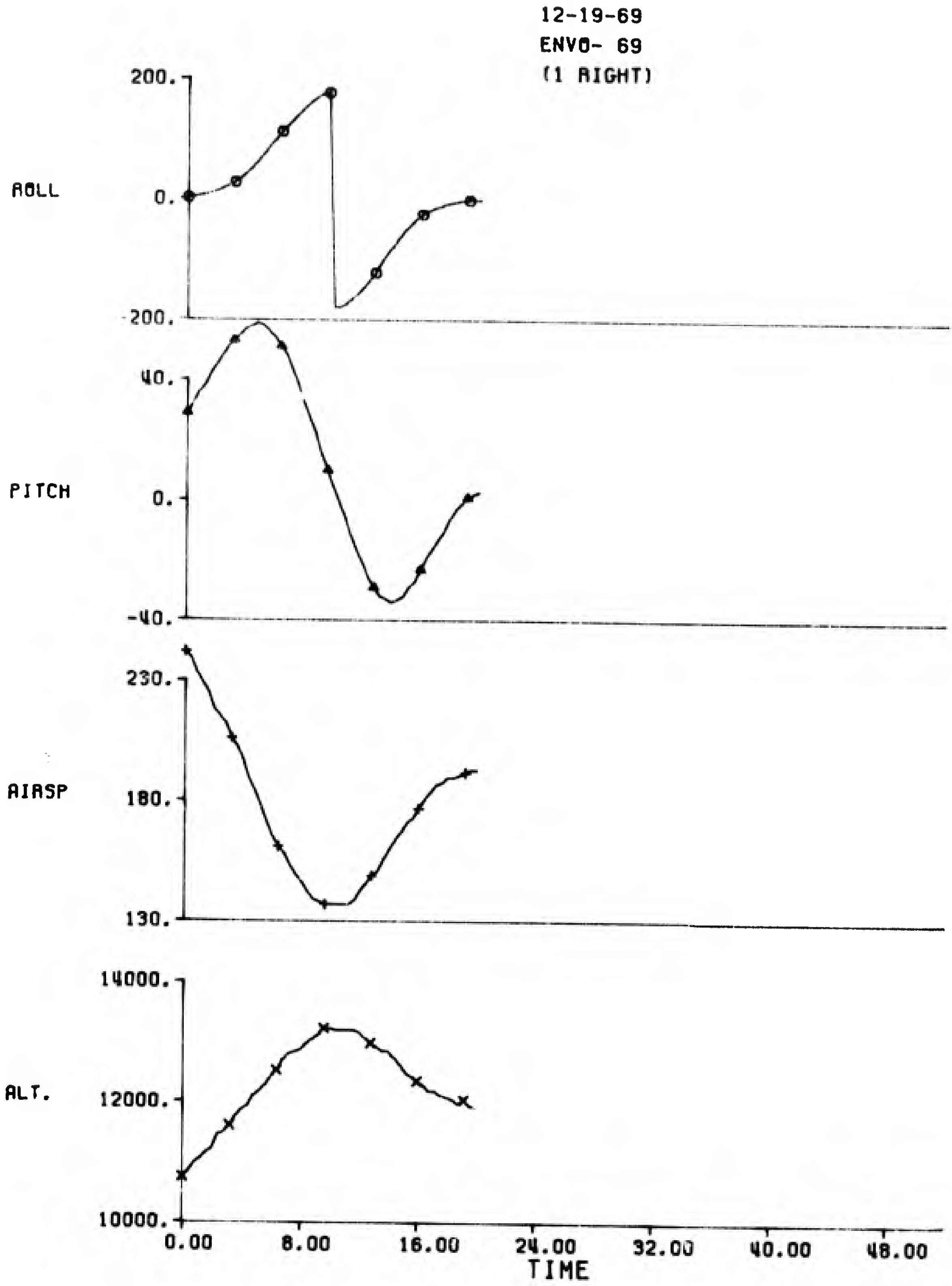
12-19-69
ENY0- 57
(1 LEFT)


12-19-69
ENV6- 57
(1 LEFT)
ROLL
200.
0.
-200.
PITCH
20.
-20.
-60.
AIRSP
250.
200.
150.
ALT.
22000.
14000.
6000.
0.00
8.00
16.00
24.00
32.00
40.00
48.00
TIME

(PILOT'S COMMENTS)

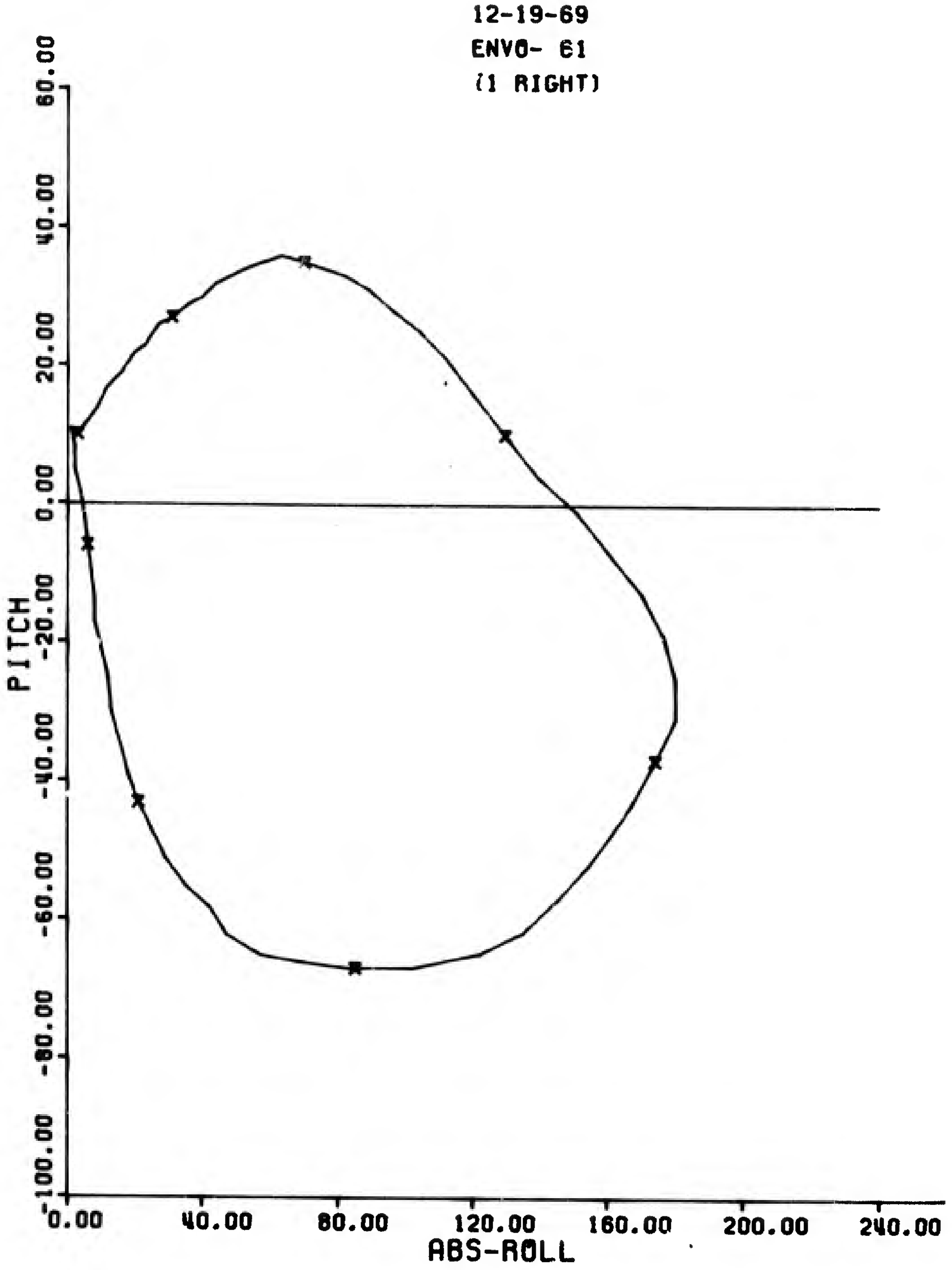
"The barrel roll is much easier to mess up on the entry than even this one is. This one will be barrel roll 10, event 69. Driving around he wants to do a barrel roll, again they just make up their mind. The airspeed is already 230 knots as a maximum entry airspeed. They pick out their point, lower the nose below the point. The airspeed is already 240. Then they lower the nose, start to do the maneuver, come up with much too much airspeed, 250, 260, 270, they worry about the airspeed, getting the nose way up too high. Generally disorganized. That would have been an unsatisfactory."

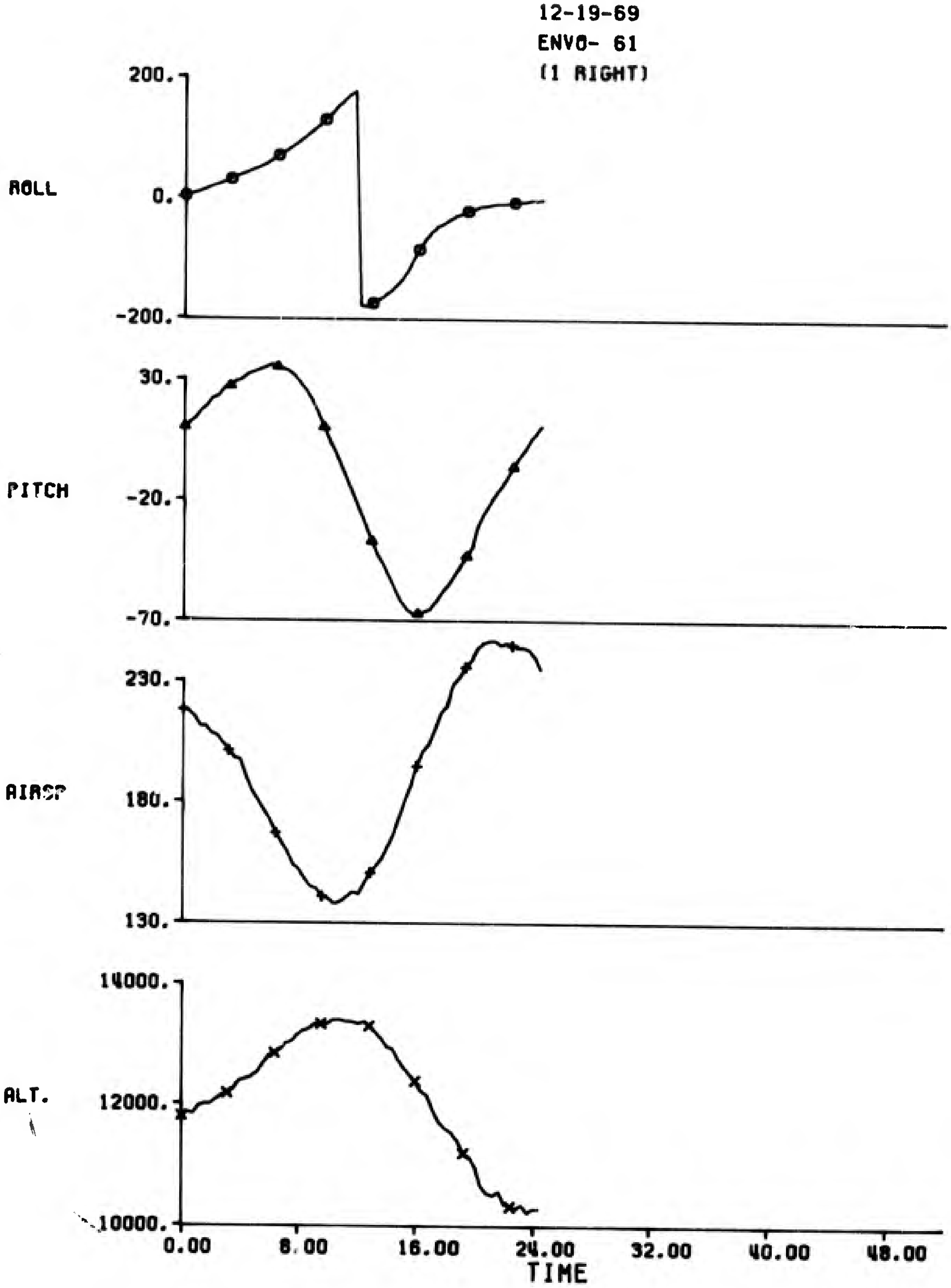

12-19-69
ENV0- 69
(1 RIGHT)
PITCH
100.00
80.00
60.00
40.00
20.00
0.00
-20.00
-40.00
-60.00
0.00
40.00
80.00
120.00
160.00
200.00
240.00
ABS-ROLL


12-19-69
ENVO- 69
(1 RIGHT)
ROLL
200.
0.
-200.
PITCH
40.
0.
-40.
AIRSP
230.
180.
130.
ALT.
14000.
12000.
10000.
0.00
8.00
16.00
24.00
32.00
40.00
48.00
TIME

(PILOT'S COMMENTS)

"The most common tendency on the barrel roll for an unsatisfactory maneuver is what we are about to do, barrel roll No. 8, event No. 61, and that is flattening out across the top like we have shown before, with the rate of roll a little too slow in the second quadrant, winding up coming through the horizon with bank still and the nose coming much too low. Winding up with essentially a high speed dive recovery. And I am getting myself into an area, headingwise, that I should not be in on those."


12-19-69
ENVO- 61
(1 RIGHT)
PITCH
60.00
40.00
20.00
0.00
-20.00
-40.00
-60.00
-80.00
-100.00
0.00
40.00
80.00
120.00
160.00
200.00
240.00
ABS-ROLL


12-19-69
ENV0- 61
(1 RIGHT)
ROLL
200.
0.
-200.
PITCH
30.
-20.
-70.
AIRSP
230.
180.
130.
ALT.
14000.
12000.
10000.
0.00
8.00
16.00
24.00
32.00
40.00
48.00
TIME

REFERENCES

1. Glaser, R., and Klaus, D. J., "Proficiency Measurement: Assessing Human Performance," (R. Gagne, Ed.), Psychological Principles in Systems Development, New York: Holt, Rinehart, and Winston, 419-476 (1963).

2. Brown Operation and Maintenance Manual For Pulse Code Modulation Data Acquisition System. Brown Engineering Company, Inc., Huntsville, Alabama.

3. Connelly, E. M., Schuler, A. R., Bourne, F. J., and Knoop, P. A. Application of Adaptive Mathematical Models to a T-37 Pilot Performance Measurement Problem, AFHRL-TR-70-45, Air Force Human Resources Laboratory, Wright-Patterson AFB, Ohio (1971).

4. Air Training Command, 1967. Primary Flying, Jet, ATC Manual 51-4, Headquarters Air Training Command, Randolph AFB, Texas (1967).

5. Connelly, E. M., Schuler, A. R., and Knoop, P. A., 1969. Study of Adaptive Mathematical Models for Deriving Automated Pilot Performance Measurement Techniques, AFHRL-TR-69-7, Volumes I and II, AFHRL, WPAFB, Ohio (1969).

6. Smith, J., Flexman, R., and Houston, R., Dec 1952. Development of an Objective Method of Recording Flight Performance, Technical Report 52-15, Human Resources Research Center, Air Training Command, Lackland AFB, Texas (Dec 1952).