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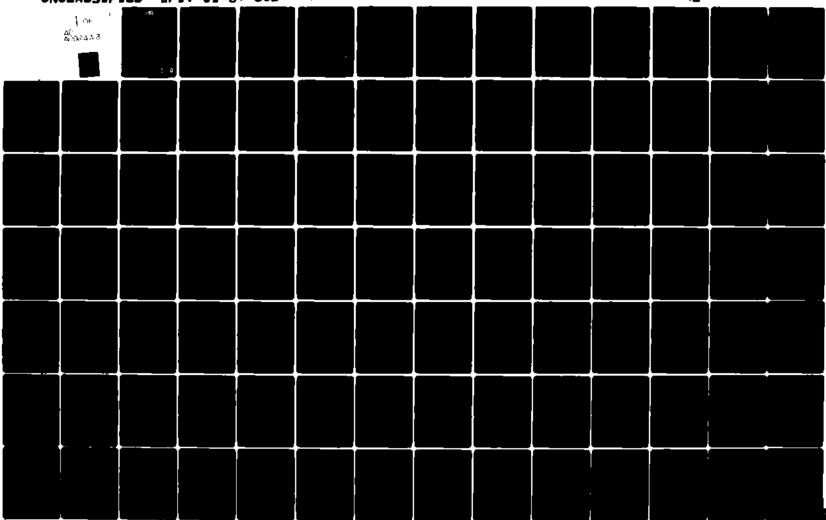

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AIRCREW COMPLIANCE WITH STANDARD OPERATING PROCEDURES

AS A COMPONENT OF AIRLINE SAFETY

DISSERTATION

Presented in Partial Fulfillment of the Requirements for

The Degree Doctor of Philosophy in the Graduate

School of The Ohio State University

By

Jeffrey Edward Schofield, B.S., M.A.M.

* * * * * * *

The Ohio State University

1980

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CHAPTER I

INTRODUCTION

Improving the safety of complex human-machine systems is a continuing challenge. Available information concerning system failures, which are usually called accidents, incidents, or mishaps, regularly points to human operators as the "brittle elements." (5:1) The need for greater understanding of operator behavior is recognized in a variety of technologically sophisticated systems, for example, industrial processes, health care, public utilities, and national defense; but nowhere is it more obvious than in the aftermath of a commercial airline accident.

Following the November 1979 crash of an Air New Zealand DC-10 which killed 257 people in Antarctica, United Press International noted that the ten worst disasters in aviation history have all occurred since October 1972. (61:4) Although the degree of operator culpability varies, the fact that the five deadliest accidents have occurred since March 1974 is particularly significant. At least one commercial airliner was completely destroyed, and over 200 people were killed in each of the five crashes. Wide-body jetliners, either Boeing 747 or McDonnell Douglas DC-10 aircraft, were involved in each instance. The sheer size of such vehicles portends grave consequences in case of system failure, be it human, mechanical, or a combination of the two. Despite steadily decreasing rates for total air carrier accidents (cf. Table 1), when a system failure does occur, the potential for tragedy is great.

TABLE 1

U.S. AIR CARRIER ACCIDENT RATES
ALL OPERATIONS 1967-1978 (1,33)

	Accidents		Accident Rate Per 100,000 Aircraft Hours Flown		Accident Rate Per Million Miles Flown
Year	Total	Fatal	Total	Fatal	Total
1967	70	12	1.193	.204	.032
1968	71	15	1.109	.203	.028
1969	63	10	.935	.134	.023
1970	55	8	.850	.124	.020
1971	48	8	.752	.094	.018
1972	50	8	.793	.127	.019
1973	43	9	.661	.138	.016
1974	47	9	.769	.134	.019
1975	45	3	.745	.050	.018
1976	28	4	.450	.064	.011
1977	26	5	.404	.078	.010
1978	26	6	.389	.088	.009

Rationale for Research

For many years safety conscious individuals from nearly all segments of the commercial aviation community--manufacturers, government regulators, airline executives, accident investigators, air traffic controllers, pilots--have recommended patchwork modifications within the system. They have concentrated on the accident potential of traffic flows, information displays, mechanical reliability, warning devices, and similar components of the total system which could be logically segregated. As a consequence, regulatory and engineering changes have been imposed on aircrews almost continuously. Inertial navigation systems, computerized flight plans, low visibility approach criteria, and Standard Terminal Arrival Routes (STARs) are just a few of the modifications affecting routine operations during the past decade. Procedures have proliferated with virtually every change and every accident.

If accident statistics are meaningful in this context, then definite progress has been made. From 1967 through 1978 the number of accidents involving U.S. air carriers decreased markedly. As previously implied, however, the rate of fatal accidents actually shows an increase for each year since 1975. The chronological data are contained in Table 1.

During the past five years, growing concern has been focused on the need to improve human performance aspects of the man-machine interface. Expanded knowledge of operational behavior is a logical precursor to improvements. In November 1975 at the Air Transport Association's conference on "Safety in Flight Operations," the study of basic human behavior and human limitations was accorded top priority for enhancing safety. (4:2) In 1978 the Air Line Pilots Association (ALPA) issued "A Statesmanlike Challenge" to the scientific community to advance the state of knowledge regarding operator workload in airline cockpits. (18) Throughout the period, the National Aeronautics and Space Administration (NASA) has been supporting a Flight Management Research Program (24:411) aimed at developing greater understanding of crew roles, interpersonal relations, and human-machine interactions in commercial air transportation. The research reported in this dissertation is one outgrowth of an experiment conducted in 1976 by Dr. H. P. Ruffell Smith under the auspices of the NASA-Ames Research Center. (53)

Research Objectives

That 1976 study signaled the beginning of a new era in aircrew research, full mission simulation. The present study critically examines the earlier effort and utilizes some of the original data to depict routine cockpit behavior in substantial detail. The emphasis here is on the customary tasks of flight operations, not rare or unusual tasks.

The following chapters address seven central objectives. In brief, these are: (1) definition of a finite set of routine crew procedures, (2) classification of the routine procedures into meaningful subsets, (3) quantification of operator compliance with one selected subset of routine procedures, (4) subjective evaluation of the managerial talent of crew commanders, (5) attribution and enumeration of previously identified crew errors to specific operators, (6) comparison of the measures of procedural compliance, management skill, and operator error, and (7) evaluation of full mission simulation as a means of studying the operational behavior of aircrews.

The routine or normal operating procedures are culled from the Aircraft Operating Manual, the Company Operations Manual, the Federal Aviation Regulations, crew handbooks, and assorted navigational documents. They are set against a backdrop of simulated airline flight by fully qualified crews on a Boeing 747. Taxonomies of normal procedures are based upon various characteristics of published form, sequence, and content. A subset called Crew Coordination Procedures is chosen as a standard for documenting typical operator compliance. The perpetrators, circumstances, and frequencies of different types of noncompliance portray the status of standardization within a sample of one airline's active crew force. Routine operational behavior has not previously been described at this level of detail.

Subjective evaluations of managerial skill are based upon three established precepts of sound management: continuity, cooperation, and discipline. Comparisons among the various quantitative and qualitative assessments of operator behavior illustrate the value of multidimensional measures of human performance. Finally, the usefulness of full mission simulation as a data collection methodology is considered, and its first experimental application is reviewed.

Fundamental Definitions

While some isolated aircrew tasks and standard operating procedures (SOPs) have received attention in other studies (59,60,69), routine procedures have been slighted. Generic classes of ordinary procedural activity have been almost wholly ignored (67). For some readers the words "task" and "procedure" may have colloquial overtones which differ from their intended sense in this manuscript. The definitions and explanations offered below are meant to alleviate possible confusion. They have been developed from concepts embodied in a paper by Funk and Miller (16) and from discussions with the authors.

A task is simply a collection of goal-oriented behaviors. At the most elementary level, any required behavior could be thought of as a task whose goal is subordinate to or subsumed by another goal at a higher level of abstraction. Throughout this text the aggregation level of goals/tasks will be completely determined by the contents of the procedures presented for their accomplishment. As a result, some tasks may have relatively few sub-tasks (e.g., altitude callout during a climb) while others may contain so many sub-tasks that procedures within procedures are provided (e.g., Predeparture Planning as described in Chapter III).

What, then, is a procedure? It is a symbolic and mnemonic representation of a set of sensory, cognitive, and/or motor activities which, when recalled and executed within determinable tolerances, complete a task as designed. A given operating procedure need not be the "best" one or the only one appropriate to a particular task. But, at least in airline transportation systems there exist explicit SOPs prescribed for a whole class of operators across a range of environmental conditions. In this context the phrase "standard operating procedure" is surely apropos.

Organization of the Dissertation

Two major areas of research relating cockpit SOPs and behavior have been selected for examination. The first concerns attributes of existing procedures. Questions regarding the nomenclature, form, source, and extent of individual crew member involvement must be addressed before representative procedures can be chosen for more intensive scrutiny. The product of this first portion of the study is a collection of taxonomies. Jointly, they characterize the procedural framework within which one airline's crews were directed to operate in early 1976.

The second area of SOP research deals with the definition, calculation, and interpretation of descriptive statistics associated with a set of representative crew coordination procedures and behaviors. Questions about the appropriateness of procedural imperatives and the conformance of aircrew behavior are discussed. One result is a quantitative assessment of ten crews' adherence to sampled procedures in a high fidelity, full mission simulation experiment. Also, statistical models are used to test the distribution of enumerated operator errors and to examine the empirical relationships among independent measures of human error and procedural behavior.

A minor portion of the research identifies three precepts of management which are particularly appropriate to the cockpit situation. Each captain's management style is subjectively graded against these precepts, and the qualitative assessments are compared to the previously developed quantitative yardsticks of procedural compliance and operator error. Relationships among different operator metrics are suggested.

The remainder of this dissertation is divided into five distinct but interdependent chapters. Chapter II contains a review of related literature, descriptions of pertinent on-going research, and a detailed discussion of the experiment which provided essential data. The third, fourth, and fifth chapters respectively treat the aforementioned subdivisions of the investigation-procedural taxonomies, quantitative assessments of compliance, and procedural conformity as a reflection of management style. Major conclusions and recommendations for further research are included in the final chapter.

A compilation of aviation acronyms and abbreviations used throughout the manuscript is provided in Appendix A. A flow chart depicting the various analytical efforts in the research process appears in Appendix B.

CHAPTER II

RELATED LITERATURE AND RESEARCH

Allusions to vaguely defined "operating procedures" can be found in numerous technical reports (e.g., 23,31,52,68) and journal articles (e.g., Human Factors and Ergonomics) under titles dealing with flight simulation, safety, decision making, and human performance. References to specific aircraft or airline SOPs are commonplace in crew publications (e.g., Aerospace Safety, Crosscheck, or Air Line Pilot) and accident reports, several of which are cited below. Expository treatments of procedures are usually limited to textbooks (28,29,48) within the general discipline known as human factors. All of these contribute to an appreciation of the purpose and status of SOPs in the multifaceted operating environment of commercial aviation.

This chapter highlights material from limited access as well as open sources. It is divided into five sections. The first section reviews evidence of procedures in the context of airline system failures. The second section looks at nonspecific man-machine procedures from a designer's point of view. Past and present research bearing potential implications about the essence of SOPs is covered in the next two sections. The final section summarizes pertinent information from Ruffell Smith's NASA-sponsored airline study. (53)

Operating Procedures and Airline Accidents

A 1974 review of "pilot error" accidents by the Lovelace Foundation states that "Airline training and operational procedures must be updated to improve the reliability of the pilot as an information processer." (23:55) The report does not recommend modification of any specific procedure, but readers are given the unmistakable impression that existing SOPs were inadequate. Crew member complicity in accidents receives little attention, but procedural noncompliance is openly acknowledged as a fact of airline life. The authors, some of whom were and are airline pilots, admit the long-range adverse effects of accepting "out of tolerance" conditions and operating "off-profile." (23:50) They do not, however, suggest even a cursory analysis of such pilot behavior. Like many other powerful lobbies in the aviation community, airline pilots would never permit themselves to become the scapegoats for diverse deficiencies in air carrier safety. Though problems with procedural compliance have been recognized for some time, political and economic considerations continue to impede the collection and publication of hard data to support the insider's wisdom about noncompliance.

In a more recent (1979) report for the Federal Aviation Administration (FAA) two Battelle researchers analyze air carrier accident history from 1964 through 1976. They conclude that the percentage of accidents attributable to human error (pilot, mechanic, air traffic controller, etc.) has been increasing. (8:4-8) In giving special attention to pilot complicity, they point out that "The gravity of this problem area is accentuated by the fact that these human errors are occurring in spite of the elaborate mechanical and procedural systems now in place to mitigate these errors." (8:4-9) Support for their assertion can be found throughout airline accident reports, but the authors contention that existing SOPs are "well written" (8:4-6) seems to be pure conjecture. Acceptance of a procedural ideal is not equivalent to acceptance of existing procedures as ideal. Standardized aircrew directives as well as the operators for whom they are designed must both be viewed critically.

The Battelle analysts' opinion that SOPs constitute a de facto contribution to aviation safety appears to be shared by the National Transportation Safety Board (NTSB). The NSTB regularly cites failure to comply with explicit SOPs and failure to challenge noncompliance as casual factors in airline accidents. Quotes from three representative Aircraft Accident Reports (AARs) disclose the Board's bias in favor of published procedures. The first citation concerns the crash of a United Airlines' DC-8 in the mountains northeast of Salt Lake City. The Probable Cause section of the report reads as follows:

> The National Transportation Safety Board determines that the probable cause of this accident was the approach controller's issuance and the flightcrew's acceptance of an incomplete and ambiguous holding clearance in combination with the flightcrew's failure to adhere to prescribed impairment-of-communications procedures and prescribed holding procedures. The controller's and flightcrew's actions are attributed to probable habits of imprecise communication and imprecise adherence to procedures developed through years of exposure to operations in a radar environment.
>
> Contributing to the accident was the failure of the aircraft's No. 1 electrical system for unknown reasons. (45:34)

In reviewing the circumstances surrounding the crash of a National Airlines' Boeing 727 in Escambia Bay off Pensacola, Florida, the NSTB again refers to both aircrew and Air Traffic Control (ATC) procedures. For example,

> National Airlines' B-727 procedures do not recommend that the flight crew insert the MDA [minimum descent altitude] into the altitude alert system. (38:19)
>
> In summary, the Safety Board concludes that the ATC procedures affected the conduct of the approach, and, therefore, contributed to the chain of events which led to the accident. Although the controller had placed the aircraft in a position from which the approach could have been completed safely, he also had placed it in a position where the captain had to alter the timing of his checklist procedures in order to configure his aircraft more rapidly than usual. While the controller's handling of the flight did not place the aircraft in a dangerous position, his non-standard procedures made the approach more difficult for the crew to accomplish. (38:33)

Finally, a large portion of the report about an Allegheny Airlines' BAC 1-11 mishap at Rochester, New York is devoted to direct quotation of crew member SOPs from airline manuals. Three of the Board's 15 Findings are notable for their dependence upon procedural imperatives:

> 7. The crew did not comply with checklist procedures during the approach and landing in that no callouts were made and cockpit instruments were not monitored.
> 8. The crew failed to comply with recommended approach and landing airspeeds.
> 9. The approach was not made according to prescribed procedures and was not stabilized. (34:27)

These Safety Board comments indicate a degree of blind faith in SOPs which is not always warranted. The AAR for American Airlines' Flight 191, which crashed shortly after takeoff from O'Hare Airport, reveals that the crew did act in accordance with the existing engine-out procedure; but the procedure did not account for the magnitude of the failure that had occurred. (35:53-54) This kind of knowledge is probably not conducive to passenger or pilot confidence in SOPs, and it could be used as rationale for selective noncompliance. Regardless, two essential questions remain unanswered. How meticulous is the average crew concerning routine procedures? Are the prescribed procedures appropriate in the typical operating environment? No documents in the open literature properly address these questions. This research is an attempt to partially fill that void.

Procedures in General

As man-machine systems have become more complex, ergonomists have been periodically redefining and enriching the concept of a procedure. In the early 1960s Kinkade and Wheaton stated that "A procedure is a step-by-step series of activities involving no special skill requirements." (21:676) Although that simplistic view would likely be rejected by many highly skilled, highly trained operators (including most pilots), it may indicate a basic human difficulty in appreciating someone else's tasks and procedures. Weiner observes that the lack of empathy between airline pilots and air traffic controllers can be especially acute. (66:174) The same difficulty might account for coordination problems among particular crew members. The actions of tyrannical captains, reticent copilots, and other widely recognized airborne personality types could be magnified by an incomplete comprehension of the procedural demands on other crew members.

Elevation of the status of procedures and intuition about their character advanced significantly under the mid 1960s tutelage of Meister and Rabideau. (29) They never synthesize a concise definition of procedures, but they categorize and describe identifiable types. In particular, they distinguish among individual operator, crew, and system procedures (the first two being more specific than the last) as well as between operation and maintenance categories. The authors emphasize "the need for the human engineer to pay great attention to their [procedures] format, their information-content, and how they are developed." (29:109) Seven attributes of a well designed procedure are listed, including the use of a tabular checklist format. The steps in each checklist are to meet the following sequential requirements:

> 1. Time at which the step is to be performed.
> 2. If the task as a whole requires more than one operator, the particular operator (by job title) who will perform the step.
> 3. The stimulus for the operator to initiate a procedural step.
> 4. The operator response required (in terms of monitoring, deciding, manipulating).
> 5. Required communications.
> 6. Feedback display or communication. (29:109)

Few, if any, cockpit SOPs satisfy all the criteria of Meister and Rabideau; though some would certainly appear more acceptable than others. Their criteria are not the only meaningful measures of worth, however. The regularity of operator commitment to families of SOPs and the nature of nonconforming behavior can be important indicators of both procedural utility and personal style.

In a later text Meister (28) differentiates a procedural checklist (describing actions to be performed) from an evaluative checklist (describing a desired quality). His commitment to the checklist format for SOPs is so strong that he never mentions other forms. He does observe that seemingly small systems may have more procedures than an analyst can thoroughly review--a fact clearly illustrated in this study. Consequently, he recommends examination of only those SOPs necessary for accomplishment of major system objectives and those whose incorrect performance is "likely to lead to serious equipment, personnel, or system consequences." (28:208) One shortcoming of this advice is that in airline operations, at least, numerous SOPs and many forms of noncompliance have been associated with disaster. (39, 41,43,44)

Laboratory Research

A 1972 review of man-machine experiments by H. M. Parsons views procedures more as they really are than as they ought to be. His idea of "self-procedurization" (48:547), which includes modification of published procedures as well as development of new ones, recognizes a fundamental reality of human behavior. People adopt and rely on behavior patterns without much conscious effort. Manifestations of this phenomenon in airline cockpits have previously been implied but not documented. Possible evidence of their existence occurs in the data for this research.

Parsons also comments on a major issue of this investigation. In writing on the diversity of procedural variables he says, "If they tend to constitute a grab-bag, this may be so partly because there exists in the human engineering literature no taxonomy of procedures, nor even much of an attempt to create one." (48:208) Eight years after that statement was published, it still applies with full force. Thus, this author will take the opportunity to create not one but several situation specific taxonomies.

Parsons' recapitulation of 20 years (approximately 1948-1967) of human-machine systems research forms an appropriate backdrop for more recent studies. Papers presented at the International Symposium on Monitoring Behavior and Supervisory Control in 1976 focus on the development of internal models of human behavior. (32,50,57,63) One interpretation of a procedure is that it constitutes a major portion of the external input to a corresponding internal model. A procedural ideologue might go so far as to propose that a properly designed SOP could be wholly embodied, without appendage, into an internal model. A more plausible case can be made for the inclusion of additional inputs, internal as well as external, which combine to form an internal model and which are reflected in the concept of self-procedurization.

Many participants in the aforementioned symposium helped organize a workshop on mental workload the following year. There, Johannsen, Moray, et al., suggested the need for long duration, behaviorally complex experiments. (20:110) The Ruffell Smith experiment is already in the vanguard of such research. In addition, Johannsen crystalized the notion that procedures form one portion of the mental load placed on skilled operators; he describes the environment and the situation as the other two. (19:4) At present no objective scales are available for "weighing" any portion of mental load. Simple enumeration and categorization offer the best subjective indication of an operator's procedural burden. On-going research gives some hope for objective measures and new insights.

Research in Progress

Theories now being developed by Funk suggest that a methodology for objectively measuring procedural load in any man-machine system may soon be realized. (15) Numerous other researchers sponsored by the military departments are engaged in studies which could influence the nature of procedures taught to the next generation of combat aviators. Burks, Engler, and Sears are using a computer simulation to try to identify control strategies [procedures] in a one-dimensional tracking task. (7:22-23) Damos is doing a comparison of multiple-task performance using natural and imposed strategies to evaluate differences in cognitive style. (10:26-27) Models which distinguish between the mental processes of novice and skilled operators are being investigated by Dreyfus and Dreyfus (12:28-29) They have hypothesized that novices rely heavily on predetermined procedures while experts improvise their own.

Perceptronics, Incorporated and the Canyon Research Group are conducting studies specifically concerned with aircrew behavior. The first is an attempt to create taxonomies of emergency situations and the decision processes that pilots use to resolve those situations. (25:48-49) That study is an off-shoot of earlier research in self-procedurization by the Air Force Human Resources Laboratory. (59)

Canyon has tri-service sponsorship of its effort to facilitate comparison of disparate human factors research by establishing standardized protocols for measurement of crew performance. (64:102-103) Taken together, the results of these studies could significantly alter the role of combat pilots and the characteristics of their SOPs. However, any impact on air carrier pilots would probably be negligible. For research involving airline procedures one must turn to Ruffell Smith's work.

The Ruffell Smith Experiment

As early as 1974 Dr. H. P. Ruffell Smith, a noted British physician, ergonomist, and pilot, proposed a full mission flight simulation experiment to study the performance of fully qualified airline crews under varying conditions of workload. (53:1) The proposal garnered the support of the National Research Council and NASA. Intensive preparations began in July 1975; data collection took place early in 1976.

An unidentified major air carrier agreed to provide a state-of-the-art simulation, volunteer crews, and technical assistance. Because of the company's training schedule, each simulator session was constrained to require no more than four and one-half hours. The simulator was a Singer-Link platform with six degrees of motion freedom. The cockpit was that of a Boeing 747 configured identically to company aircraft. It accommodated the usual three-person crew (captain, copilot, and flight engineer) plus two observers (experimenters), a simulator operator/traffic controller (company training captain) and an audio coordinator. The latter managed playback of the ATC tapes that were used throughout the scenario (12 for each of the two mission segments) to enhance realism. Since computer generated imagery was not installed, video films of the landing runway were used.

a. Scenario

A full mission scenario was assembled by Dr. Ruffell Smith, Mr. George Cooper, former Chief Test Pilot of NASA-Ames, and a senior flight instructor from the participating airline. The scenario was predicated upon charter service from Dulles Airport near Baltimore to Heathrow Airport (London) with a 30-minute intermediate stop at Kennedy Airport (JFK, New York) for fuel and cargo. The first segment of the mission was intended to place relatively low workload on the crews; the load during the second segment was to be much higher. Crews were not aware of the workload differences before their flights.

One of the three flight data computers (for autopilot and flight director operation) was disabled throughout the mission; otherwise, normal mechanical redundancies were operative. There were no preprogrammed equipment failures during the Dulles-JFK leg. Since most of the 18 test crews were unfamiliar with the routes/airports involved and since they were not given avigation information until arrival for the mission, this writer believes that the actual mental load for the first leg may have been considerably higher than intended. Even so, only published normal operating procedures were needed during that segment. ATC vectoring around a small area of thunderstorms was included as a routine occurrence, but it may also have produced an unintended increase in workload.

Because the Dulles-JFK leg of the scenario tried to recreate a typical operating environment, the crew activity associated with it is thought to be representative of habitual behavior. In contrast, the second segment incorporated two mechanical failures, one of which necessitated an engine shutdown, diversion to an alternate airport (return to JFK), fuel dumping, holding, repeated distractions by dispatch/cabin crew personnel and a heavyweight landing on a slippery runway with a strong crosswind. Although crew behavior in unanticipated, stressful situations deserves careful consideration, it is not of primary interest here.

Crew adherence to standard operating procedures is of concern in this study. Cockpit management, task pacing, and control of aircraft parameters caused the length of time spent in the simulator to vary slightly. For example, some pilots slowed to approach speed further from their destination than others; but the same basic SOPs were appropriate for every experimental run. Explicit procedural directives were adequate for all situations. Imaginative or creative responses to scenario developments were not required. Nevertheless, cases of non-compliance with procedure, perceptual uncertainty, and judgmental error resulted in different procedural sequences and loads across the crews.

b. Simulation Fidelity

Ruffell Smith's goal was to simulate the operating environment in sufficient detail to evoke the same operator behavior that occurs in actual flight. Determining the degree of contextual detail necessary for a "full mission" simulation was then and is now more of an art than a science. Although all of the participants in the experiment affirmed the prevailing realism of the scenario as presented, several deviations from verisimilitude are detectable.

To begin with, the external visual cues were not of high quality. There were no external cues for taxi or takeoff. The landing runway films lacked the scope and flexibility which computer generated images have today. The research simply had to proceed with the simulator technology on hand. That constraint also accounts for the occasionally unsatisfactory functioning of the inertial navigation system (INS) and the one serviceable autopilot, discrepancies which were noticed by the crews. These deficiencies seem to have had only a tangential effect on individual and crew behaviors.

An aspect of the simulation which did temporarily distract or confuse several crew members centered upon the background audio recordings. In the first segment one tape was too short for its phase of the mission so the technician continuously replayed it. Two other tapes contained operating information which was different from that issued to the crews by the simulator controller, thus necessitating some clarification. Finally, the recorded voices of air traffic controllers changed from tape to tape, but the live voice of the simulator controller was always the same (and at a different pitch and volume from those on tape). Moreover, the quality of simulator controller transmissions was not on a par with that usually emanating from professional air traffic controllers. These facts may have influences crew behavior with respect to extra-cockpit radio communications. For example, constant omission of the "Heavy" suffix to the aircraft call sign by the controller seems to have induced some crews to respond similarly. The effect on other types of crew behavior is unknown.

Two other features of the experiment could have persuaded crew members to depart from the physiological and psychological normalcy of an actual flight mission. First, a single electrocardiogram (ECG) electrode was applied to each subject throughout the mission. Second, because they were in a simulator usually reserved for emergency actions training and evaluation, crew members were initially sensitive to and suspicious of potential mechanical problems. Beyond a very brief period of adjustment to these conditions, neither evoked any negative comments from the subjects. One might reason that given the obvious scrutiny, crews would likely be on their "best (procedural) behavior." The reader may draw his own conclusions on this issue after reviewing the relevant data.

c. Subjects

Most of the participants were assigned to a single aircrew domicile. The one captain who came from a different domicile is subjectively ranked between the extremes of managerial performance. The number of errors attributed to him and his crew combined with their aggregate adherence to procedures rendered their overall performance genuinely "average." Some of the subjects had flown together before; others had not. Some of the highest and some of the lowest error counts were generated by crew members flying together for the first time. In the pragmatic world of standard operating procedures and forceful labor unions, crew composition is not supposed to be a factor in procedural conformance or in operational safety.

The experiment used 18 crews for comparative data purposes. Since captains and copilots typically alternate mission responsibilities as the "pilot flying" (PF) and "pilot not flying" (PNF) for whole flight segments, the experimenters permitted each crew to determine who would "fly" which leg. Thirteen of the eighteen captains were the PF for the Dulles-JFK segment. This could be indicative of many captains' desire to establish their prerogative at the earliest opportunity, but there is no data to support such speculation.

The subjects were nearly unanimous in complimenting the design and execution of the scenario. Some wrote letters to the research team expressing appreciation for the opportunity to participate and concern about the general state of crew performance. Several volunteered to participate in any extensions of the research.

d. Data

Since the technical quality of the data collected and the experimentum personae were not uniform for all eighteen simulator runs, it has become necessary to eliminate some trials from the current investigation. Ten runs have the same pair of observers and usable audio data throughout have been selected for detailed procedural analysis. The characteristics of the ten crews and the range of observed behaviors compare favorably with those of the total experimental population. Historical information for the sample and the total population is summarized in Table 2.

The ranges on age and years of flying experience for captains in the experimental population are relatively small, 54 to 59 and 32 go 41 respectively. These numbers represent considerable seniority with the airline, familiarity with company policies, and exposure to diverse operational conditions. These men are at the top of the company's pilot ladder.

The copilots, though younger (average age 43.4 versus 55.8 for captains), all have at least 16 years of flying experience. Some have enough seniority to soon qualify for upgrade as captains of the company's smaller planes. They might reasonably be anticipating the responsibilities and rewards of captaincy. Other copilots have little experience in the B-747 and may be looking to their cohorts for operational acumen.

The flight engineers are among the last of an old order. They are career flight engineers as opposed to pilots passing through the second officer rank on the way to becoming a first officer (copilot). Since career engineers are no longer hired by the airline, the patterns of crew member experience are now changing. In the near future the flight engineer will usually be the youngest member of any crew. In the experimental population the average age of flight engineers is

TABLE 2

AIRCREW HISTORICAL DATA
(53: 7,8)

Run No.	Age P1[a]	Age P2[b]	Age FE[c]	Years flying P1	Years flying P2	Years flying FE	Flying hours (in B-747) P1	Flying hours (in B-747) P2	Flying hours (in B-747) FE	Days since last flight P1	Days since last flight P2	Days since last flight FE	Hours out of bed P1	Hours out of bed P2	Hours out of bed FE	Report time (local)
1	56	38	54	32	20	35	100	310	2500	1	3	3	10	12	12	1915
2	56	43	49	33	18	22	2000	3100	2500	10	13	5	12	12	12	1915
3*	55	43	48	37	25	22	3500	3000	2800	3	3	11	4.5	6	8	1500
4*	54	50	57	35	32	35	600	1500	3200	7	17	1	3	2	2.5	1015
5*	58	38	52	38	18	28	5000	700	3000	4	1	20	13	12	13	1915
6*	55	48	58	37	21	34	600	2400	400	34	11	5	11	11	12	1915
7	57	46	45	34	24	20	500	2400	400	32	7	34	2	2	1	0600
8*	55	50	49	37	32	20	2000	1800	600	1	7	2	10	13	11	0600
9	55	40	51	36	16	28	3000	250	3500	3	4	41	12	11	12	1915
10*	54	47	56	36	31	37	1800	1800	4800	2	3	5	8	8	8	1500
11	57	40	57	35	20	34	2500	420	4500	11	70	5	2	2	2.5	1015
12*	57	42	53	35	20	33	350	750	3000	3	7	6	5	2	2.5	1015
13*	55	41	56	35	22	33	500	450	3300	4	2	6	2	2	2	0600
14*	54	49	52	35	31	32	600	2000	1800	4	2	5	9	6	6	1500
15*	57	45	50	36	25	22	600	2600	2400	4	2	3	9	13	9.5	1915
16	55	38	48	34	17	23	2500	550	4000	8	13	10	13	13	12	1915
17	59	46	52	41	23	27	4200	1500	2400	3	5	6	9	7	7	1500
18	56	38	54	35	16	26	3000	400	4000	14	43	75	6	4	3	1015

* = Data runs used in this analysis.
a = Captain.
b = Copilot.
c = Flight Engineer.

slightly less than that of captains (roughly three years) and decidedly greater than that of copilots (about eight years). In several cases the engineer has more B-747 flying time than either one of the pilots. However, the effect of different combinations of experience is impossible to isolate in the data.

Three separate modes of data collection were used in the experiment: frequency modulated (FM) tape, hand written documents, and computer printout of aircraft (i.e., simulator) parameters. In the order of recording, the seven tracks of FM tape contained the following information: (1) captain's ECG, (2) copilot's ECG, (3) flight engineer's ECG, (4) pilot observer commentary, (5) engineer observer commentary, (6) intra-cockpit communications, and (7) extra-cockpit communications. The four audio tracks are the primary sources of data on procedural behavior.

At the end of every mission the observers and the training captain transcribed their recollections and impressions in longhand on protocols. Biographical data such as that shown in Table 2 were logged prior to each mission. Takeoff computation sheets, fuel consumption logs, and any other pieces of crew paperwork completed the pencil and paper data.

A high-speed line printer connected to the computer which was driving the aircraft simulator provided the third data collection mode. Seventeen different aircraft parameters were sampled; many others might have been useful. Output was generated from the application of takeoff thrust until the end of the landing rollout. Data were printed once every second when the aircraft was below 1800 feet and once every five seconds above that altitude. These data help define the environmental state of the system at particular points in time, but they contribute little to an appreciation of the operator behavior which produced the various states.

e. Purpose and Problems

Ruffell Smith has written that the study was "a specific attempt to investigate the kind and number of errors [by crews] and how these related to overall workload and arousal." (53:14) Unfortunately, neither precise definitions nor bibliographic references are offered for such essential concepts as workload, arousal, and error. However, in view of the numerous unresolved issues in conceptualizing and measuring pilot workload presented by Gartner and Murphy (17) this is understandable. While contemporary usage of "workload" permits a basic low/high distinction between the two mission legs, fluctuations of load within each leg appear significant. No specific measure of workload is ever mentioned.

Likewise, the notion of arousal is treated untuitively. It seems to be somehow linked to workload in the experimenter's mind, but the relationship is never explained. Different types of workload and arousal (e.g., mental versus physical) are not discussed, but pure heart rate is identified as the sole measure of arousal.

Ruffell Smith's explanatory neglect is perhaps most severe regarding the concept of error. Performance tolerances or scales are rarely provided. The subjective judgment of the experimenters appears to be the usual yardstick. According to the final report, "Special notice was taken of errors in procedures (e.g., the use of checklists) and of specific errors (e.g., mistakes in setting up navigation and communication frequencies)." (53:12) However, his nine error categories do not clearly make such distinctions. A summary of the errors (by category and by crew) that the author identified during the Dulles-JFK segment is shown in Table 3.

Ruffell Smith's confession that the errors are "arbitrarily classified" (53:14) reveals nothing about the underlying purpose of his scheme. Errors are attributed to an entire crew regardless of how many people have the opportunity, knowledge, and ability to either prevent or rectify a given fault. For example, the stated distinction between a flight engineer's error in improperly emptying a fuel tank and an entire crew's concurrence in loading with an improper flap setting is that the former is considered to be Systems Operation while the latter is designated as a Tactical Decision.

Supposed distinctions between Flying errors and Flying Skill errors exacerbate a reader's frustration. They certainly do not aid in the recognition of crew member behavior patterns. According to the report, Flying errors arise when a pilot is judged to have successfully controlled his aircraft to the wrong parameters, e.g., maintaining 270 knots below 10,000 feet. Flying Skill errors pertain to a pilot's presumed inability to control his aircraft to the parameters he desires. Failure to stay within ten knots of desired speed during an approach and "rough" handling of the throttles on final (even if the speed criterion is satisfied) are examples of errors in Flying Skill.

TABLE 3

ERRORS REPORTED BY RUFFELL SMITH
(53: 16)

Run	Naviga-tion	Communi-cation	Systems Operation	Flying	Tactical Decisions	Crew integra-tion	Flying skill	Auto-pilot	Other	Total
1		1		1	1				1	4
2	1									1
3*				2	1		2	1		6
4*					1		1	1		4
5*	1		1		3			1	1	7
6*	1	5	6		1	1	3	2		19
7		1		2		1	1	1		6
8*	3	1	1	2			1			8
9		1	1	1	1		1	2		7
10*	1		1	1	1			1		5
11			1		1		3			5
12*	2			3	1					6
13*	1	4	1	1	1		2	2		12
14*	1	3						1	1	6
15*				2	1			1		4
16		2		2	2					6
17	1		1		2					4
18	2		1	3	2		5	1	2	16

*Data runs used in this analysis.

Distinguishing between these categories requires an estimation of pilot intent which the data cannot support.

f. Conclusions

According to Dr. Ruffell Smith crews committed more errors per unit time during the second or "high" workload segment than during the "low." This result is intuitively appealing, but it does not provide any information about the nature or distribution of the errors observed in either segment. Although experimental interest was concentrated on the second leg of the mission, few conclusive quantitative results were captured there.

The researchers were especially interested in establishing statistically significant physiological or historical predictors of crew performance during the second leg. The most significant relationship found was that changes in the status quo of the aircraft produced a higher percentage rise in heart rate for the PF than for the PNF regardless of crew qualification (i.e., captain or copilot). (53:30) The analysis of variance relationships between total number of errors in the first segment and days since last flight were significant for captains and flight engineers, but not for copilots. (53:30) No such relationships were significant for the second segment. Similarly, first leg error totals were not a good predictor of second leg error counts. Relationships between by-operator errors and specific by-operator behaviors were not addressed.

g. Comments

It is particularly interesting to note that Ruffell Smith displays errors by crew rather than by individual operator or combinations thereof. Examination of his protocols and working papers reveals that sometimes errors are attributed to particular crew members; other times they are not. Multiple reviews of the recorded data have convinced this writer of the need to reclassify errors according to the crew member(s) responsible. This, in turn, facilitates a comparison of individual procedural behaviors (yet to be defined) with individual and group errors previously identified.

The efforts of Dr. Ruffell Smith and his associates were not without some technical and analytical shortcomings. However, these should not be overemphasized. The investigation was "breaking new ground" in applied aircrew research. No study of comparable magnitude and detail has ever been released to the public. The voluminous data could easily support future analyses in small group processes, verbal communications, or manual control. Further analysis of procedural compliance, especially in the second segment of the scenario, should be initiated as soon as possible.

CHAPTER III

ENUMERATION AND CLASSIFICATION OF AIRCREW PROCEDURES

In the final paragraph of his NASA report Dr. Ruffell Smith asserts that,

> The same techniques [of full mission simulation] might be beneficial in developing and validating standard operating procedures to achieve optimum integration of flightcrews and to avoid conflicting instructions and activities. (53:35)

In this statement he seems to align himself with those who believe that established procedures are completely acceptable and that new procedures are more deserving of analysis than present ones. Yet, his own data reveal problems of crew integration and conflicting activity which relate directly to noncompliance with explicit SOPs. A study of existing procedural imperatives and crew behavior ought to begin precisely where the published report stops. The manuals, charts, approach plates, data tapes, and protocols from the original experiment are available to extend the previous research. The FAA and company prescribed SOPs applicable to routine operations such as the first segment of the experimental scenario constitute a norm against which the subjects' behaviors can be judged.

The present chapter clarifies the procedural milieu of the research. It begins with examples of semantic difficulties which tend to obscure recognition of operating procedures. Next, a basic set of SOPs applicable to the Dulles-JFK segment of the experimental scenario is enumerated. Both empirical and analytical taxonomies are constructed using the identified procedures. Finally, a subset of SOPs associated with leadership and crew coordination is selected for further analysis.

Semantics

Before enumerating or classifying a single aircrew operating procedure, a review of the definition in Chapter I is appropriate.

> A procedure is a symbolic and mnemonic representation of a set of sensory, cognitive, and/or motor activities which, when recalled and executed within determinable tolerances, complete a task as designed.

This conceptualization is unlike any reference to procedure in aircrew directives. In fact, the available crew documents do not define a generic procedure at all. [Henceforth, all references to specific aircrew directives shall be those of the FAA and the unnamed air carrier involved in the Ruffell Smith experiment.] Still, the word "procedure" and the concepts embodied in it, often masked by a variety of aliases, appear throughout the literature of operational aviation.

The aircraft operating manual (AOM) and the company operations manual (COM) are the principal, but certainly not the only sources of standard aircrew procedures. Federal Aviation Regulations (FARs), aeronautical maps and charts, instrument departure depictions, instrument approach plates, airport directions, Notices to Airmen (NOTAMs), crew handbooks, and other miscellaneous documents contribute to the plethora of operating procedures.

The frequency of change and the necessity for cross referencing vary with each document, but collectively they require seemingly constant relearning and integration. The single side area of documents applicable to the simulated mission <u>other than</u> the AOM, COM, and crew handbooks covered twenty square meters. (53:33-34)

All of the major organizations which influence or regulate airline operations and safety recognize the reality of aircrew procedures, but they have no universally accepted definition which expounds the meaning of the concept. For the time being, the definition above must serve as a prototype. Even within the crew directives of a single air carrier the idea of procedure is susceptible to overuse and underdefinition.

Excerpts from the "Introductions" to the AOM and COM each indicate a preoccupation with the procedural mystique. One of the first statements in the AOM is that "The procedures in this manual include those in the FAA Approved Flight Manual expanded as necessary for [company] operations." The COM is equally blunt: "This manual contains the policies, rules and procedures that govern the operational activity of the Operations department." Despite a whole chapter of definitions in the COM, neither it nor the AOM explains what constitutes a procedure. Similarly, neither publication points out any of the words which are frequently used as pseudonyms for "procedure." One basic reason may be that conceptual understanding is lacking.

Another may be terminology. Aviation jargon has clearly added to the semantic confusion surrounding SOPs. A variety of words used in specific contexts connote prescribed operator activity in the same sense that a "standard operating procedure" does. Some of the more familiar terms are listed in Table 4. Each can have a connotation akin to the earlier definition of procedure. An example of a usage having the connotation of a behavioral imperative accompanies each word.

TABLE 4

AVIATION WORDS AND PHRASES WITH PROCEDURAL CONNOTATIONS

WORD	COMMON PHRASE
callouts	altitude callouts
checklist	the Pre-Start Checklist
clearance	an Air Traffic Control clearance
directions	directions for re-filing in flight
guidelines	fuel management guidelines
instructions	instructions for determining dry tank weight
limitations	engine operating limitations
method	a method for computing threshold airspeed
plan	an instrument flight plan
policy	company policy concerning copilot landings
practices	communications practices
profile	a profile descent
process	the process of troubleshooting a malfunction
regulation	the regulation on flight station manning
restriction	a standard instrument departure restriction
rule	a rule for holding pattern entry
schedule	the optimal climb schedule
steps	the steps in proceeding direct to a station
technique	throttle control technique during an approach

Unfortunately, the authors and editors of aircrew directives, including the AOM and COM, have never been constrained to use consistent terminology with respect to procedures. In the ideal, a policy should be more abstract than a procedure which should be more abstract than a technique which should be more abstract than a limitation. However, these words are used almost interchangeably in the manuals. The COM has one major section entitled Fuel and Flight Planning Policy and another named Instrument Approach Procedures, which can be found in the same chapters with Aircraft Loading Limitations and Approach and Landing Limitations respectively. The level of abstraction is essentially the same in every section. Thus, the expression standard operating procedure (SOP) has been chosen to represent all words and phrases with a procedural connotation. Identification of a finite collection of SOPs corresponding to the expected tasks in the simulated mission sequence can now proceed.

The entries in Table 4 indicate the diversity of procedural expression. They also suggest that procedural imperatives, like the tasks for which they are designed, lie along a continuum. At one extreme are simple single-step procedures of limited duration and activity. At the other extreme are grand strategies which involve multiple actors, tasks, and sub-procedures.

Enumeration of Operating Procedures

Only those SOP applicable to routine flight operations are of concern in this research. In aviation phraseology these are the Normal Operating Procedures as opposed to the Abnormal, Alternate, Irregular, or Emergency designations which are also found in crew publications. The order of presentation does not follow that of any single crew directive. Rather, it is an idealized sequence based on the events in the Dulles-JFK segment of Dr. Ruffell Smith's experimental scenario (cf. Chapter II for description).

After assembling the crew in the flight dispatching center, the captain is directed by the Predeparture Planning Procedure to brief other crew members and coordinate their activities. This SOP appears in the Flight Conduct chapter of the COM. It incorporates a lengthy list of predeparture activities, but it does not specify a rigid sequence of accomplishment or the responsible operator(s). Nor does this procedure have a companion checklist for easy verification of completed activities. Whether these characteristics should be classed as defects remains open to future investigation. Each of the numerous tasks of predeparture planning (see Table 5) has its own explicit procedure printed elsewhere. Most of them tolerate an ill-defined degree of self-procedurization. Only the Engineer's Aircraft Preflight has an abbreviated checklist in addition to textual explanation of desired behavior.

The Predeparture Planning Procedure is shown in toto because it typifies a popular means of providing normal operating strategy. Major milestones or considerations (metatasks) are briefly presented without accompanying elaboration on their subtasks or interdependencies. Greater detail is provided with individual sub-procedures. In a complex multi-dimensional operating environment the question of where to begin and end elaboration has no simple answer. Designers of SOPs face a quandry. Some level of operator intelligence must be assumed. The problem is: how much? Requiring operators to regularly refer to other parts of a manual may be the only concise way to deal with manifold contingencies.

TABLE 5

THE PREDEPARTURE PLANNING PROCEDURE

Step Number	Sub-procedures
1.	Captain's briefing.
2.	Aircraft preflight.
3.	Enroute and terminal weather.
4.	Applicable NOTAM [Notice to Airmen] and maintenance bulletin review.
5.	Flight plan and weight and balance review.
6.	Track or waypoint verification.
7.	Verification of adequate fuel for dispatch.
8.	Determination of the limiting takeoff gross weight, the engine thrust settings, and the prescribed speeds for the anticipated takeoff conditions.
9.	Execution of the dispatch release.
10.	Collection of required papers and charts.
11.	Aircraft maintenance log review.
12.	Restricted Articles Loading Notification form review.

If the necessary audio and video data had been recorded [they were not], analysis of crew conformance with the Predeparture Planning procedure would be a valuable study by itself. In fact, Predeparture Planning is representative of a number of highly aggregated procedures which bear mightily on aircrew behavior but which generate physical movement as well as sound. The aircraft ground and flight control procedures are other prime examples. Their names are basically the same as the operational phases of a typical mission (cf. Table, Mission

Phase Taxonomy): taxi, takeoff, departure, climb, level off, cruise, descent, approach, landing, and parking. Crew directives rely largely on narrative or pictorial descriptions of the associated manual control tasks. The procedures appear deceptively simple to the uninitiated. One reason for this is that they tacitly assume adherance to a multitude of sub-procedures. As a result, an elemental analysis of crew behavior in response to any set of operational tasks should begin with a lower level of component procedures.

The SOPs listed in Table 6 begin where Predeparture Planning ends. They display various levels of task aggregation, but they are all considered mandatory for normal flight operations in instrument meteorological conditions. The published format of each SOP is indicated by the letters C (checklist), G (graphical or pictorial), and N (narrative). The cockpit crew members expected to exhibit active procedural behavior are identified by the symbols A (all), P1 (captain), P2 (copilot), FE (flight engineer), PF (pilot flying), PNF (pilot not flying), and U (unspecified). As a general rule, whenever operating conditions permit, other crew members are supposed to passively monitor acceptable behavior and actively intercede to proscribe substandard behavior.

TABLE 6

NORMAL OPERATING PROCEDURES

Index Number	Name	Format codes	Operator codes
1.	Basic ATC communications practices	N	PNF
2.	Preflight Radio Checklist	C,N	P2
3.	Gear pin status report	N	P1
4.	Hydraulic system pressurization	N	P1 & FE
5.	ATIS report	N	U
6.	Clearance Delivery communications	N	PNF
7.	Ground Control communications	N	PNF
8.	Pre-start Checklist	C,N	A
9.	Ground crew report	N	P1
10.	Cabin report	N	P1
11.	Engineer's Start Checklist	C,N	FE
12.	Start Checklist	C,N	A
13.	Engine starting	N	P1 & FE
14.	Ground connections and hand signals report	N	P1
15.	Engineer's Taxi Checklist	C,N	FE
16.	Pre-taxi Checklist	C,N	A
17.	Transfer of EGT monitor	N	P1 & FE
18.	Ground Control communications	N	PNF
19.	Taxi	N	PF
20.	Takeoff and departure briefing	N	PF
21.	Final weight and balance computation	G,N	FE
22.	Taxi Checklist	C,N	A
23.	Tower communications	N	PNF
24.	Passenger pre-takeoff announcement	N	PF
25.	Engineer's Takeoff Checklist	C,G,N	FE
26.	Runway line up	N	PF
27.	Takeoff Checklist	C,N	A
28.	Thrust setting (takeoff power)	G,N	PF & FE
29.	Takeoff	N	PF
30.	Takeoff callouts	N	PNF
31.	Noise abatement departure	G,N	PF
32.	Gear retraction	N	PF & PNF
33.	Departure Control communications (initial contact)	N	PNF
34.	Thrust setting (rated power)	G,N	PF & FE
35.	Departure Control communication (radar vector)	N	PNF
36.	Flap retraction	G,N	PF & PNF
37.	Altitude callout	N	PNF
38.	Intermediate level off	N	PF
39.	Departure Control communications (climb clearance)	N	PNF

Table 6 (Contd.)

Index Number	Name	Format codes	Operator codes
40.	Airways navigation practices	N	PF & PNF
41.	Thrust setting (rated power)	G,N	PF & FE
42.	Climb (below 10,000 feet MSL)	N	PF
43.	Company departure report	N	U
44.	ARTCC communications (initial contact)	N	PNF
45.	Seat belt sign	N	U
46.	Climb (above 10,000 feet MSL)	N	PF
47.	After Takeoff Checklist	C,N	PF & FE
48.	Altimeter reset [not applicable for cruising below 18,000 feet]	N	A
49.	ARTCC communications (route clearance)	N	PNF
50.	Cruise data	G,N	FE
51.	Altitude callout	N	PNF
52.	Level off	N	PF
53.	Mach number/airspeed crosscheck	N	FE
54.	Cruise	N	PF
55.	ARTCC communications (radar vector)	N	PNF
56.	Turbulence penetration	N	A
57.	ARTCC communications (radar vector)	N	PNF
58.	Turbulence exit	N	A
59.	ARTCC communications (route clearance)	N	PNF
60.	Fuel systems management	G,N	FE
61.	ARTCC communications (center change; initial contact)	N	PNF
62.	ATIS report	N	U
63.	Company arrival report	N	U
64.	Approach briefing	N	PF
65.	ARTCC communications (sector change; initial contact)	N	PNF
66.	Approach data and speed bugs	G,N	A
67.	Passenger arrival announcement	N	PF
68.	Descent Checklist	C,N	A
69.	ARTCC communications (descent clearance)	N	PNF
70.	Descent (above 10,000 feet MSL)	N	PF
71.	Altimeter reset	N	A
72.	Seat belt sign and landing lights	N	U
73.	Descent (below 10,000 feet MSL)	N	PF
74.	Approach Control communications (initial contact; clearance)	N	PNF
75.	Approach Checklist	C,N	A
76.	Category I Instrument Landing System (ILS) Approach	G,N	PF
77.	Approach radio checks	N	PF & PNF

Table 6 (Contd.)

Index Number	Name	Format codes	Operator codes
78.	Altitude callout	N	PNF
79.	No smoking sign	N	U
80.	Approach Control communications (radar vector)	N	PNF
81.	Approach flap extension	G,N	PF & PNF
82.	Course bar and glide slope callouts	N	PNF
83.	Approach Control communications (approach clearance)	N	PNF
84.	Landing gear/landing flap extension	G,N	PF & PNF
85.	Landing Checklist	C,N	A
86.	Final approach fix (FAF) communications	N	PNF
87.	FAF instrument crosscheck	N	PNF
88.	Precision approach callout	N	PNF
89.	Outside scan and visibility callouts	N	PNF
90.	Landing	N	PF
91.	Landing roll callouts	N	PNF & FE
92.	Tower communications	N	PNF
93.	After Landing Checklist	C,N	A
94.	Taxi	N	PF
95.	Ground Control communications	N	PNF
96.	Parking	N	PF
97.	Blocks Checklist	C,N	A

The foregoing list does not include "optional" procedures such as those pertaining to autopilot tasks or the transfer of aircraft control between pilots. The former category was of particular interest to Dr. Ruffell Smith; the latter is employed in the current investigation. Instrument scanning procedures for each operator, although different for flight versus ground operations, are omitted because of their continual repetition from engine start through parking. Uncounted operating limitations, restrictions, and regulations apply to individual crew members and aircraft subsystems. These, too, are omitted. Thus, the enumerated SOPs represent a lengthy, albeit simplified and technically incomplete, standard for cockpit activities lasting approximately 75 minutes. The first segment of the experimental scenario was intended to elicit all but the last five Normal Operating Procedures.

Empirical Taxonomies

From the mid 1960s through the mid 1970s R. B. Miller (30,31), E. A. Fleishman (13), W. H. Teichner (58), and others devoted considerable effort to the development of human task taxonomies. In his well known paper on the rationale for different constructs of these taxonomies Miller started with a basic premise: "a taxonomy is a means of classifying objects or phenomena in such a way that useful relationships among them are established." (30:167) His statement applies as well to procedures as to the tasks for which they are synthesized.

The Normal Operating Procedures above have already been denoted as belonging to an empirical or colloquial taxon which is distinct from the Abnormal, Alternate, Irregular, and Emergency classifications. The status of aircraft equipment and the characteristics of the operating environment are factors which usually determine which class of SOP is appropriate in a given situation. There is extensive grouping of procedures in the AOM and COM according to these taxa, but the segregation is not perfect. Moreover, since circumstances may require a combination of these procedural types, a publication devoid of cross references is probably not feasible. While the colloquial categories are not transcendent, they are useful.

Another empirical classification scheme is determined by the agency which prescribes or enforces an SOP. A source document taxonomy is a further refinement of the same idea. The purpose served by these taxonomies is in knowing where to appeal for revisions to unsatisfactory procedures. Not incidentally, operator knowledge of these schemes also permits compliance effort to be concentrated on whichever SOPs are in a particular evaluator's jurisdiction or area of interest. The three agencies responsible for the vast majority of aircrew procedures are the FAA, the company (airline), and the aircraft manufacturer.

Some SOPs clearly belong to one organization or the other. Speed restrictions in controlled airspace are published and enforced by the FAA. The pre-arrival radio message to Operations is decreed by the company. Many more SOPs, for example, checklists, are hybrids. They are comprised of steps partially designed by the aircraft manufacturer with the approval of the FAA and partly included at the company's initiative. Irrespective of the source of SOPs, the foremost issue in this research, as in many accident investigations, is the type and extent of aircrew noncompliance.

Two other organizations have the ability to influence the design of operational procedures. Either group's dominance in the regulatory domain could produce profound changes in operator behavior and flight safety. They are the pilots' and controllers' unions, ALPA (the Air Line Pilots Association) and PATCO (the Professional Air Traffic Controllers' Organization). Since none of the SOPs for the experimental scenario is known to be directly attributable to either agency, the importance of their input to SOPs is impossible to assess. Recognition of potential taxa attributable to them merely implies additional layers of complexity, in accounting for aircrew or controller behavior.

A third empirical taxonomy is one based on arbitrary definitions of the operational phases of a mission segment. The taxa are variations on the names of the aggregated control procedures previously mentioned. The Normal Operating Procedures are easily reclassified according to this taxonomy. The class names and membership are shown in Table 7.

TABLE 7

MISSION PHASE TAXONOMY

Mission Phase	Normal Operating Procedures (by index number)
Pre-start	1 through 12 (total 12)
Start/Pre-taxi	1, 13 through 18 (total 7)
Taxi for takeoff	1, 19 through 23 (total 6)
Takeoff/Departure	1, 24 through 39 (total 17)
Clumb	1, 40 through 51 (total 13)
Cruise	1, 40, 52 through 59 (total 20)
Descent	1, 40, 70 through 74 (total 7)
Approach	1, 75 through 83 (total 10)
Landing	1, 84 through 91 (total 9)
Taxi after Landing	1, 92 through 95 total 5)
Parking/Shutdown	96 and 97 (total 2)

Miller has observed that the usefulness of a taxonomy is not predicated upon rigor, in other words mutually exclusive taxa. (30:168) The mission phase taxonomy illustrates that point. Several SOPs appear in more than one phase. The purpose is to give a coarse indication of the distribution of Normal Procedures throughout a fairly typical flight, namely the first segment of simulated mission. It is not intended to be a measure of procedural load. SOPs vary too much in content, duration, and criteria to let their total numbers be considered as weights. The mission phase taxa point to the need for more analytical classifications.

Analytical Taxonomies

The ground work for two analytical taxonomies has already been laid. The earlier annotations concerning presentation format and crew member involvement lead directly to informative taxa.

a. Format

Checklists, graphs or pictorials, narratives, and combinations thereof are the explicit formats for aircrew SOPs. Checklists and graphs never occur in isolation; they are always accompanied by explanatory material. In contrast, narrative SOPs frequently stand alone. Crew members have no quick reference memory aids for narrative procedures. Presumably, they do not need any.

Checklists, on the other hand, are tangible reminders. Fifteen of them are applicable to a normal flight segment. They are scattered among nearly all the operational phases of the flight. At least one checklist appears in ten of the eleven previously identified mission phases. Six phases, Pre-start, Pre-taxi, Taxi for Takeoff, Takeoff, Approach, and Landing, are in many respects anchored around checklists with similar names.

Only five checklists require less than complete crew participation. Three of those are restricted to flight engineer initiative and activity. A fourth (Preflight Radio) is designed for accomplishment by the copilot. The fifth, the After Takeoff Checklist, specifies flight engineer activities at the behest of the flying pilot. The other ten checklists all prescribe complete crew participation. The implicit requirement for coordination among unique personalities and roles brings these SOPs to the forefront of subsequent behavioral analysis.

Thirteen normal cockpit procedures are at least partially in pictorial format. Portions of the Noise Abatement Departure, Flap Retraction, ILS Approach, Approach Flap Extension, and Landing Gear/ Landing Flap Extension procedures utilize diagrams or plan view drawings to convey procedural information to crew members. A generalized ILS approach depiction appears as Figure 2 of the Appendix C. The The specific ILS approach plate for JFK Runway 4R is also shown in the Appendix C (Figure 3). Although a picture may not literally be "worth a thousand words," graphical and tabular formats are unquestionably efficient ways of packaging procedural imperatives. The pilots are responsible for executing these SOPs and for integrating them with others as required.

The flight engineer has the primary responsibility for compliance with the procedures concerning weight, center of gravity, thrust, and fuel consumption computations. Each of these SOPs is in some manner dependent on interpretation of graphical or tabular data. A simple chart displaying expected aircraft performance parameters for a .84 Mach cruise condition is shown in Table 25 of Appendix C. All operators must possess visual acuity as well as cognitive and motor agility to comply with procedures in pictorial format.

All of the Normal Procedures, including checklists, have narrative elements. The same is true of Alternate and Emergency Procedures; however, a number of Abnormal Procedures, including these concerned with hydraulic system failures, fuel jettisoning, and inflight engine shutdown/restart, are presented exclusively in checklist format.

When viewed in terms of the major activities prescribed, the Normal Procedures can be viewed as three large families, one small family, and a few unattached offsprings. The first family contains aircraft control procedures, both highly aggregated and otherwise. In general, they are of relatively long duration, they necessitate few communications, and they can seemingly be executed in parallel with other SOPs. A second family consists of extra-cockpit audio communications. They are of short duration, often just a matter of seconds; and they usually require the absence, interruption, or termination of other activity by one operator to complete. Intra-cockpit coordination procedures are in the third family. Briefings, checklists, performance parameter callouts, control transfer, and some configuration changes are members of this family. The durations of procedural behavior have high variability, and their characteristics regarding parallel activity are not consistent.

The smallest family consists of six procedures which are related to aircraft subsystems and are reserved for the flight engineer. There are three silent checklists (index numbers 11, 15, and 25) and three silent numerical computations (index numbers 21, 53, and 60).

The remaining SOPs lack strong ties to any one family. The passenger seat belt and no smoking sign procedures deal more with general safety than with aircraft control, communications, or subsystem operation. In contrast, the altimeter resetting procedures possess characteristics of each of the four other families. They simultaneously belong to every family and to none.

In summary, a taxonomy based on procedural format provides an appreciation of the mental flexibility and integrative capacity which a crew of "by the book" aviators must exercise. The classifications described above are condensed into Tables 8, 9 and 10.

TABLE 8

FORMAT TAXONOMY

Format	Normal Operating Procedures (by index number)
Check list only	*
Narrative only	1, 3-7, 9, 10, 13, 14, 17-20, 23, 24, 26, 29, 30, 32, 33, 35, 37-40, 42-46, 48, 49, 51, 52, 54-59, 61-65, 67, 69-74, 77-80, 82, 83, 86-92, 94-96
Checklist and narrative	2, 8, 11, 12, 15, 16, 22, 27, 47, 68, 75, 85, 93, 97
Graph and narrative	21, 28, 31, 34, 36, 41, 50, 53, 60, 66, 76, 81, 84
Checklist, graph, and narrative	25

*There are no "checklist only" Normal Procedures, but that format does appear among the Abnormal Procedures.

TABLE 9

NORMAL CHECKLIST PROCEDURES CLASSIFIED BY MISSION PHASE

Mission Phase	Checklist Procedures (by index number)
Pre-start	2, 8, 11, 12
Start/Pre-taxi	15, 16
Taxi for Takeoff	22
Takeoff/Departure	25, 27
Climb	47
Cruise	68
Descent	--
Approach	75
Landing	85
Taxi after Landing	93
Parking/Shutdown	97

TABLE 10

FAMILIES OF NARRATIVE PROCEDURES

Family	Narrative Procedures (by index number)
Aircraft control	19, 26, 29, 31, 38, 40, 42, 46, 52, 54, 56, 58, 70, 73, 76, 90, 94, 96
Extra-cockpit communications	1, 3-7, 9, 10, 14, 18, 23, 24, 33, 35, 39, 43, 44, 49, 55, 57, 59, 61, 62, 63, 65, 67, 69, 74, 80, 83, 86, 92, 95
Intra-cockpit communications	2, 8, 12, 13, 16, 17, 20, 22, 27, 28, 30, 32, 34, 36, 37, 41, 47, 50, 51, 64, 66, 68, 75, 77, 78, 81, 82, 84, 85, 87, 88, 89, 91, 93, 97
Aircraft subsystems	11, 15, 21, 25, 53, 60
Unattached	45, 48, 71, 72, 79

b. Operator Involvement

Personal supervision of military transport crews and analysis of the full mission flight simulator data have convinced this author of the importance of yet another taxonomy of procedures. This classification is determined by the prescribed operator involvement with individual SOPs. The purpose is to recognize predominate responsbilities for required crew activity, with emphasis on manual control and communications. Pure monitoring activity is disregarded in this taxonomy. Justification for the omission of monitoring behavior is based on the assumption that any crew member not executing assigned motor tasks should be periodically monitoring the performance of all system components, including other humans.

The distribution of Normal Operating Procedures according to operator involvement is as follows: 4 for the captain, 1 for the copilot, 7 for the flight engineer, 18 for the flying pilot, 30 for the nonflying pilot, 3 for the captain and flight engineer together, 6 for the two pilots together, 4 for the PF and FE jointly, 1 for the PNF and FE jointly, 15 for the whole crew, and 7 for unspecified operators. By themselves these numbers do not provide meaningful comparisons of operator load.

For instance, the procedures assigned to the PF and PNF are just not comparable. Approximately two-thirds of the PF's unassisted activities concern aircraft control while a similar portion of the PNF's tasks have to do with external communications. This basically distinct division of labor is somewhat compromised by the fact that a total of 21 SOPs dictate challenge and response coordination between the pilots and another 13 mandate a one-way transfer of information.

The flight engineer's procedures are unlike those of either pilot. When all subsystems are working properly, the FE is clearly a supporting actor. Although he cooperates on 23 SOPs with one or both of the pilots, he has only seven tasks exclusively reserved. Under "normal" operating conditions the engineer is constrained by fewer procedures than are the pilots. As a result, he may appear better able to comply with the prescribed SOPs. Subjectively, at least, the FE's total procedural load is considerably below that of the pilots. Table 11 summarizes the by-operator taxonomy.

TABLE 11

BY-OPERATOR TAXONOMY

Operators	Normal Operating Procedures (by index number)
Captain (P1)	3, 9, 10, 14
Pilot flying (PF)	19, 20, 24, 26, 29, 31, 38, 42, 46, 52, 54, 64, 67, 70, 73, 76, 90, 94, 96
Copilot (P2)	2
Pilot not flying (PNF)	1, 6, 7, 23, 30, 33, 35, 37, 39, 44, 49, 51, 57, 59, 61, 65, 69, 74, 78, 80, 82, 83, 86, 87, 88, 89, 92, 95
Flight Engineer (FE)	11, 15, 21, 25, 50, 53, 60
P1 and FE	4, 13, 17
PF and PNF	32, 36, 40, 77, 81, 84
PF and FE	28, 34, 41, 47
PNF and FE	91
PF, PNF, and FE	8, 12, 16, 22, 27, 48, 56, 58, 66, 68, 71, 75, 85, 93, 97
Unspecified	5, 43, 45, 62, 63, 72, 79

Consideration of the Normal Operating Procedures in light of the by-operator taxa discloses the dominant responsibilities of the pilot team as well as the criticality of crew coordination. These realities weigh heavily on the choice of which behavioral imperatives to analyze. One other fact is also divulged; namely, despite essentially equivalent instruments and controls at the two pilot stations, the behavioral roles of the occupants are intended to be vastly different. One pilot, the PF, is primarily a system controller and monitor; the other (PNF) is a facilitator, compensator, conciliator, and communicator. For normal operations the procedural distinctions between a captain PNF and a copilot PNF are theoretically nil. Yet, in practice, the distinctions are remarkable.

The expected relationships between a captain and the rest of his crew are set forth in two explicit narrative procedures (not listed above). The COM policy on Command and the separate policy on Management detail basic role differences within the crew. The authority to command, i.e., to issue instructions and require compliance is expressly vested in the pilot-in-command. In commercial air carrier operations the pilot-in-command is the captain whether he is the flying pilot or not. Thus, the captain can, indeed he must, "exercise full control" over every operational activity even though he may not be manually controlling the aircraft or its subsystems. The potential for role conflict in a captain as PNF and copilot as PF situation is omnious. Lack of confidence, cooperation, or empathy between the pilots could produce nonstandard behavior by one crew member that no amount of procedural compliance by others could neutralize.

In further elaborating upon operator roles, the COM offers a flight management policy apparently designed to pacify government regulators and subordinate crew members without substantively lessening the captain's authority. The policy calls for management according to the "crew concept." As explained, that concept necessitates full communication and coordination among crew members. It demands "constant vigilance, cross-checking, and sharing of information." However, after informing the captain to whatever extent is possible, other crew members are required to give full support to his directions and decisions. (It should be pointed out that company procedures are typically drafted and approved by senior captains in executive positions.)

The problem of striking a proper balance among authority, explicit SOPs, and subordinate crew member responsibilities faces all operational managers. The COM summarizes one airline's approach to the problem in a single paragraph.

> The use of standard procedures and terminology promotes confidence and precision within the crew. The level of standardization must be high enough to discourage unsafe practices and carelessness but should not limit operational flexibility unnecessarily or discourage the use of good judgment.

The Ruffell Smith data show how this company philosophy is actually applied in the operational environment.

Crew Coordination Procedures

Since a captain's position of leadership is well documented and since crew coordination is in many respects dependent upon exemplary leadership, a crew's procedural behavior or the lack thereof can be a guage of the strength of internal leadership. A subset of the Normal Operating Procedures which elicit verbal interactions between a captain and his crew has been chosen for further examination. A complete listing is shown in Table 12.

TABLE 12

CREW COORDINATION PROCEDURES
(To be used for quantitative compliance assessments)

Index Letter	Procedure Name
A.	Pre-start Checklist
B.	Start Checklist
C.	Pre-taxi Checklist
D.	Transfer of EGT Monitor
E.	Taxi Checklist
F.	Takeoff Checklist
G.	Takeoff Callouts
H.	Gear Retraction
I.	Flap Retraction
J.	Altitude Callout
K.	After Takeoff Checklist
L.	Altitude Callout
M.	Transfer of Aircraft Control
N.	Descent Checklist
O.	Approach Checklist
P.	Altitude Callout
Q.	Approach Flap Extension
R.	Landing Gear/Landing Flap Extension
S.	Landing Checklist
T.	Precision Approach Callouts
U.	Landing Roll Callouts

These crew coordination SOPs are published in all of the various formats described above. They occur in eight of the eleven mission phases. Descent is not represented because of its short duration in the scenario. No data were collected for the Taxi after Landing or Parking/Shutdown phases. In most cases, the two pilots are the main actors, but flight engineer participation is not ignored. The optional Transfer of Aircraft Control procedure is included because its use implies the flying pilot's willingness to trust in and to share responsibility with the other pilot.

Eight of the nine checklists require full crew participation. Each of the eight is to be accomplished via challenge and response interactions. The copilot and the flight engineer are the usual challengers. Of particular interest are the identity of the crew member who initiates each checklist, the manner of initiation, and the meticulousness of both challengers and respondents. According to the COM the captain or the PF should initiate normal operating checklists, and "in most instances" prescribed activity should be accomplished before the challenges begin. When used in this manner, a checklist helps to notify all crew members of task status. A different but familiar use of a checklist is as a triger for commencement of task activity. The COM does not condone such use, and it specifically prohibits continuation of checklist challenges beyond any incomplete sub-task.

Normal operating checklists are to be initiated and completed within established, control-oriented time frames. They are supposed to be started so that adequate time is available to accomplish all activities without interruption. This is not possible in either the simulated or the real world operating environments. Radio communications and manual control requirements force interruptions. Regardless, challenge and response checklists are to be completed without deviation, including a statement of the checklist's name prior to the first challenge and an announcement of procedure completion following the last challenge.

The procedures (index letters G, J, L, P, T, and U in Table 12) mandating callout of aircraft performance parameters at specified values do not require acknowledgement by any other crew member. The nonflying pilot is responsible for all callouts except two. Those two occur during the landing roll. They concern the status of thrust reversers, and they are to be made by the flight engineer. Compliance with callout procedures demands perceptual diligence. It also indicates a commitment to the basic flight management policy stated in the COM.

Of the six remaining procedures four embody changes in the configuration of the aircraft (gear or flap extension and retraction). The importance of pilot coordination and agreement concerning such changes is obvious. Execution of the other two procedures, Transfer of EGT Monitor and Transfer of Aircraft Control, conveys primary accountability for essential monitoring and control functions from one operator to another. Again, the need for complementary behavior is apparent. In all six procedures verbal communication by two crew members is mandatory. The Transfer of EGT Monitor responsibility is between the pilot who starts the engines (normally the captain) and the flight engineer, usually following the latter's pre-taxi checks. Transfer of Aircraft Control is supposed to occur whenever the flying pilot must divert his attention to another task. The other task might employ a prescribed SOP such as briefing the crew, or an implicit, personalized procedure such as studying an avigation chart.

The interaction or crew coordination procedures identified here capture essential ingredients of group leadership, crew management, and behavioral conformity. Objective data pertaining to crew compliance with these SOPs have not previously been compiled. Although Dr. Ruffell Smith recognized problems of crew integration, he concentrated on errors in control of aircraft parameters and operation of subsystems. He did not elaborate on the possibility of a relationship between meticulous compliance with coordination procedures and his determinations of crew error. The next chapter will explore that possibility.

CHAPTER IV

COMPLIANCE ASSESSMENTS

This chapter looks at compliance with twenty-one crew coordination procedures from two very biased vantage points. The first perspective is that of a person who believes qualified crew members should have the benefit of any doubt concerning the suitability of procedures. From that point of view explanations of noncompliant aircrew behavior are sought in the procedures themselves or in the circumstances encompassing their use. The alternative perspective is that of an evaluator who thinks that existing procedures are basically flawless. With that belief the assessment of individual and group performance hinges on operator compliance with a collection of SOPs. Aberrant behavior is ascribed to particular operators, and patterns of nonstandard behavior may be symptoms of aptitude or training deficiencies.

In the latter part of this chapter the crew errors previously identified by Ruffell Smith are reconfirmed. They are also recategorized according to operator involvement, like the procedures in Chapter III. New error statistics are computed and their distributions are studied. Indicators developed to describe individual and crew compliance with coordination procedures serve as predictors of categorical error counts. The implications of several statistical relationships are discussed.

Procedures and Circumstances

The crew coordination procedures identified in Chapter III are the basis of a quantitative assessment of compliance across crews. The previously noted subdivisions (checklists, callouts, configuration changes, and transfers) form natural groupings for diagnosing unsatisfactory procedural imperatives and locating circumstantial anomalies.

a. Checklists

The Pre-start, Start, Pre-taxi, Taxi, and Takeoff Checklists are supposed to be initiated upon command of the captain or the flying pilot. The other pilot is to then announce the name of the checklist, presumably as a confirmation of the command, and read the opening challenge. Once initiated, checklists may be delayed by interruptions from outside the cockpit or from within; but the checklist must ultimately be resumed and completed in toto. In every experimental run this requirement is met. The requisite challenges are made and a response is given for each challenge. However, some of the operator actions and replies are contrary to procedural specifications. Dr. Ruffell Smith notes several such actions as errors, but he does not observe the verbal requirements of proceduralized crew coordination.

The first four checklists named above are entirely challenged by one of the pilots. Challenges in the Takeoff Checklist are begun by a pilot and completed by the flight engineer. After a proper response to the final challenge in each procedure, the challenger is directed to state "[name] Checklist is complete." This concluding statement is printed at the bottom of each checklist. The Descent, Approach, and Landing Checklists are similar to those above except that the flight engineer is the sole challenger. The After Takeoff Checklist is unlike the rest because there are no verbal challenges; the engineer accomplishes all steps silently and merely verifies completion to the pilots.

Among the ten sampled crews there are remarkable differences in the patterns of behavior associated with who the prescribed challenger is. Considering the first five checklists, or a total of fifty opportunities over ten flights, the command-announcement-challenge sequence is fully executed only five times. Two occurrences involve the Prestart Checklist; three are on the Pre-taxi Checklist. Table 13 contains the data for all pilot-challenged checklists. The assortment of noncompliant behaviors includes: 23 occasions when the SOP is initiated without any command, 22 occasions when there is a command but no confirmation announcement, and 13 occasions when there is neither a command nor an announcement.

These behaviors raise two questions about the prescribed procedural communications. First, should an explicit command be required to initiate a normal operating checklist? The data clearly reveal that checklist tasks can be accomplished without a specific command or announcement. In circumstances necessitating conservation of time, such shortcuts seem to be widely accepted expedients. But when time constraints are not severe, similar omissions appear to strain crew cohesion. One shortcut often begets another, and a crew's framework of mutual trust and structured leadership may undergo progressive

TABLE 13

CHECKLIST INITIATION BEHAVIOR WITH A PILOT AS CHALLENGER

	Experimental Run Number									
Checklist	3	4	5	6	8	10	12	13	14	15
Pre-start	C	C	C	CA		C	C	C	C	CA
Start	A	A	C	A		A			A	C
Pre-taxi	C	CA	CA	A		C	C		A	CA
Taxi	A		C	A		C	C	C	C	C
Takeoff			C	A	C	C				C

C = issurance of the prescribed initiation command.

A = announcement of the appropriate checklist.

CA = prescribed command and announcement accomplished.

deterioration. Rapport among the crew of experimental run number six practically vanishes by the time they "land" at JFK.

One purpose for mandating audible checklist initiations lies in the sweeping Command and Management Procedures. They affirm that responsibility for all operational activity resides in the captain. Even if he expressly delegates a portion of his authority to another crew member, he knows that he cannot dispense the final responsibility for operational safety to anyone. He should also know, though the SOPs do not state it, that whenever any operator exceeds the established limits of authority or the bounds of procedural tolerance without subsequent negative reinforcement, that behavior is more likely to be repeated and emulated. In short, checklist commands are necessary. They reduce uncertainty and preserve internal order.

The second question about checklist communications has to do with the challenger's first intonation. Should he be required to announce each checklist by name? Nearly half of the observed pilot challengers fail to comply. Nevertheless, the existing requirement can be easily rationalized. The announcement should occur regardless of the presence or absence of a formal initiatory command. If a command is given, then the announcement serves as an acknowledgement to the issuer and as a secondary notification to the flight engineer. If no command is given, then the announcement becomes an internal cue to crew members engrossed in other activities.

In some cases internal cues may seem superflous. For example, in the experimental scenario the simulator controller consistently hurries the crews through the taxi phase and into takeoff position.

Most crew members appear to sense the need for rapid coordinated action. Consequently, crew meticulousness in adhering to the formal verbal preliminaries of the Take-off Checklist is exceedingly lax. Six crews start the Takeoff Checklist without command or announcement; yet no extraordinary problems are encountered. When all crew members share a common expectation of events, internal coordination can appear automatic.

In rather stark contrast to the paucity of audible checklist introductions between the two pilots are the more extensive verbalizations when the flight engineer is the challenger. Table 14 displays these data. Exactly half of the 30 checklist sequences (Descent, Approach, and Landing) represented in the data begin in the prescribed command-announcement-challenge order. Only one of the 30 is missing the initial command. Pilots seem to recognize the importance of clear and concise instructions to a teammate who works outside their normal field of vision. For their part, the flight engineers collectively make as many announcements (15) in their 30 opportunities as the pilots do in 50. In addition, more engineers are self-consistent. Three of them omit all announcements, and three others omit none. The origins or stimuli of such behavior are not apparent, but the absence of true standardization is.

One other aspect of checklist behavior deserves special mention. It reinforces the previously noted differences between pilots and engineers as challengers. In eight of the forty cases when a pilot gives the last challenge, he fails to follow the response with the prescribed procedure completion statement. This is considerably

TABLE 14

CHECKLIST INITIATION BEHAVIOR WITH THE FLIGHT ENGINEER AS CHALLENGER

	Experimental Run Number									
Checklist	3	4	5	6	8	10	12	13	14	15
Descent	CA	CA	CA	CA	C	C	C		C	C
Approach	CA	CA	CA	CA	C	CA	CA	C	C	C
Landing	CA	CA	CA	C	C	CA	C	C	CA	C

C = issuance of the prescribed checklist command.

A = Announcement of the appropriate checklist.

CA = prescribed command and announcement accomplished.

different from the two omissions in fifty opportunities demonstrated by the flight engineers. Tables 15 and 16 display these data.

There are at least four plausible explanations for the observed disparities in operator behavior. First, the engineers, or perhaps the whole crew, may be more attentive to procedural detail in flight (e.g., the checklists read by the engineer) than they are on the ground (e.g., checklists read by a pilot). Data concerning use of the After Landing and Blocks Checklist might have shed some light on this notion. Secondly, the flight engineers, by training or nature, may be more observant of detail than are the pilots. In this author's own experience, professional flight engineers seem somewhat less inclined to "cut corners" than do some of their more aggressive pilot counterparts. Thirdly, flight engineers may simply have more time to attend to the finer points of procedures than do pilots. Generally speaking, during normal operations the engineer has the most freedom to set his own pace. Finally, since the flight engineer is removed from the pilots' normal fields of vision, both he and they may be predisposed to rely on formal verbal communications for initiation and termination of checklists. If this supposition is true, crew coordination might be improved by making the flight engineer the challenger of all checklists.

b. Callouts

Callouts of aircraft parameters by the nonflying pilot or the engineer to the rest of the crew represent procedures fundamentally different from checklists. There are no preparatory commands or

TABLE 15

CONFIRMATION OF CHECKLIST COMPLETION WITH A PILOT AS CHALLENGER

	Experimental Run Number									
Checklist	3	4	5	6	8	10	12	13	14	15
Pre-start	S	S	S	S	S	S	S	S	S	S
Start		S	S	S	S	S		S	S	S
Pre-taxi	S	S	S	S	S	S			S	S
Takeoff	S		S	S		S		S		S

S = verbalization of required checklist completion statement.

TABLE 16

CONFIRMATION OF CHECKLIST COMPLETION WITH THE FLIGHT ENGINEER AS CHALLENGER

	Experimental Run Number									
Checklist	3	4	5	6	8	10	12	13	14	15
Takeoff	S	S	S	S	S	S	S	S	S	
After Takeoff	S	S	S	S	S	S	S	S	S	S
Descent	S	S	S		S	S	S	S	S	S
Approach	S	S	S	S	S	S	S	S	S	S
Landing	S	S	S	S	S	S	S	S	S	S

S = verbalization of required checklist completion statement.

announcements; there is no statement of completion; and no responses are required. In all but one case the nonflying pilot acts as a back-up or second-level visual monitor who audibly relays operating information to the flying pilot. Airline, FAA, and NTSB advocacy of callout procedures has resulted from a large number of mishaps in which the flying pilot seemed to be distracted or overloaded during periods of rapid change in aircraft parameters, namely, the takoff, climb, approach, and landing phases.

Each of the flight phases just mentioned is represented by a callout procedure in the data. The Takeoff Callouts include: first instrument indication of airspeed, four predetermined speeds during takeoff roll, instrument indication of a positive rate of climb, and an altitude of 800 feet above field elevation (AFE). The Altitude Callouts are to occur during climb and descent when the aircraft reaches 1000 feet from its clearance altitude. (A mechanical Altitude Alert System is also installed to provide aural and visual notification when the aircraft comes within 900 feet of a selected altitude.) Four reports of decreasing altitude and confirmation of passing the final approach fix (FAF) constitute the Approach Callouts. The five Landing Callouts relate to thrust reverser position (two calls by the flight engineer) and deceleration (three calls by the nonflying pilot).

As a group, the sampled crews are more uniform in their compliance with callout procedures than with checklists. Table 17 contains the pertinent data. During takeoff only one crew (run number six) fails to make all of the required calls. In run number three the flying pilot twice preempts the nonflying pilot. The remaining eight

TABLE 17

NONSTANDARD CALLOUT BEHAVIOR

PHASE	CALLOUT	3	4	5	6	8	10	12	13	14	15
		Experimental Run Number									
Takeoff	Initial airspeed				0						
Takeoff	Takeoff speeds(4)										
Takeoff	Positive Climb	PF									
Takeoff	800 feet	PF			0						
	"1000 feet to level off"										
Climb	(at 3000 feet)	L	L	0		L	L	0	L		L
Climb	(at 14000 feet)	L	L	L					PF		
Descent	(at 5000 feet)	L	L	L		0			PF	PF	0
Approach	Outer marker							L			
Approach	500 feet AFE				PF						
Approach	200 feet ADH		0		PF						
Approach	100 feet ADH								0		
Approach	Minimums				0						0

TABLE 17 (Contd.)

		Experimental Run Number									
PHASE	CALLOUT	3	4	5	6	8	10	12	12	14	15
Landing	All in reverse (FE)										
Landing	100 knots				0						
Landing	90 knots				0						
Landing	60 knots	0		0	0					0	
Landing	All out of reverse (FE)						0	0	0		0

L = late callout.

0 = omitted callout.

PF = callout made by flying pilot rather than nonflying pilot.

FE = flight engineer

"blank" = accomplished per SOP.

crews behave as expected. No deficiencies in the procedure itself are evident.

Compliance with the Approach Callouts is similar. Four isolated omissions are detectable, but they do not point to any particular deficiency in the procedure. Data for the first three callouts during landing appear consistent and unaffected by the scenario (two omissions by one captain form part of a larger pattern of noncompliance). However, the last two callouts in that procedure are sometimes omitted because of the intervention of the simulator controller in terminating the first segment.

Only the Altitude Callouts during climb and descent are treated with the type of casualness seen earlier in some checklists. Sixteen out of 30 required altitude calls either are not made or are made at other than the prescribed time. One possible reason is that crew members perceive negligible safety benefit from a "high altitude" callout. In isolated situations other tasks interfere with callouts, but in general the mental load on the nonflying pilots is not especially heavy at these points.

Another explanation of such behavior is that the built-in redundancy of the mechanical alerting device tends to make operators less diligent. If this is true then the allocation of tasks between men and machines should be reconsidered in light of operational experience as well as theoretical concepts. The "1000 feet to level off" callout requirements may be excessive and demeaning. Procedure designers must consider the psychological as much as the physiological effects of their prescriptions to human operators. Simple modification of the callout altitude such as "500 feet to level off," might have several advantages. The mechanical warning at 900 feet could be more valued than it is now. The nonflying pilot's callout would then occur without mechanical back-up, and the flying pilot would have an additional short-suspense prompt for control action. In any event, extensive operational testing of revised altitude callout procedures should be completed as soon as possible.

c. Configuration Changes

The rudimentary procedures for gear and flap extension/retraction probably do not require validation. Few pilots argue with the desirability of verbally commanding and acknowledging impending changes in aircraft configuration. In fact, since the landing gear level in the Boeing 747 is located on the copilot's side of the instrument panel, flying captains are physically dependent on copilot assistance in changing the position of the undercarriage. In addition, captains and copilots alike rely on their nonflying counterpart to audibly confirm and manually select commanded changes in flap position.

The experimental data (Table 18) reveal no deviations from established oral procedures for Gear Retraction and a single instance of noncompliance for Flap Retraction. Likewise, the Approach Flap Extension and Landing Gear/Landing Flap Extension SOPs exhibit high rates of behavioral conformity (95% and 90% respectively). A total of four configuration changes (of 104 actually made) evidence omission of one of the two prescribed verbalizations. One change (from flaps 1 to flaps up) is made without comment by either pilot. None of these facts provide much enlightenment about the underlying procedural

TABLE 18

VERBALIZATION OF CONFIGURATION CHANGES

Configuration Change	Experimental Run Number									
	3	4	5	6	8	10	12	13	14	15
Gear up	CA	CA	CA	CA	CA	CA	CA	CA	CA	CA
Flaps 5	CA	CA	CA	CA	CA	CA	CA	CA	CA	CA
Flaps 1	CA	CA	CA	CA	CA	CA	CA	CA	CA	CA
Flaps up	CA	CA	CA	S	CA	CA	CA	CA	CA	CA
Flaps 1	CA	CA	CA	CA	CA	CA	CA	CA	CA	CA
Flaps 5	C	CA	CA	CA	CA	CA	CA	CA	CA	CA
Flaps 10	A	CA	CA	CA	CA	CA	CA	CA	CA	CA
Flaps 20	CA	CA	CA	CA	CA	CA	CA	CA	CA	CA
Gear down	CA	CA	C	CA	CA	CA	CA	CA	CA	CA
Flaps 25	C	CA	CA	*	CA	CA	CA	CA	CA	*
Flaps 30	*	CA	*	CA	CA	*	*	CA	CA	CA

C = issuance of configuration change command.

A = acknowledgement of change command.

S = silence (configuration changed without verbalization).

* = prescribed configuration not used by crew.

imperatives. However, the integration of configuration change SOPs within the corresponding flight control procedures is noteworthy.

Aircraft altitude and location over the ground vary considerably at the initiation point of selected configuration change procedures. The start of Flap Retraction occurs as early as the "800 feet" callout on takeoff and as late as the intermediate level off at 4000 feet during departure. Neither of these extremes conforms to the Noise Abatement Departure procedure which is to be accomplished concurrently. Flight control parameters at the commencement of the Landing Gear Extension procedure show comparable variability. Aircraft altitude ranges from approximately 3500 feet down to 1500 feet; distance from the airport lies between eleven and five nautical miles.

The foregoing observations illustrate the difficulty in isolating and interpreting a small, yet meaningful, number of human performance variables. This study does not incorporate flight control parameters per se in the assessment of procedural compliance. Instead, it focuses on verbal behavior. This author does not eschew other indicators of operator performance or crew coordination. The ones chosen bear directly on crew integration. Aircraft parameters relate indirectly. Verbal behavior has intuitive as well as substantive appeal in assessing leadership and teamwork. The fact that audible indicators yield no new truths about the synchronization of configuration change activity does not discount their value in studying other tasks.

d. Transfers

Verbal indicators of compliance with the Transfer of Exhaust Gas Temperature (EGT) Monitor and the optional Transfer of Aircraft Control

Procedures are more revealing. Both SOPs typify the quality of communications between specific pairs of crew members. The EGT procedure is designed to elicit flight engineer initiative in lessening pilot load and increasing his own for the remainder of a flight. The control transfer procedure is intended for use as many times during flight as the pilot team deems appropriate.

In the experimental data (Table 19) two of the ten flight engineers fail to advise the flying pilot when he can relinquish responsibility for monitoring EGT. As a result of engineer noncompliance with the SOP, the pilot team theoretically carries a larger procedural load throughout the mission. On one crew (run number twelve) the engineer actually declines separate requests by each pilot to assume EGT monitoring during taxi. In that case the pilots obviously desire to reduce their load; but the engineer repeatedly says he is unable to relieve them. During run number thirteen EGT monitoring responsibility is never mentioned. Neither the pilots' awareness of their load nor the reason for the engineer's failure to initiate the procedure becomes evident. Nevertheless, since eight of the ten observed crews have no difficulty whatsoever in complying with the EGT monitoring procedure, it must be assumed that the procedure itself is adequate.

The Transfer of Aircraft Control procedure also seems well conceived. Eighty per cent of the pilot teams go through at least one full "double transfer." That type of exchange is desirable whenever the flying pilot must temporarily divert his attention from aircraft control. He should direct the other pilot to assume control ("You have it") and require him to acknowledge ("I have it"). When the

TABLE 19

EMPLOYMENT OF TRANSFER PROCEDURES

	Experimental Run Number									
Procedure	3	4	5	6	8	10	12	13	14	15
Transfer of EGT monitor (mandatory)							T	0		
Transfer of aircraft control ("optional")	1C 1I	1C	2C	0	1C 1I	2C 2I	0	1C	2C	2C

(#) C = (number of) complete "double transfers" accomplished.

(#) I = (number of) incomplete "double transfers" accomplished.

0 = omitted task.

T = task attempted; procedure not used; task never completed.

"blank" = task accomplished per SOP.

original flier is ready to resume control, the sequence may be reversed (e.g., "OK, I have it" followed by "You have it"). The importance of knowing who has control of the aircraft is unmistakable. Similarly, there is no doubt about the merit of periodically transferring control to review maps and charts, to conduct crew and passenger briefings, or to just relax.

In this regard, the most striking data from the experiment are that in runs six and twelve the pilot teams never once transfer control. Even though the flying pilots, both of whom happen to be co-pilots, are unable to accomplish other mandatory tasks, no member of either pilot team suggests transfer of control. In both instances the nonflying pilot (captain) gives the Approach Briefing; also the Passenger Arrival Announcement is skipped altogether. Such behavior should constitute a basis for explicitly requiring the Control Transfer procedure in conjunction with other SOPs or at prespecified points in a normal flight.

Three other pilot teams have at least one instance each of failure to verbally accomplish the second half of a "double transfer." In each case the flying pilot is the captain. It is conceivable that some sort of visual sign is substituted for the prescribed statements, but that would still be noncompliance. Since the observers do not describe any visible transfer activity, the true state of the system must be hypothesized. Two major assumptions are logical: (1) sometimes both pilots think they have control; and (2) sometimes neither pilot thinks he has control. The safety implications of either assumption are indefensible. The prescribed procedural dialogue succinctly eliminates these potentially dangerous situations.

In summary, the procedures for checklist initiation/completion, parameter callout, configuration change, and responsibility transfer dictate verbal behaviors that can reasonably be expected to enhance crew coordination and flight safety. Except in the case of Altitude Callouts, noncompliance appears to depend more on the operator(s) involved than on the requirements of the procedures. Further support for this hypothesis is developed in the next section.

Individuals and Crews

Now that behavior patterns relative to specific SOPs have been discussed, it is time to consider within-crew procedural compliance. The perspective of the foregoing examination disclosed that although some existing crew coordination procedures could be improved, their purposes are noble, and their demands are generally realizable. Hence, the following paragraphs treat noncompliance as a shortcoming by one or more operators. The extremes of observed behavior for both individuals and crews receive principal attention.

a. The Upper Levels of Compliance

None of the experimental crews demonstrate totally compliant behavior across all three operators and the sampled internal coordination procedures. Every crew does have at least one member who conforms to prescribed verbal behavior with high consistency, but each crew also has at least one operator who regularly violates a coordination imperative. Examples of compliance by one crew member and noncompliance by a partner are prevalent in all tasks which involve two-way communications.

With respect to pilots and checklist initiations, for example, the captains of experimental runs five and fifteen properly command the start of all eight challenge and response checklists. In addition, these individuals uniformly comply with the verbal requirements for initiating configuration changes and transferring aircraft control. Their copilots on the other hand, frequently fail to confirm checklist commands with the required announcement; and the copilot on run five fails to confirm the "gear down" command.

A partial reverse image of the pilot teams just described is the one participating in run number six. The copilot of that crew is the only pilot checklist challenger who announces all five of his checklists. No other copilot announces more than two. Regrettably, the copilot on run six does not maintain his singularly high level of performance in other areas, most notably control of airspeed, angle of attack, and sink rate, and the captain's behavior is nonstandard in many respects including checklist commands. In fact, that pilot team has the worst composite level of compliance observed. Their problems are detailed in the section entitled The Lower Levels of Compliance. In the meantime, proper behavior merits further attention.

Perfect adherence to SOPs is certainly not an impossibility. The flight engineers on runs three, four, and five each execute the sampled procedures flawlessly; but, as before, their associates are less than perfect. Copilot noncompliance on run five has already been mentioned. On runs three and four the captains as well as the copilots give multiple demonstrations of nonstandard coordination behavior. Checklist initiation/completion requirements are not fully met by either crew, and run three is plagued by incomplete communications regarding configuration changes. Clearly, perfect procedural compliance by a single operator does not guarantee the same kind of behavior by the remainder of the crew.

In terms of adherence to the crew coordination SOPs, the best overall performance occurs on run number ten. This is essentially an objective appraisal. Compliance counts are generally among the best observed in every category.

The captain misses only one checklist command, and all checklist completion statements are accomplished. The only callout omission is induced by the simulator controller. Coordination of configuration changes is sound despite landing with flaps 25 instead of flaps 30 on a short runway. Lastly, more control transfers are accomplished than by any other crew.

During run ten, as in runs five and fifteen, the captain's awareness of the demands on his subordinates combined with his assertiveness in directing joint activities appears to have a positive influence on crew cohesion and procedural compliance. Even though none of these captains is procedurally perfect, each maintains a high standard. Collectively, their attention to the fine points of crew coordination procedures sets them apart from their peers. In a very real sense they exhibit a positive form of leadership by example.

b. The Lower Levels of Compliance

Among the lower levels of personal and group compliance with SOPs, attention to detail by the pilot-in-command is anything but exemplary. Each of the operators in run number eight exhibits very selective compliance with crew coordination procedures. The captain is typical. He omits the first four checklist commands but does not miss a single configuration change instruction. Similarly, the copilot omits every checklist announcement but confirms every configuration change. In terms of quality and quantity the crew's use of verbal coordination procedures is questionable, but there is no question about who is in command. The captain sets the pace of crew activity and regularly rechecks the status of various tasks.

The same cannot be said for runs six, twelve, and thirteen. In all outward respects, the pre-experiment characteristics of these three crews resemble those of other crews in the study. However, for unknown reasons, the copilot becomes the flying pilot on the Dulles-JKF segment. In each instance the captain neglects to explicitly allocate command authority to the copilot.

All three crews experience some breakdown in internal communications. Uncertainty about who should command, announce, and challenge the first five checklists is one indication of fundamental confusion over proper roles. The most pronounced rivalry for leadership and the most serious failure to exercise command responsibility both occur during experimental run number six.

The copilot on that run attempts to exert leadership by announcing and then immediately reading the challenges of the Start, Pre-taxi,

Taxi, and Takeoff Checklists. He does this without a command from the captain, and he actually tries to accomplish the tasks of the flying and nonflying pilots simultaneously. Between the start of the takeoff roll and level off at cruising altitude crew coordination shows signs of very serious deficiencies. The captain misses two Takeoff Callouts. All three members contribute to a low altitude stick shaker activation (a near stall condition). Both pilots fail to verbalize the last increment of Flap Retraction (from flaps 1 to flaps up), and the copilot issues three separate orders to the engineer to do the After Takeoff Checklist before any form of acknowledgement is offered.

At no time during flight does the copilot suggest or initiate transfer of control to the captain. Regardless, the copilot's attempt at physical as well as symbolic leadership is ultimately supplanted by the captain's command to the flight engineer to begin the Descent Checklist. That action serves as an omen of further deterioration in aircraft control and crew management. The Approach Radio Checks are neither properly commanded nor properly completed. The copilot preempts the captain on the first two Approach Callouts during a poorly executed ILS approach which finally ends in a go-around (following a second outburst from the Ground Proximity Warning System). The captain fails to intervene when prescribed flight parameters are exceeded, and on the second ILS approach he fails to callout "minimums." The pilot team's substandard behavior is culminated by the captain's omission of all mandatory callouts during the landing roll.

No other crew has a pattern of procedural noncompliance as broad or as deep as the one just described. However, leadership and crew coordination problems are evident in each of the two other crews with a flying copilot. On run number twelve the captain directs the copilot to start three of the first four checklists. He also commands the engineer to begin the After Takeoff Checklist. Meanwhile, the copilot performs nonflying duties and reads all appropriate challenges in the first five checklists. The copilot does not formally announce any of the checklists, and his only formal completion statement accompanies the Pre-start Checklist. Twice prior to takeoff the flight engineer tells the pilots that he is unprepared to assume EGT monitoring responsibilities. After his second refusal no crew member makes further mention of that Transfer Procedure.

The captain intermittently performs leadership functions in flight, especially when the copilot appears "overloaded" or "behind the aircraft." For example, the captain advises the passengers of turbulence, he conducts the Approach Briefing during descent; and he requests the go-around EPR setting from the engineer. All of these things are normally accomplished by the flying pilot. The copilot does manage to call for initiation of the Descent, Approach, and Landing Checklists; but he does so hesitatingly without much conviction or self-confidence. He seems to be caught between two cockpit roles, leader and follower.

Neither pilot ever suggests the desirability of transferring control of the aircraft. The one fact of which the copilot seems certain is that he is flying the airplane, and he does nothing to change that. Although animosity is not apparent and cooperation between the pilots does occur, their specific communications tend to inhibit rather than enhance crew coordination.

When interpretations and expectations regarding command authority and responsibility are not consistent among crew members, uncertainty and confusion may preclude any sense of satisfaction in procedural compliance. The pilots on run twelve seem unsure of who should provide basic leadership.

In run thirteen leadership and compliance with SOPs take on two new dimensions. First, the captain informs the engineer that the two pilots have flown together before, and they know each other's style. At the same time he advises the FE to freely question any pilot activity that does not appear prudent. Second, the captain actually performs some of the checklist duties of a nonflying pilot. In particular, he reads the challenges for the Pre-taxi, Taxi, and Takeoff Checklists. For the Taxi Checklist the copilot even issues an initiation order to his nominal supervisor. Throughout the mission the two pilots work in fairly close cooperation. Although their compliance with crew coordination procedures is far from impeccable, they freely discuss operational issues and responsibilities. They formally transfer control of the aircraft. They seem to enjoy sharing leadership and support activities.

In contrast, the flight engineer seems like an outsider. He does not act like a full fledged member of the crew. He never explicitly takes responsibility for EGT monitoring. He does not offer any information about the status of the After Takeoff Checklist until after the copilot's second request. He initiates the Descent Checklist without any direction from the pilots, and finally he fails to respond to the first order to commence the Approach Checklist. None of the engineer's behavior blatantly degrades flight safety, but the observed deficiencies clearly suggest the need for improvement in total crew coordination. Ascribing the engineer's noncompliance to the presence of a flying copilot or to a particular pairing of pilots is problematical. Nevertheless, the absence of a single identifiable leader on any of the three crews just described is cause for concern about crew member perceptions and compliance with procedures whenever a copilot is at the helm.

Categories of Operation Error

The instances of procedural noncompliance given above are imputed to one or more individual operators. This is in contrast to the amorphous assignment of diverse errors to entire crews in the original NASA study (cf. Chapter II). In the qualitative stages of analysis Dr. Ruffell Smith and his colleagues pay scant attention to the identity of the flying pilot or to the perpetrator(s) of error. The data they collected permit somewhat greater specificity than they employed.

Most of the errors tabulated in the original report have been reverified and affiliated with the appropriate crew member(s). Appendix D contains a complete listing of errors by run number, original category, descriptive phrase, and applicable operator(s). Two of the reported errors could not be substantiated. A Flying error for run ten was not supported by any available documentation, and a

Navigation error listed for the first segment of run thirteen actually occurred on the second segment of that mission. In addition, three previously unrecorded Communication errors were detected and logged, one each on run numbers three, ten, and twelve.

This author's review of the experimental protocols, the audio data, the aircrew manuals, and Dr. Ruffell Smith's notes has led to the updated error summary in Table 20. The new categories of error refer directly to the responsible operator(s): pilot flying (PF), pilot not flying (PNF), captain, copilot, pilot team, flight engineer (FE), and entire crew. Other combinations of operators, such as PF/FE or captain/FE are possible; but no errors are recorded in any such category.

A synopsis of the errors attributable to different operators discloses that flying pilots, nonflying pilots, captains, and copilots have similar numbers of total errors (20, 21, 20, and 21 respectively). Naturally enough, PF errors tend to involve manual control activities such as improper use of the autopilot or the flight director and frequent, abrupt throttle movements during the approach to landing. The PNF errors encompass most of the communications and navigation miscues listed in the NASA report. Aircraft or ground station call sign problems and radio tuning difficulties comprise the majority of PNF mistakes. Seventeen of the twenty-one PNF errors relate to communication or navigation activity.

Are errors by the PF more serious than those of the PNF? context of the experimental scenario the answer would have

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TABLE 20

RUFFELL SMITH'S ERRORS[a] ATTRIBUTED TO OPERATORS

		Experimental Run Number									
Operator(s)	Code	3	4	5	6[b]	8	10	12[b]	13[b]	14	15
Pilot flying	PF	4	1	1	6	2	0	1	4	0	1
Captain	CAP	4	1	1	6	2	0	3	2	0	1
Pilot not flying	PNF	1	1	0	6	2	2	3	2	4	0
Copilot	COP	1	1	0	6	2	2	1	4	4	0
Pilot team	PTM	1	2	2	4	3	2	2	4	1	2
Flight engineer	FE	0	0	2	0	0	0	0	0	0	0
Entire crew	CRW	1	0	2	3	1	1	1	1	1	1

[a]Error categories and descriptions are individually related to operators in Appendix D.

[b]On runs 6, 12, and 13 the captain is the PNF and the copilot is the PF.

"yes." In actual flight operations the answer is a more equivocal "probably." In the simulator neither the PNF nor the "air traffic controller" is overly sensitive to nonstandard communication or navigation practices. No other aircraft will be in the simulator's "airspace," and no violations of the FARs will be forthcoming. In contrast, the PF must be genuinely concerned about aircraft performance. Although simulated mid-air collisions may not be plausible, unintended contacts with the "ground" certainly are.

At present it is impossible to say whether pilots are more or less prone to err in the simulator than they are in operational flight. Errors are known to occur in both environments. Dr. Ruffell Smith, for one, believes that his composite error rates are comparable to those observed aboard a European short-haul airline during routine operations. (53:19-20)

Thus far, only errors imputed to a single crew member have been discussed. Many significant errors involve more than one operator. Attention is first given to those implicating the pilots jointly.

Every crew has at least one pilot team error. Aircraft control, equipment operation, and Air Traffic Control procedures are violated. The verified deficiencies include early retraction of flaps on take-off, improper pairing of the Flight Director computers, exceeding speed/altitude tolerances, failing to use the Turbulence mode of the autopilot and selecting the wrong navaid. Some of these errors appear to be associated with distraction, inaccurate perception, ignorance, or lack of personal motivation; but causal factors are impossible to assign.

In some situations one pilot verbally acknowledges awareness of the other's act or intent (e.g., flap retraction and computer selection). In other cases silence prevails. A reticent pilot could be unaware of his partner's error; he could be giving tacit approval; he could be fearful of "making waves"; or he could be uncertain and therefore unwilling to expose his own lack of knowledge. At any rate, errors that are either ratified or undisputed are reinforced and are likely to recur in similar circumstances. The degree to which the observed nonflying airline pilots monitor and question the behavior of their comrades is certainly less than that envisoned in company policy.

The same can be said of crews as a whole. The errors attributed to an entire crew display the same shortage of awareness, knowledge, and/or initiative that is seen in pilot team errors. Of the ten experimental runs, only one has no verifiable crew errors (run number four). A total of four crews use the wrong flap configuration for landing, and a fifth uses the proper configuration but for the wrong reason. Two separate crews fail to turn on anti-icing systems prior to takeoff and then compound their problems with power reduction during departure. Another crew omits the anti-ice step of the turbulence penetration procedure. If captains cannot be counted on to supervise their subordinates' activities and if copilots and engineers are too preoccupied to assist their leader when he errs, then flying may have become too complicated.

Perhaps there are too many procedures for the average crew member to know and employ. The Normal Operating Procedures presented in

Chapter III are augmented by literally scores of unique instrument approach procedures, aircraft operating limitations, and airport restrictions as well as the aforementioned Alternate, Abnormal, Irregular, and Emergency procedures.

The selected crew coordination procedures constitute a small but important portion of a crew member's procedural inventory. How he behaves in relation to those few SOPs may be indicative of his propensity for involvement in other types of operating procedure error.

Mathematical Modeling

Trying to investigate potential relationships between discrete, enumerative error data and discrete, enumerative compliance data is a challenge under ideal conditions. In this research the scarcity of usable data has made conditions far from ideal. From the beginning, all types of error and noncompliance were necessarily assumed to be of equal criticality.

At first blush a supposition of this sort seems rash. It equates a higher than prescribed angle of attack to omission of the aircraft call sign during a radio transmission. These are vastly different errors; however, the criticality of each is truly situation dependent. A high angle of attack in smooth, clear air with airspeed well above a stall is hardly critical; but the same angle of attack at a low altitude and airspeed could be critical indeed. When air traffic and ATC radio communications are dense, even a missed call sign can be dangerous. In other words, there is no convenient scale for ranking operator errors independent of unknown state variables.

A parallel predicament applies to the evaluation of noncompliance with crew coordination procedures. In some situations, for example the pre-takeoff rush in the simulator flight, omission of a checklist command or announcement may seem justified; but identifying all the combinations of state variables which might vindicate noncompliance is outside the scope of this project. Consequently, diverse deviations in crew coordination (omissions, preemptions, tardiness, etc.) are treated equivalently.

Aggregating behavioral variables, whether they are error counts or compliance counts, eliminates a difficult scaling problem and a profusion of low frequency classifications. However, the relatively small size of the experimental data base also creates modeling problems. Discrete multivariate techniques are not suitable because cell frequencies would be too small for the statistical tests to have satisfactory power.

One mathematical model which can be used with a limited number of observations is the Poisson probability distribution. It has been employed in analyses of human behavior (65) as well as product reliability (27). The underlying assumption of the model is that errors occur randomly over time. If this assumption is true, then the number of errors observed conforms to a Poisson distribution. In standard notation the Poisson probability of experiencing m errors during a time interval of length t is given by

$$p(m,t) = [\exp(-\lambda t)]\cdot[\lambda t]^{m} / m!, \quad m=0,1,2,\ldots;$$
$$\lambda > 0, \ t > 0$$

In the simulated flight mission the time period is considered to be approximately the same for each experimental run ($t=1$) so the probability function simplifies to

$$p(m) = [\exp(-\lambda)]^{m}/m!, \quad m=0,1,2,\ldots; \; \lambda > 0$$

The only parameter which must be determined to permit testing of this model is λ, the mean of the distribution.

Estimation of the single parameter λ permits testing of the randomness assumption. In fact, randomness can be tested even when λ is different for each trial of an experiment as long as the parameter is treated as a function of one or more variables which can be measured in every trial. The calculations herein assume that the particular λ applicable to an individual operator, pilot team, or crew can be computed as a linear function of the procedural compliance counts developed earlier in this chapter. The specific linear functions to be used are determined by regression analysis.

The appropriateness of the Poisson distribution for error counts is examined by means of a test statistic Z, where $z = (m - \hat{m})/\sqrt{\hat{m}}$ with m the actual number of errors observed and $\hat{m}$ the number predicted by the regression equation. If the distribution of m is Poisson, then the distribution of Z will be approximately normal with mean zero and variance one. Departures from normality can be visualized by plotting Z on probability paper. This type of analysis is justifiable whenever λ is large enough that the corresponding Poisson distribution is not severely skewed. In this study the smallest mean error count ($\hat{\lambda}$) is 1.1, and the mean values of greatest interest lie between 2.0 and 10.9;

hence, the test just described is suitable. A complete list of the dependent variables of interest and their observed means is shown in Table 21.

TABLE 21

DEPENDENT VARIABLE CATEGORIES AND MEANS
(Error Counts)

*Category	Code	Mean ($\hat{\lambda}$)
PF alone	PF	2.0
Captain alone	CAP	2.0
PNF alone	PNF	2.1
Copilot alone	COP	2.1
Pilot team	PTM	2.3
PF + team	PTM	4.3
CAP + PTM	TCAP	4.3
PNF + PTM	TPNF	4.4
COP + PTM	TCOP	4.4
Entire crew	CRW	1.1
PF + PTM + CRW	CPF	5.4
CAP + PTM + CRW	CCAP	5.4
PNF + PTM + CRW	CPNF	5.5
COP + PTM + CRW	CCOP	5.5
PF + PNF + 2(PTM) + 2(CRW)	PLTS	10.9

*Note: Although certain error categories are mutually exclusive, e.g., PF alone and PNF alone, others are not, e.g., PF alone and Captain alone. Mutually exclusive categories are treated as independent random variables and combined linearly to form other meaningful categories.

a. Regression

A basic linear statistical model of the following form is used to estimate the Poisson parameter.

$$Y_i = \beta_o + \sum_{j=1}^{n} \beta_j X_{ij} + \varepsilon_i$$

where Y_i is the value of a particular variable (categorical error count) on run i

β_o is the intercept parameter

β_j, j=1,2...,n are the regression coefficients (parameters)

X_{ij}, j=1,2,...,n are values of the j predictor variables on run i

ε_i is a normally distributed random term with mean zero and variance σ^2

i = 1,2,...,10.

When only one predictor variable is used, the model can be written as $Y_i = \beta_o + \beta_1 X_1 + \varepsilon_i$. It is then called a simple regression model, and the usual measure of association between the independent variable X and the dependent variable Y is the coefficient of simple determination, r^2 where $r^2 = [\Sigma(\hat{Y}_i - \bar{Y})^2]/\Sigma(Y_i - \bar{Y})^2$, $\hat{Y}_i$ is the value of the dependent variable predicated by the model, and $\bar{Y}$ is the mean of the observed values.

When more than one X_j appears in the equation, a multiple regression model is represented, and R^2, the coefficient of multiple determination is computed identically to r^2. It measures the proportionate reduction of the total variation in Y associated with use of the set of variables X_1, X_2, ..., X_n. Both the simple and multiple coefficients of determination must lie in the interval [0,1]. The larger the value, the more the total variation in the dependent variable is reduced by introduction of the independent variable(s). When regression models are used for descriptive purposes, as they are here, there is no implication of causality between the independent and dependent variables. A coefficient of determination close to unity indicates a relatively high degree of association between a specific set of Xs and a particular Y, but the Xs do not produce the Y. Elucidation on the theory and application of numerous statistical models is contained in an excellent treatise by Neter and Wasserman (46).

b. Independent Variables

The verbal behaviors previously illustrated in Tables 13 through 19 have been quantified by straightforward enumeration. This simplistic approach has two salient limitations, but it does yield a set of independent, predictor variables some of whose elements look remarkably like the error counts above.

The first limitation has to do with the range of each variable, that is the difference between the maximum and minimum values each could possibly assume. For example, the verbal interchange required to accomplish the Transfer of EGT Monitor responsibility has to occur only once during each mission segment. It is supposed to be initiated by the flight engineer and concluded by the captain. Thus, the behavioral variable is binary for both operators. Since no other SOP prescribes a comparable interchange between the same two crew members this single data point predictor has limited utility in characterizing routine behavior.

The second limitation on activity counts is variability. The variance of a random variable is restricted by its range. If counts of procedural activity show little variability (even when the possible range is large), then prediction of wider performance gradations may be impossible.

Among crew coordination SOPs, the configuration change interactions between pilots and the checklist completion statements required of engineers produce behavioral variables with too little variation to suggest distinctions among the subjects. Eight of ten flying pilots do not miss a single configuration change request; the others miss one and two respectively. The engineers are similarly uniform with respect to checklist completions. Two FEs omit one statement each; all the rest comply perfectly.

Despite the limitations, or insensitivity, of many crew coordination variables, there are several aspects of pilot behavior which have potential as predictor variables. These indicators possess moderate range and variability. They are listed along with two variables displaying crew member experience in Table 22.

The first three behavioral variables in the table deal with the initiation of normal challenge and response checklists. Eight command opportunities are available for the flying pilot in each data run (PFCK); the number of occasions of procedurally compliant behavior is

TABLE 22

INDEPENDENT VARIABLES

		Experimental Run Number									
Variable name	Code	3	4	5	6	8	10	12	13	14	15
PF checklist commands	PFCK	5	5	8	1	3	7	3	3	5	8
Pilot checklist announcements	PA	2	2	1	5	0	1	0	0	2	2
FE checklist announcements	FEA	3	3	3	2	0	2	1	0	1	0
PNF callouts	PNFC	11	13	13	9	15	16	15	13	15	14
Aircraft control transfers	TRAN	3	2	4	0	3	6	0	2	4	4
Crew members with more than 1000 hours in B-747	CREX	3	2	2	1	2	3	1	1	2	2
Pilots with more than 1000 hours in B-747	PEX	2	1	1	1	2	2	0	0	1	1

recorded. Correspondingly, there are five checklist announcement opportunities of pilots (PA) and three for flight engineers (FEA). Again, *instances of procedural compliance* are counted.

Another type of pilot behavior which displays variability among the nonflying pilots concerns the existence and timeliness of mandatory callouts. This particular indicator (PNFC) represents the number of prescribed callouts completed by the appropriate pilot (the PNF) at the proper time. It makes no allowance for "late" altitude callouts (accomplished after the automatic mechanical alert at 900 feet from target altitude) or for callouts accomplished by the flying pilot. Seventeen on-time callouts are possible; however, sixteen is the largest observed value.

An aspect of procedural compliance which has no mandated or maximum value concerns Transfer of Aircraft Control between the pilots. Implementation of this optional procedure is not restricted to any particular phase of a mission or set of environmental circumstances. Compliance depends solely on the level of initiative, cooperation, trust, and communication residing in the pilots.

Each complete "double transfer" of control is counted as two occasions of compliance with the transfer procedure (TRAN). Each partial or incomplete "double transfer" counts as one instance of compliance. Across the ten pilot teams the average number of transfers is 2.8 and the sample standard deviation is 1.87. Significantly, though, two crews have no transfer whatsoever while the crew on run ten actually completes six transfers.

Two additional independent variables which are not direct measures of internal coordination but are believed to capture a material feature of crew composition have to do with flying experience in the B-747 aircraft. Since crew members must accept assignment to different airframes as part of career progression, experience within a crew can vary widely. Accumulation of 1000 flying hours in a given aircraft is an arbitrary reference point for experience-in-type. The total number of crew members (CREX) and the total pilots (PEX) with more than 1000 hours each in the B-747 are the chosen variables. For an average pilot who flies 600 to 700 hours per year this equates to approximately one and one-half years of line flying experience. No crew member participating in the experiment has fewer than 5000 total flying hours, but many have less than 1000 hours in the 747.

The NTSB, the FAA, and individual airlines have at various times noted checklist behavior, callout performance, transfer of aircraft control, and experience-in-type as factors which are associated with airline mishaps. The statistical relationships between those factors as quantified here and other manifestations of human performance are highlighted below.

c. Correlations

A frequent objective of descriptive regression analysis is to account for a sizable percentage of the variability in a dependent variable using as few independent variables as possible. In this study corroboration of operator error using a maximum of two predicators is desired.

Coefficients of determination have been computed for each of the fifteen categories of operator error using each of the seven independent variables alone, in pairs, and in triples. The maximum values and corresponding variables are shown in Table 23. All calculations were accomplished with the aid of the RSQUARE routine in the Statistical Analysis System (SAS) computer package (3:216).

For eight of the dependent variables (PNF, COP, TCAP, TPNF, TCOP, CPNF, CCOP, and PLTS) the flying pilot's compliance with procedure in issuing checklist commands (PFCK) is the single best predictor. All of the other error counts, except pilot team (PTM), are best predicted by the nonflying pilot's callout compliance (PNFC). Only PTM errors and entire crew errors (CRW) have coefficients of determination less than 0.5. Interestingly, the PFCK indicator is usually the best predictor of copilot or nonflying pilot error counts while the PNFC indicator is better for captain and flying pilot errors.

When two predictor variables are used, PFCK belongs to the maximum R^2 pair for all dependent variables except PTM and TPF. PNFC occurs in eight of the best pairs. The PFCK and PNFC combination has the largest value of R^2 for seven of the error counts, and for five others its R^2 value differs from the maximum by less than 0.08. In most cases the addition of a third independent variable adds relatively little to the largest pairwise coefficient of determination while eliminating another degree of freedom from the mean square error calculation in the regression model. Consequently, the PFCK-PNFC combination receives primary attention.

TABLE 23

MAXIMUM COEFFICIENTS OF DETERMINATION

Dependent variable	Independent variables					
	One		Two		Three	
	Code	r^2	Codes	R^2	Codes	R^2
PF	PNFC	.749	PFCK, PNFC	.869	PFCK, FEA, PNFC	.912
CAP	PNFC	.651	PFCK, PNFC	.824	PNFC, TRAN, PEX	.878
PNF	PFCK	.579	PFCK, PA	.709	PFCK, PA, PNFC	.864
COP	PFCK	.513	PFCK, TRAN	.642	PFCK, PA, TRAN	.798
PTM	CREX	.446	CREX, PEX	.626	TRAN, CREX, PEX	.665
TPF	PNFC	.571	FEA, PNFC	.785	PFCK, FEA, TRAN	.848
TCAP	PFCK	.595	PFCK, PNFC	.825	PFCK, FEA, PNFC	.856
TPNF	PFCK	.692	PFCK, PA	.763	PFCK, PA, PNFC	.808
TCOP	PFCK	.567	PFCK, TRAN	.637	PFCK, TRAN, CREX	.789
CRW	PNFC	.317	PFCK, PNFC	.363	FEA, CREX, PEX	.550
CPF	PNFC	.595	PFCK, PNFC	.769	PNFC, CREX, PEX	.820
CCAP	PNFC	.569	PGCK, PMFC	.794	PNFC, CREX, PEX	.852
CPNF	PFCK	.606	PFCK, PA	.710	PFCK, PA, CREX	.743
CCOP	PFCK	.532	PFCK, PA	.624	PFCK, TRAN, CREX	.705
PLTS	PFCK	.597	PFCK, PNFC	.741	PNFC, CREX, PEX	.796

With respect to the dependent variables which reflect errors by the flying pilot (PF, TPF, CPF), by the captain (CAP, TCAP, CCAP), and by the two pilots collectively and individually (PLTS), the regression models for PFCK and PNFC together are all highly significant ($p < .01$). The coefficient of multiple determination is never less than 0.741. Moreover, the STEPWISE regression routine (3:251-6) keeps both independent variables in its model for each dependent variable. When the same two predictors are regressed with the other error counts, none of the models is highly significant. In fact, STEPWISE never allows more than one of the two predictors in its final model. In no case does the coefficient of multiple determination reach 0.7.

Clearly, the best two-variable corroboration of Ruffell Smith's crew assessment occurs between the captain/flying pilot error counts and the conformance to selected crew coordination imperatives by the two pilots. Although compliance with one type of procedure has no mechanical connection to compliance with another type, a methodology for more detailed description of operator behavior has been demonstrated. Since human evaluation of human performance is always subject to innumerable fallacies and biases, it can only be hoped that the simple metrics presented here reflect more complex and more ambiguous attributes which cannot be readily measured.

d. Error Distributions

The final issue of concern in this assessment of aircrew performance is the appropriateness of the Poisson assumption for error counts. In two of the error categories for which PFCK and PNFC yield highly significant regression models, namely PF and CAP, the predicted number of errors for run ten happens to be negative. Since an error count less than zero is an impossibility, the previously described test cannot be applied to those categories of error.

No comparable problem is encountered with TPF, TCAP, CPF, CCAP, or PLTS, error counts with sizable mean values. Their test plots are shown in Appendix F. The graphical analysis reveals that each error category other than PLTS shows considerable deviation from the ideal standard normal line, especially in the tails of the distribution. This could indicate that the errors are not random or that the crew members belong to more than one identifiable population. On the other hand, the Poisson assumption cannot be dismissed for PLTS. Its sample data points conform to the standard normal line remarkably well. Since PLTS is a linear combination of four variables with unknown distributions, there is no obvious reason why it should be Poisson distributed. Although the plots (Appendix F) are not conclusive evidence as to the distribution of any of the error counts, they suggest that some other distributions may be more suitable for modeling the frequency of error in operator specific categories.

In summary, PFCK, a crew coordination indicator representing the flying pilots' initiative, meticulousness, and ability to communicate in a leadership position, is well correlated with twelve of the fifteen error categories studied. Also, the PFCK-PNFC duo achieves excellent results in predicting captain, flying pilot, and total pilot error counts. Despite the relatively small number of sample data points, the correlations established here warrant a review of existing procedural imperatives, the frequency of their applicability in line operations and the level of compliance among a cross section of major air carriers.

CHAPTER V

COCKPIT MANAGEMENT AND AIRCREW PROCEDURES

The behaviors recorded by Ruffell Smith emphasize manual control and external communication. The crew coordination behaviors reported in Chapter IV emphasize verbal interaction among the cockpit crew members themselves. Both views tempt an observer to fixate on isolated events. A more holistic perspectiveon human performance is desirable and beneficial.

In this chapter three general precepts of good management are defined, and their applicability to airline captains is discussed. Subjective evaluations of managerial style in the simulator are then compared to the principal objective measures of performance used earlier. Relationships between qualitative and quantitative assessments suggest the strengths as well as the weaknesses of a procedural compliance perspective on cockpit management.

Management Precepts

The study of management philosophy and managerial performance goes on continuously in many organizations. The United States Air Force is an excellent example. For many years the Air Force has published an official document, Air Force Manual/Regulation 25-1, which explains universal principles and processes of management. Its influence on this author's thinking and research is undeniable. In fact, it contains one particular statement which concisely describes the value of procedures for all levels of management; to wit,"procedures . . . are the heart of an operational system; they give direction to its effort, coordinate it in place and time, and determine whether it will perform in line with predetermined objectives." (62:14) This assertion presupposes compliance with established procedures, but realities of human behavior are not overlooked. Dealing with noncompliance and with its perpetrators is treated as another phase of managerial responsibility.

The management guide also proffers sixteen fundamental precepts which have been "proved by broad experience to contribute to good management." (62:44) To some degree each one can be applied to cockpit management, but many of them are most appropriate in relatively large, stable organizational settings. Because of the limited size and the transitory nature of a cockpit organization, this author considers three of the precepts to be more pertinent than the rest. These are continuity, cooperation, and discipline.

Continuity is defined as the ability to "plan and organize, insofar as possible, for the full period of contemplated operations." (62:45) Among pilots, continuity is frequently referred to as the capability to "stay ahead of the aircraft." Command of a sophisticated jet aircraft demands continuity, but some captains display the faculty to a much greater degree than do others.

Concerning the precept of cooperation, the Air Force says, "to cooperate is to render active aid," and to recognize that "the organization's coordinated effort is greater than the sum of the individual uncoordinated efforts of its components." (62:45) In an airline cockpit tasks are often multi-step and time-sensitive. Many tasks overlap each other in space and time. Operational safety demands cooperation. Captains must be willing to aid their subordinates and to accept aid from them when it is needed. In the experimental scenario considerable variation in crew cooperation was observed.

Similarly, the discipline displayed by different captains varied greatly. The precept directs managers to "establish and enforce directives and procedures that are essential to orderly accomplishment of the objective." (62:45) Thus, dicipline recognizes the imperfections in all mortals and stresses the manager's responsibility to assure procedural conformance. Since SOPs are prescribed for virtually every flight task (objective), discipline is an essential aspect of effective cockpit management.

Subjective Assessments

This writer applied the foregoing definitions to each captain's documented management efforts in the simulation. Individuals were judged as personifying each precept to a high, moderate, or low degree. The evaluations attempted to compare the captains to a model pilot-in-command rather than to their peers in the experiment. The author's judgment was based upon detailed knowledge of the experimental scenario coupled with personal flight experience in similar circumstances.

The orientation was global; one exceptional example of performance, good or bad, did not qualify a subject for an extreme rating. The judgments reflected in Table 24 have been introduced at this point to provide

TABLE 24

QUALITATIVE ASSESSMENT OF CAPTAINS' MANAGEMENT STYLES

Experimental Run Number	Management Precepts		
	Continuity	Cooperation	Discipline
3	M	L	M
4	H	M	H
5	M	H	M
6	L	L	L
8	M	H	M
10	M	M	M
12	L	L	L
13	L	H	L
14	H	H	H
15	H	H	M

H = High
M = Moderate
L = Low

a retrospective estimation of each captain's managerial profile. The purpose is to obtain a comprehensive subjective evaluation which could be collated with more objective measures of performance. Differences among the qualitative and quantitative measures delineate the likelihood that volunteers for the experiment should not be thought to belong to a single aircrew population.

If cooperation was present at all, it was often abundant. Half of the captains were regarded as highly cooperative. Typically, they shared external communication tasks with their copilots, helped accomplish preflight radio checks, and/or discussed their intentions with subordinates. However, among three of the commanders, cooperation was definitely insufficient. In each case the copilot could have used assistance which was not forthcoming. Two flying copilots had to complete nonflying tasks because their captains did not assume those duties. A third copilot was repeatedly interrupted during task executions by an impatient, ego-centric captain.

Neither continuity nor discipline received as many high marks. Distribution of continuity grades was more nearly uniform, but this evaluator was struck by several examples of poor planning; namely rushed checklists, missed passenger announcements, and incomplete analysis of the route or the instrument approach.

Of all the managerial qualities, discipline needed the most improvement. If subordinates' shortcomings were recognized at all, they rarely drew a comment. A laissez faire form of management seemed in vogue on at least half of the flights. Nevertheless, safety was seriously compromised only when subordinates were not as competent as the captain had apparently imagined them to be.

Eight of the nine "low" scores were awarded to three captains. Every one of the three was the nonflying pilot for the segment in question, and each one had 600 or fewer hours as a pilot-in-comand of the B-747 aircraft. Two of the three did not work well with either subordinate. The third was very congenial with his crew, but none of the three actively enforced procedures.

The subjective evaluations presented have been pictorially compared to behavioral indicators, experience indicators, and error counts defined in Chapter IV. The individual graphs are shown in Appendix G. The most significant findings for each precept are summarized in the following paragraphs.

Continuity scores appear inversely related to error counts for the captains but unrelated to copilot errors. This corresponds with the intuitive notion that captains who "get behind the aircraft" commit more errors. All of the high and low continuity scores are associated with pilot teams that have relatively low experience-in-type (PEX). These extremes may indicate that as experience-in-type accumulates, the better planners feel less need for anticipation of events while the poorer planners learn from their mistakes and improve.

Cooperation shows no obvious relationship to error counts, experience, or compliance with crew coordination procedures. Although the three commanders with low cooperation scores have the three highest solo error counts (CAP), the counts of copilot (COP), pilot team (PTM), and crew (CRW) error do not confirm any affiliation to cooperativeness. Additionally, adherence to checklist initiation (PFCK), callout (PNFC), and control transfer (TRAN) procedures has no apparent connection to cooperation. Establishing a spirit of fraternity in the cockpit may be an invitation to excessive trust as well as a summons for mutual support.

A linear relation with negative slope exists between discipline and captains' errors, but no similar relation is apparent for discipline and copilot errors. The extremes of the discipline scale belong to captains with low experience-in-type. As time in the aircraft builds, discipline as well as continuity may tend toward a middle ground.

In general, these managerial evaluations substantiate the lower levels of procedural compliance better than they do the middle or upper levels. Pilot performance on simulator runs six, twelve, and thirteen appears unsatisfactory in several respects. All other pilot teams behave suboptimally at specific points in time according to at least one of the available metrics; but the others' deficiencies are not as diverse or as pervasive as those of the three teams whose copilot is flying the experimental segment.

One of the benefits of qualitative assessments of cockpit management is that they illuminate the advantages and disadvantages of quantitative measures. The quantitative approach to procedural compliance meets the issue of frequency head on. A human operator can be given feedback on exactly how many times he executes specific tasks in accordance with SOPs. A large numerical data base would permit computation of behavioral norms and would allow statistical inferences about the individual and population performances of many crew members. However, enumerative data and statistics do not convey information about the circumstances surrounding an instance of procedural noncompliance or about the criticality of recorded activity. Both of these considerations are certainly relevant to system safety. The disparate relationships among the various quantitative and qualitative measures confirm the need to study cockpit performance along multiple dimensions. No single set of indicators or single assessment methodology should be considered sufficient for evaluating cockpit management and crew behavior.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

This final chapter summarizes the entire research effort. Conclusions emanating from the accomplishment of stated objectives are presented first. Then comments based on the examination of crew coordination procedures are offered. Finally, recommendations concerning the methodology and the emphasis of future procedural research are given.

Accomplishment of Objectives

In a setting as structurally complex as a commercial airliner, analyzing human performance is an imprecise and introspective process. Identification of meaningful performance variables is necessarily dependent upon the evaluator's experience and intuition. His understanding of system components, tasks, and procedures determines the importance placed on particular aspects of human behavior. Dr. Ruffell Smith converged on the crews' interactions with control mechanisms and on aircraft parameters in relation to the operating environment. This author has focused on the crew members' interactions with each other in terms of their affinity to published procedures and management precepts.

The objective of defining a countably finite set of Normal Operating Procedures was satisfied in Chapter III. The SOPs listed there represent highly distilled information from manifold sources. No single document puts together all of the aircraft subsystems, airline operations, traffic control, navigation, airport, communication, and assorted miscellaneous procedures which are applicable to the enormous range of "normal" operating conditions. When "alternate," "abnormal," "irregular," and "emergency" procedures are added to the list, the stack of crew directives becomes truly imposing. Crew members face an impossible challenge in attempting to mentally catalogue all of the SOPs published for them.

The diversified classifications or taxonomies of the Normal Operating Procedures further illustrated the potential for perplexity in temporally organizing SOPs. Crew directives seem to favor the mission phase taxa suggested earlier, but not all publications employ them, and none uses them exclusively. Too many procedures belong to more than one meaningful taxon. Aircraft, company, and FAA procedures are often presented sequentially as they might be applied in flight. However, the level of abstraction is inconsistent; formats are diverse; operator involvement is not always well defined; and integration of the total procedural load clearly depends on the intellectual capacity and operational experience of individual operators. Based on experimental observations the extrinsic value of any particular routine procedure depended more on crew composition and the personal experience of the users than on any outsider's measure of its worth.

The objective of quantifying compliance with an observable sample of the Normal Operating Procedures was realized through definition of the Crew Coordination category. That classification was based on explicit procedural imperatives. The set contained SOPs which mandate a verbal transfer of information from one crew member to another. Behavioral equivalence classes (checklists, callouts, configuration changes, and transfers) were identified within the general category. Multiple opportunities for compliant behavior in each class permitted counting of conformable activities. The individual operators and crews in the experiment varied greatly in their adherence to Crew Coordination Procedures. Since their compliance with other SOPs (e.g., flight control, navigation, and systems operation) varied as well, it became apparent that in any given situation standardized procedures are no guarantee of uniform behavior. Routine noncompliance with an assortment of SOPs has now been documented by two independent researchers.

The subjective assessments of each captain's practice of the management precepts of continuity, cooperation, and discipline were an especially troublesome aspect of this research. Since the evaluations were made with prior knowledge of operator error counts and crew coordination figures, a potential bias cannot be discounted. However, each pilot-in-command was viewed in his preeminent role as a resource manager. The resources were personnel, material, time, and information. The subjective measures reflected this author's confidence in and agreement with each captain's management of his resources. Similar judgments by subordinates, peers, and other analysts would have significantly increased the reliability of the subjective managerial assessment. However, the logistics involved in obtaining such judgments, including the nonavailability of qualified crew members and the extensive time required, precluded their incorporation in this investigation.

Another goal of this research was to attribute the "crew" errors identified in Dr. Ruffell Smith's original study to specific operators. Analysis has revealed that many errors were in fact committed by two or more crew members. Of the 77 errors listed in Appendix D, 23 can be ascribed to the pilots jointly (PTM) and 12 others are attributed to all three crew members (CRW). The rest are distributed as follows: Captains (CAP) 20, copilots (COP) 20, and flight engineers (FE) 2. This means that for 45% of the enumerated errors two or more operators were deficient simultaneously. The message of this statistic is that human redundancy by itself does not eradicate personnel error. Operators must be motivated to both give and receive admonitions concerning every facet of cockpit activity. Based on experimental observations, few crew members appear to be so motivated.

The comparisons of objective measures of procedural compliance and operator error with the aforementioned subjective assessments of managerial skill disclosed that correspondence was greatest among individuals and crews with the least desirable evaluations. In particular, the crew with the most pilot errors (PLTS = 26 for run number six) also had the worst composite record of compliance with crew coordination procedures, and the captain was rated low on every management precept. That one crew's performance was so extreme that it might be considered an experimental anomaly. However, the very occurrence of such unacceptable behavior by a fully certified crew raises doubts about the professionalism and the homogeneity of the entire aircrew population. In addition, the diverse assessments of deficiency on experimental runs twelve and thirteen strongly reinforced the notion that procedural compliance and the captain's management effectiveness both suffer when the copilot is flying a mission segment. Because of the importance of this finding and the smallness of the relevant data sample, further investigation regarding this phenomenon is essential.

Previously unrealized possibilities for studying aircrew behavior in a controlled, high fidelity, operational setting were unveiled in Dr. Ruffell Smith's pioneering attempt at full mission simulation. The methodology permits simultaneous observation of numerous details of human performance across a broad range of reproducible conditions, but it is not without drawbacks. Full mission simulation is expensive and time consuming to perform. It requires extensive preparation and can yield overwhelming amounts of data. Since individual air carriers own most of the sophisticated simulators, accessibility is often limited by high utilization rates for crew training and certification. Nevertheless, simulator data represents the best approximation to operational data attainable today.

Routine flight operations have never been open to impartial research. The FAA, the airlines, and the pilots' union have been reluctant to permit public inspection of their domain. Except for full mission simulation data, carefully edited and highly distilled accident reports from the NTSB provide the only available documentation of cockpit behavior which addresses all the complexities of the operating environment.

Future attempts at full mission simulation should utilize lessons contained in the airline experiment and in a more recent general aviation experiment at this university. To begin with, video data should be incorporated to disclose control movements, false starts, attention patterns, visual signals, and physical excitability. To the extent practical, routes, airports, and mission sequences familiar to the participating crews should be used to establish base line data. Professional Air Traffic Controllers should be involved in the development of simulation support materials like background audio tapes and, if possible, in scenario execution, performing their usual functions. Finally, the experimental population should represent a cross section of the total crew force. Participations should not be restricted to volunteers. Crew members should be scheduled for full mission simulations in the same way that they are scheduled for routine flights (seniority bidding). Recreation of operational detail is its strongest selling point with crew members.

Crew Coordination Procedures

The verbal crew coordination imperatives identified in this research are a small fraction of any crew member's procedural inventory. However, they can be just as crucial to flight safety as any other category of SOPs. Failure to comply with routine callout procedures directly contributed to the BAC 1-11 accident cited in Chapter II (34). Failure to properly transfer control has been associated with an infamous crash in the Everglades (37).

The experimental data demonstrated that noncompliance with internal coordination requirements was not restricted to any single SOP, crew position, level of experience, or phase of operations. Every crew violated procedures, but no deviations were common to all crews. Nonconforming behavior appeared to be uniquely operator and/or crew dependent. The behavioral enumerations given in Chapter IV illustrate a breadth and depth of noncompliance which must be assumed to occur throughout daily airline operations.

Among the verbal coordination procedures studied, the altitude callouts prior to level off produced a frequency of noncompliant behavior which suggested a potential need for modification. Since the mechanical altitude alerting system provided visual as well as audible indications of proximity to a pre-selected altitude, the prescribed verbal callout seemed unnecessary. From a human factors standpoint the SOP mandates operator activity comparable to that already being performed by a machine. Since machines accomplish such tasks more reliably than humans, the latter should either have their procedural load reduced or be given a different task which does not mimic a machine function.

The most disturbing aspect of the experimental data concerned the lack of unitary leadership and internal coordination observed when the captain was not flying the aircraft. Normal operating procedures of the participating airline appear to have been designed specifically for flying captains. The directives do not define the roles of a flying copilot and nonflying captain in sufficient detail. A standardized procedure for redistribution of tasks and authority is not provided.

A captain can theoretically delegate all of his authority to the copilot, but the final responsibility for safe and proper accomplishment of a flight mission can never be delegated. It always belongs to the pilot-in-command. Since most captains regularly alternate flying segments with their copilots, a simple addition to existing procedures seems in order. The pilot-in-command should be required to inform the entire crew concerning the degree of functional authority he is giving to the copilot. He should also state the degree to which he himself will perform the support task of the nonflying pilot. These items could be prescribed as part of the initial briefing to cabin and cockpit crew members.

Although this research has produced only two recommended changes to existing SOPs (for altitude callouts and flying copilot responsibilities), it has highlighted several facets of the relationship between operational safety and aircrew procedures. Most importantly, simulator data and NTSB accident reports have shown that SOPs are not a panacea for mechanical, environmental, or personnel problems. Even if procedures are available for every anticipated situation, they must be learned, practiced, recalled, and applied by fallible human operators. When those operators create internal models, SOPs are a portion of the input; but an unknown amount of self-procedurization goes on continuously.

Future Research

Future investigations of procedural compliance and the role of SOPs in aviation safety could proceed using several different methodologies. In this researcher's opinion full mission simulation is the most promising; however, it also consumes the most resources. For that reason alone other methodologies must be entertained.

Data from NASA's confidential Aviation Safety Reporting System could be surveyed to establish the kinds of procedural noncompliance which cause some crew members to acknowledge a dangerous experience. Aircrew interviews could elicit recollections of critical incidents resulting from nonadherence to SOPs. Formal surveys of crew members could be used to establish frequency and criticality indices for specific types or circumstances of noncompliance. Lower fidelity simulations can include procedural knowledge testing in paper and pencil senarios at a desk, interactive computer scenarios at a video terminal, task specific activity in an aircraft simulator, or any other imitation of flight conditions. The relative merits of these diverse methodologies have not been substantiated in comparative research, but for this author the emotional realism of full mission simulation makes its appeal overwhelming.

Since the current number of data points on procedural compliance is small, large scale experiments involving participation by distinctive groups of operators should be attempted. For example, the crews of different air carriers should be exposed to a common experimental scenario. Differences in the applicable procedures or levels of compliance could lead to significant insights regarding the effectiveness of SOP formats and content as well as operator training and motivation.

Ideally, one or two full mission simulation scenarios, complete with data gathering guidelines, should be included in the recurrent training program of every airline. The next generation of aircraft simulators should accommodate audio, video, and flight parameter data collection at any time. Crew members, instructors, flight examiners, and analysts from numerous disciplines could then review aircrew performance along several dimensions.

The safety record compiled by the commercial aviation industry in this country is truly commendable, but there is reason to believe it can be improved. The National Transportation Safety Board has consistently pointed to deviations from explicit operating procedures as causal and contributory factors in airline accidents. Until airline cockpits are opened to operational research, full mission simulation represents the most sensitive medium for evoking and detecting the behavioral nuances which can turn ordinary noncompliance into an extraordinary aviation tragedy.

APPENDIX A

ABBREVIATIONS AND ACRONYMS

AAR	Aircraft Accident Report
ADF	Automatic direction finder (a navigation radio)
ADH	Above decision height
AFE	Above field elevation
AGL	Above ground level
ALPA	Air Line Pilots Association
Alt.	Altitude
AOM	Aircraft Operating Manual
ALT HOLD	the Altitude Holding mode of the autopilot
A/P	Autopilot
App.	Approach
ARTCC	Air Route Traffic Control Center
A/S	airspeed
ATA	Air Transport Association
ATC	Air Traffic Control
ATIS	Automatic Terminal Information Service
Att	attack, as in aircraft angle of attack
BAC	British Aircraft Corporation
CAP	count of errors committed by the captain alone
CCAP	sum of errors committed by the captain alone, by the pilot team, and by the entire crew

CCOP	sum of errors committed by the copilot alone, by the pilot team, and by the entire crew
CMD	The Command mode of the autopilot
COM	Company Operations Manual
comm.	communications
COP	count of errors committed by the copilot alone
CPF	sum of errors committed by the flying pilot alone, by the pilot team, and by the entire crew
CPNF	sum of errors committed by the nonflying pilot alone, by the pilot team and by the entire crew
CREX	crew experience variable (discrete)
CRW	count of errors committed jointly by the entire crew
CVR	Cockpit Voice Recorder
dec.	decision
ECG	electrocardiograph
EGT	exhaust gas temperature
EPR	engine pressure ratio
FAA	Federal Aviation Administration
FAF	final approach fix
FAR	Federal Aviation Regulation
F/D	flight director
FDR	Flight Data Recorder
FE	flight engineer
FEA	count of flight engineer checklist announcements
FF	fuel flow
flaps( )	wing flaps (angle of extension)
FM	frequency modulation

GPWS	Ground Proximity Warning System
IAS	indicated air speed
ILS	Instrument Landing System
INS	Inertial Naviation System
JFK	John F. Kennedy International Airport (New York, New York)
( )K	( ) knots [airspeed]
MAN	the Manual mode of the autopilot
MDA	minimum descent altitude
MSL	mean sea level
NASA	National Aeronautics and Space Administration
nav	navigation
NOTAM	notice to airmen
NTSB	National Transportation Safety Board
N1	first stage compressor of a turbofan engine
OM	outer marker
PA	count of pilot checklist announcements
PATCO	Professional Air Traffic Controllers Organization
PEX	pilot team experience variable (discrete)
PF	pilot flying; count of errors committed by the flying pilot alone
PFCK	count of checklist commands by the flying pilot
PLTS	sum of errors by the two pilots (PF + PNF + 2(PTM) + 2(CRW))
PNF	pilot not flying
PNFC	count of callouts by the pilot not flying
PTM	count of errors committed by the two pilots jointly
P1	captain
P2	copilot

SOP	standard operating procedure
STAR	Standard Terminal Arrival Route
TAS	true air speed
TCAP	sum of errors committed by the captain alone and by the pilot team
TCOP	sum of errors committed by the copilot alone and by the pilot team
T/O	takeoff
TPF	sum of errors committed by the flying pilot alone and by the pilot team
TPNF	sum of errors committed by the nonflying pilot alone and by the pilot team
TRAN	count of aircraft control transfers
TURB	the Turbulence mode of the autopilot
VOR	very high frequency omnirange (a navigation radio)

APPENDIX B

ANALYSIS DIAGRAM

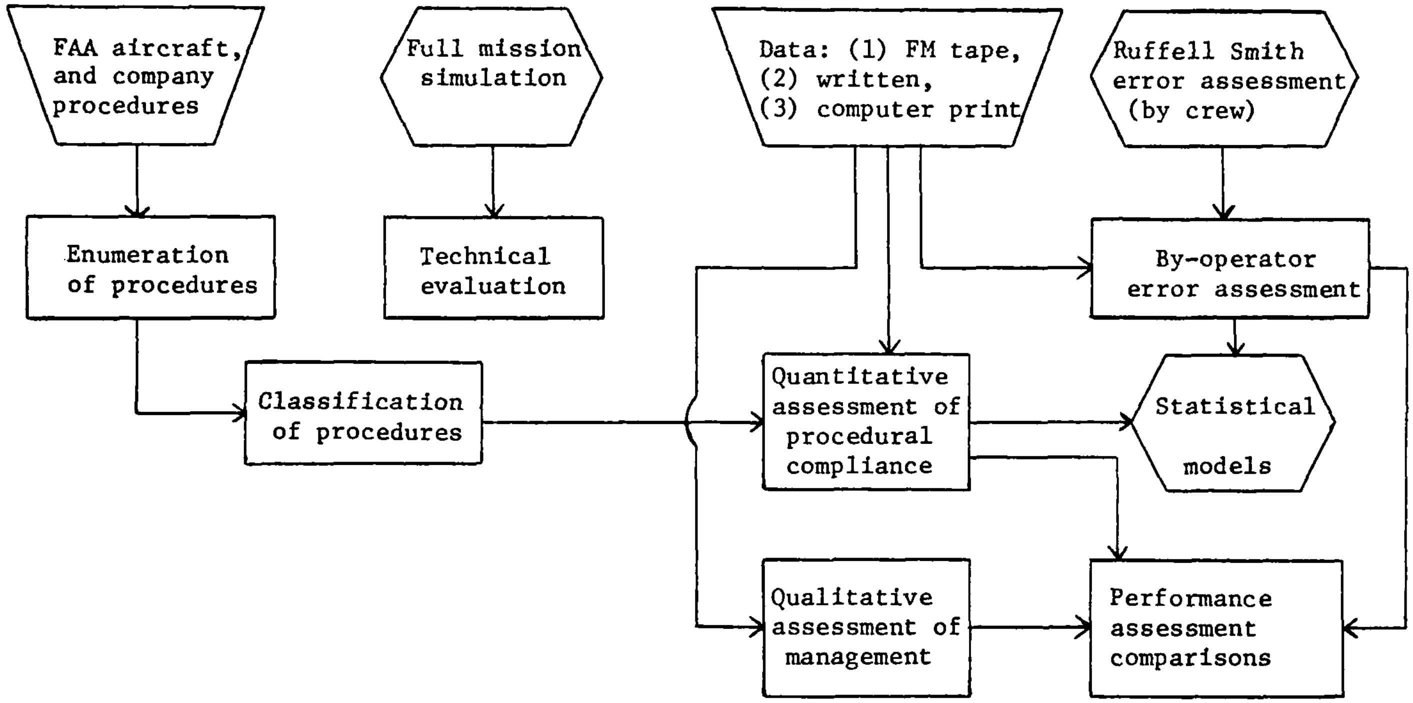

Figure 1. Analysis Diagram

APPENDIX C

EXAMPLES OF PICTORIAL AND GRAPHICAL PROCEDURES

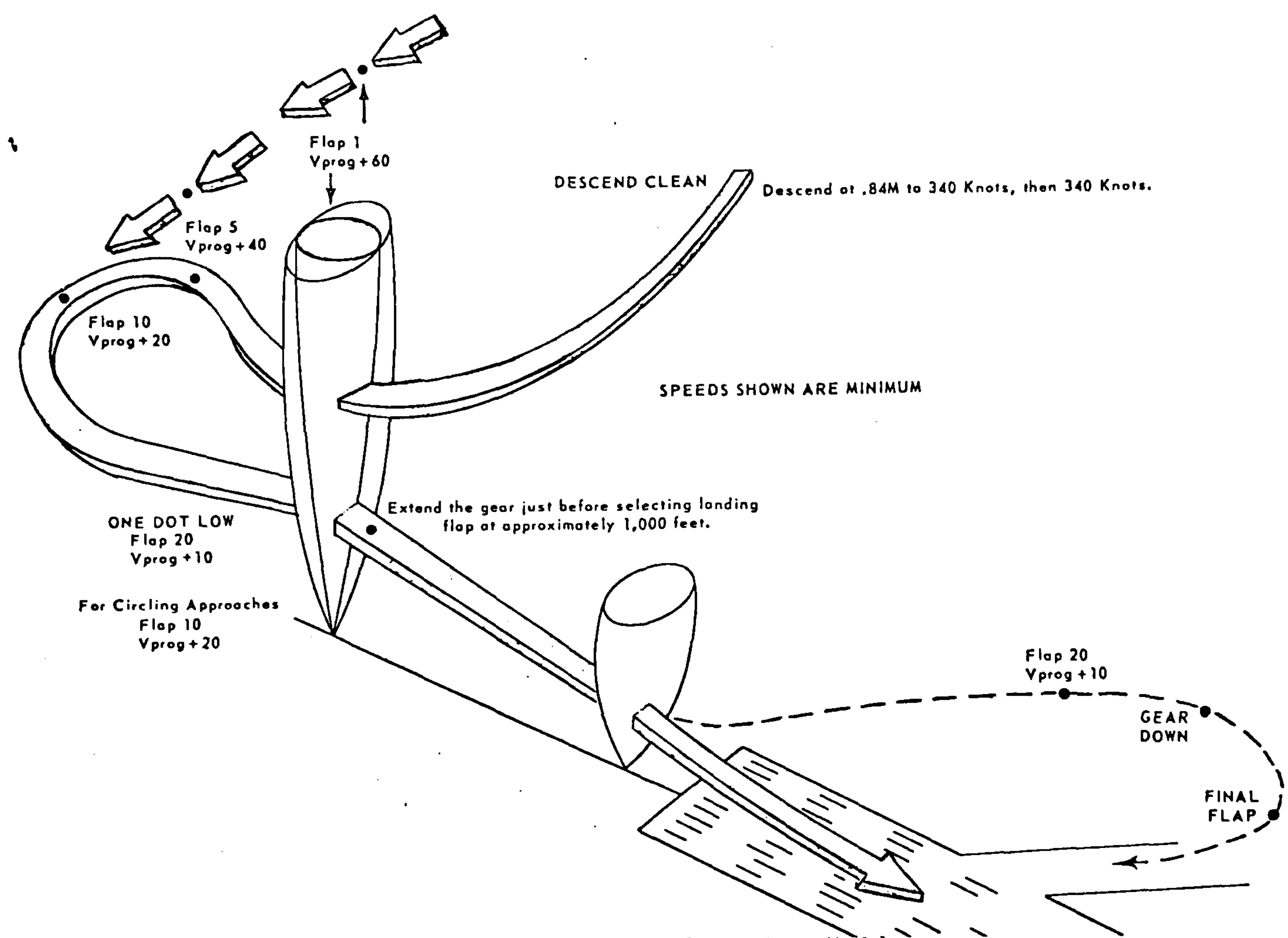

Figure 2. Typical ILS Approach

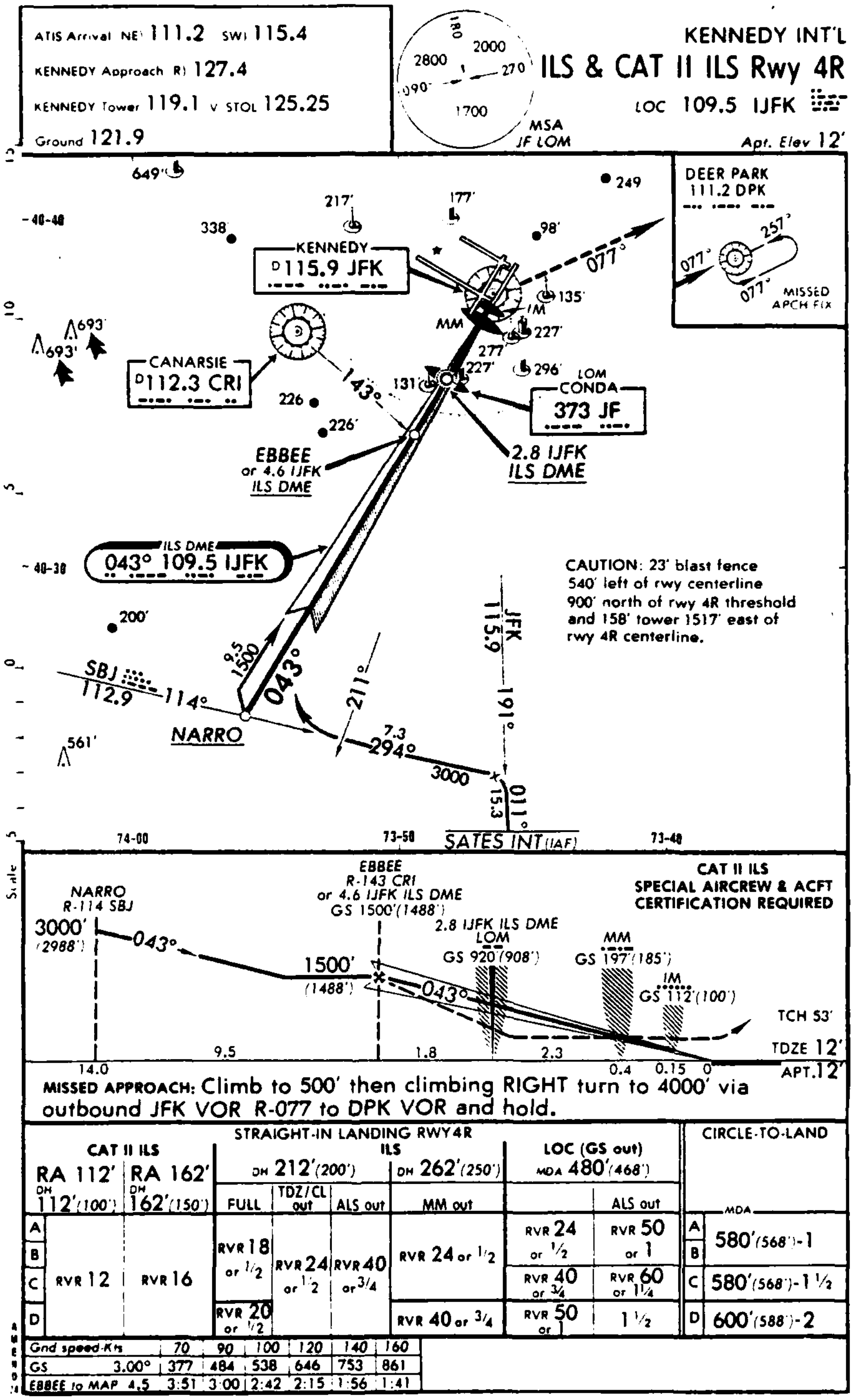

Figure 3. JFK ILS Runway 4R (not to be used for navigation)
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TABLE 25

CRUISE CHART (.84 Mach)

Flt IAS GROSS WEIGHT (1000 lbs)

TABLE 25

CRUISE CHART (.84 Mach)

Flt Lvl	IAS Std C TAS	700	680	660	640	620	600	580	560	540	520	500	480	460	440	420
		GROSS WEIGHT (1000 lbs)														
390	261 -57 481											1.44 23.2 90.6 5.19	1.41 24.1 89.7 5.00	1.38 25.0 88.8 4.81	1.35 25.8 88.1 4.66	1.32 26.5 87.5 4.54
380	267 -57 481			EPR NM N1 FF							1.44 22.3 90.4 5.39	1.40 23.1 89.5 5.20	1.37 23.9 88.7 5.03	1.34 24.7 88.1 4.87	1.32 25.4 87.5 4.74	1.30 26.0 86.9 4.62
370	273 -57 481								1.46 20.8 91.0 5.78	1.43 21.5 90.2 5.59	1.40 22.3 89.4 5.40	1.37 23.0 88.6 5.23	1.34 23.7 88.0 5.09	1.32 24.3 87.5 4.96	1.30 24.9 86.9 4.84	1.28 25.5 86.3 4.72
360	279 -57 481							1.45 20.2 90.8 5.96	1.42 20.8 90.0 5.78	1.39 21.5 89.2 5.59	1.36 22.2 88.5 5.42	1.34 22.8 87.9 5.28	1.32 23.4 87.4 5.15	1.30 23.9 86.9 5.03	1.28 24.5 86.3 4.92	1.26 25.0 85.8 4.81
350	285 -54 484						1.43 19.6 90.7 6.18	1.40 20.2 89.9 6.00	1.37 20.8 89.2 5.82	1.35 21.4 88.6 5.65	1.33 21.9 88.1 5.52	1.31 22.4 87.6 5.40	1.29 22.9 87.1 5.28	1.27 23.4 86.5 5.16	1.26 23.9 86.0 5.05	1.24 24.5 85.6 4.94
340	292 -52 486					1.41 19.0 90.7 6.41	1.39 19.5 90.0 6.22	1.36 20.1 89.3 6.04	1.34 20.6 88.8 5.89	1.32 21.1 88.3 5.76	1.30 21.6 87.8 5.63	1.28 22.0 87.3 5.51	1.27 22.5 86.8 5.40	1.25 23.0 86.3 5.29	1.24 23.4 85.9 5.18	1.22 23.9 85.4 5.09
330	299 -50 488			1.43 17.9 91.4 6.82	1.40 18.4 90.7 6.63	1.37 18.9 90.0 6.44	1.35 19.5 89.4 6.27	1.33 19.9 89.0 6.13	1.31 20.3 88.5 6.00	1.30 20.8 88.0 5.88	1.28 21.2 87.5 5.76	1.26 21.6 87.0 5.64	1.25 22.1 86.6 5.53	1.23 22.5 86.1 5.43	1.22 22.9 85.7 5.33	1.21 23.2 85.4 5.25
320	306 -48 490		1.41 17.4 91.3 7.04	1.38 17.9 90.7 6.85	1.36 18.4 90.1 6.67	1.34 18.8 89.5 6.51	1.32 19.2 89.1 6.38	1.30 19.6 88.7 6.25	1.29 20.0 88.2 6.13	1.27 20.4 87.7 6.01	1.26 20.8 87.2 5.89	1.24 21.2 86.8 5.78	1.23 21.6 86.4 5.68	1.22 22.0 86.0 5.58	1.21 22.3 85.7 5.50	1.20 22.6 85.3 5.43
310	313 -46 492	1.39 16.9 91.3 7.26	1.37 17.4 90.7 7.08	1.35 17.8 90.1 6.91	1.33 18.2 89.7 6.76	1.31 18.6 89.3 6.63	1.30 18.9 88.8 6.50	1.28 19.3 88.3 6.38	1.27 19.7 87.9 6.26	1.25 20.0 87.4 6.15	1.24 20.4 87.0 6.04	1.23 20.8 86.6 5.93	1.21 21.1 86.3 5.84	1.20 21.4 85.9 5.76	1.19 21.7 85.6 5.68	1.19 21.9 85.3 5.61
300	320 -44 494	1.35 16.9 90.7 7.31	1.33 17.3 90.2 7.15	1.32 17.6 89.8 7.02	1.30 18.0 89.4 6.89	1.29 18.3 88.9 6.76	1.27 18.6 88.4 6.64	1.26 19.0 88.0 6.52	1.25 19.3 87.6 6.41	1.23 19.6 87.2 6.30	1.22 20.0 86.8 6.19	1.21 20.3 86.5 6.10	1.20 20.5 86.2 6.02	1.19 20.8 85.8 5.95	1.18 21.0 85.5 5.88	1.17 21.3 85.2 5.81
290	327 -42 497	1.32 16.7 90.4 7.43	1.31 17.0 90.0 7.30	1.29 17.3 89.5 7.18	1.28 17.6 89.1 7.05	1.27 17.9 88.7 6.93	1.25 18.2 88.3 6.81	1.24 18.5 87.9 6.70	1.23 18.8 87.5 6.59	1.22 19.1 87.1 6.49	1.21 19.4 86.8 6.40	1.20 19.6 86.5 6.32	1.19 19.9 86.2 6.25	1.18 20.1 85.9 6.18	1.17 20.3 85.6 6.11	1.17 20.6 85.4 6.04
280	335 -40 499	1.30 16.4 90.1 7.60	1.29 16.7 89.7 7.47	1.27 17.0 89.3 7.35	1.26 17.3 88.9 7.23	1.25 17.5 88.5 7.11	1.24 17.8 88.1 7.00	1.23 18.1 87.8 6.89	1.22 18.4 87.4 6.79	1.21 18.6 87.1 6.71	1.20 18.8 86.8 6.63	1.19 19.0 86.5 6.55	1.18 19.2 86.3 6.48	1.17 19.4 86.0 6.41	1.17 19.7 85.7 6.35	1.16 19.8 85.5 6.28
270	341 -38 501	1.28 16.1 89.9 7.77	1.27 16.4 89.5 7.65	1.26 16.6 89.1 7.53	1.24 16.9 88.7 7.42	1.23 17.1 88.4 7.31	1.22 17.4 88.0 7.20	1.21 17.6 87.7 7.10	1.20 17.8 87.4 7.02	1.20 18.0 87.1 6.95	1.19 18.2 86.9 6.87	1.18 18.4 86.6 6.80	1.17 18.6 86.3 6.73	1.17 18.8 86.1 6.66	1.16 19.0 85.9 6.60	1.15 19.2 85.6 6.54
260	348 -37 503	1.26 15.8 89.6 [illegible]	1.25 16.0 89.3 [illegible]	1.24 16.3 88.9 [illegible]	1.23 16.5 88.6 [illegible]	1.22 16.7 88.3 [illegible]	1.21 16.9 88.0 [illegible]	1.20 17.1 87.7 [illegible]	1.19 17.3 87.5 [illegible]	1.19 17.5 87.2 [illegible]	1.18 17.7 86.9 [illegible]	1.17 17.8 86.7 [illegible]	1.17 18.0 86.4 [illegible]	1.16 18.2 86.2 [illegible]	1.16 18.3 86.0 [illegible]	1.15 18.5 85.8 [illegible]

Low Altitude
High Speed Cruise
(Vmo−15)
Target EPR

Alt	EPR
22	1.14
21	1.12
20	1.11
19	1.10
18	1.09
17	1.08
16	1.07
15	1.06
14	1.05
13	1.04
12	1.03
11	1.02

Note:
Based on 500,000 lbs
Increase/decrease
.01-.02 EPR
depending on weight.

		7.77	[illegible]	[illegible]	7.42	7.31	7.20	7.10	7.02	6.95	6.87	6.80	6.73	6.66	6.60	6.54
	348	1.26	1.25	1.24	1.23	1.22	1.21	1.20	1.19	1.19	1.18	1.17	1.17	1.16	1.16	1.15
260	-37	15.8	16.0	16.3	16.5	16.7	16.9	17.1	17.3	17.5	17.7	17.8	18.0	18.2	18.3	18.5
	503	89.6	89.3	88.9	88.6	88.3	88.0	87.7	87.5	87.2	86.9	86.7	86.4	86.2	86.0	85.8
		7.97	7.85	7.74	7.63	7.52	7.43	7.35	7.27	7.20	7.13	7.06	6.99	6.93	6.87	6.81
	355	1.25	1.23	1.22	1.22	1.21	1.20	1.19	1.19	1.18	1.17	1.17	1.16	1.16	1.15	1.15
250	-35	15.5	15.7	15.9	16.1	16.3	16.4	16.6	16.8	16.9	17.1	17.2	17.4	17.5	17.7	17.8
	505	89.5	89.2	88.9	88.5	88.3	88.0	87.8	87.5	87.3	87.0	86.8	86.6	86.4	86.2	86.0
		8.18	8.06	7.96	7.85	7.70	7.69	7.61	7.54	7.46	7.39	7.33	7.27	7.20	7.14	7.09
	362	1.23	1.22	1.21	1.20	1.20	1.19	1.18	1.18	1.17	1.17	1.16	1.16	1.15	1.15	1.14
240	-33	15.1	15.3	15.5	15.6	15.8	15.9	16.1	16.2	16.4	16.5	16.7	16.8	16.9	17.0	17.1
	507	89.4	89.1	88.8	88.6	88.3	88.0	87.8	87.6	87.3	87.1	86.9	86.7	86.5	86.3	86.2
		8.40	8.29	8.20	8.12	8.04	7.96	7.89	7.81	7.75	7.68	7.62	7.55	7.49	7.44	7.41
	369	1.22	1.21	1.20	1.20	1.19	1.18	1.18	1.17	1.17	1.16	1.16	1.15	1.15	1.14	1.14
230	-31	14.7	14.9	15.0	15.2	15.3	15.4	15.6	15.7	15.8	16.0	16.1	16.2	16.3	16.4	16.4
	509	89.3	89.1	88.8	88.6	88.3	88.1	87.9	87.7	87.5	87.3	87.1	86.9	86.7	86.6	86.5
		8.66	8.54	8.48	8.37	8.32	8.26	8.16	8.11	8.05	7.95	7.90	7.86	7.81	7.77	7.75
		700	680	660	640	620	600	580	560	540	520	500	480	460	440	420

NOTES:
1. N1 is nominal.
2. FF increases 3% for + 10°C, decreases 3% for -10°C.
3. TAS increases 1 knot per degree above std., decreases 1 knot below std.
4. For hot day check altitude capability 213.010 pg. 2.
5. → At flight levels above 230 and EPR values below 1.20, the 3.0 and 3.5 engine bleeds may open, causing a 5% increase in FF.

APPENDIX D

SPECIFIC AIRCREW ERRORS

TABLE 26

ERROR COUNTS

Run No.	Ruffell Smith Categories	No.	By-Operator Categories						
			PF	CAP	PNF	COP	PTM	FE	CRW
3	Communication[a]	1			1	1			
	Flying	2	2	2					
	Tactical dec.	1							1
	Flying skill	2	1	1			1		
	Autopilot	1	1	1					
	Total	7	4	4	1	1	1	0	1
4	Tactical dec.	1					1		
	Flying skill	1			1	1			
	Autopilot	1					1		
	Other	1	1	1					
	Total	4	1	1	1	1	2	0	0
5	Navigation	1					1		
	System operation	1						1	
	Tactical dec.	3					1		2
	Autopilot	1	1	1					
	Other	1						1	
	Total	7	1	1	0	0	2	2	2
6	Navigation	1					1		
	Communication	5		4	4		1		
	System operation	6	2	1	1	2	1		2
	Tactical dec.	1		1	1				
	Crew integration	1							1
	Flying skill	3	3			3			
	Autopilot	2	1			1	1		
	Total	19	5	5	5	5	4	0	3
8	Navigation	3	1	1	1	1	1		
	Communication	1			1	1			
	System operation	1							1
	Flying	2					2		
	Flying skill	1	1	1					
	Total	8	2	2	2	2	3	0	1
10	Communication[b]	1			1	1			
	Navigation	1			1	1			
	System opeartion	1					1		
	Flying[c]	1							
	Tactical dec.	1							1
	Autopilot	1					1		
	Total	4	0	0	1	1	2	0	1

TABLE 26 (Contd.)

Run No.	Ruffell Smith Categories	No.	By-Operator Categories PF	CAP	PNF	COP	PTM	FE	CRW
12	Communication[d]	1		1	1				
	Navigation	2		2	2				
	Flying	3	1			1	2		
	Tactical dec.	1							1
	Total	7	1	3	3	1	2	0	1
13.	Navigation[e]	1							
	Communication	4		1	1		3		
	System operation	1							1
	Flying	1					1		
	Tactical	1	1			1			
	Flying skill	2	1	1	1	1			
	Autopilot	2	2			2			
	Total	11	4	2	2	4	4	0	1
14	Navigation	1			1	1			
	Communication	3			3	3			
	Autopilot	1					1		
	Other	1							1
	Total	6	0	0	4	4	1	0	1
15.	Flying	2					2		
	Tactical dec.	1							1
	Autopilot	1	1	1					
	Total	4	1	1	0	0	2	0	1

[a]Error found during crew coordination procedures analysis.

[b]Error found during crew coordination procedures analysis.

[c]Error could not be verified by the data.

[d]Error found during crew coordination procedures analysis.

[e]Second segment error improperly listed for first segment.

TABLE 27

ERROR DESCRIPTIONS

Run No.	Ruffell Smith Categories	Description	By–Operator Categories
3	Communication[a]	P2 called wrong ATC station	PNF COP
	Flying	P1 follows F/D blindly	PF CAP
	Flying	flap 25 too early	PTM
	Tactical dec.	flap 25 landing	CRW
	Flying skill	P1 throttle control	PF CAP
	Flying skill	alt. excursion near end of cruise	PTM
	Autopilot	disengagement caused by P1	PF CAP
4	Tactical dec.	raise gear before 800' AFE	PTM
	Flying skill	P2 rough	PNF COP
	Autopilot	TURB mode not selected	PTM
	Other	P1 short term memory	PF CAP
5	Navigation	nav switches in ADF for T/O	PTM
	Sys. operation	P3 drains reserve fuel tank	FE
	Tactical dec.	no ice protection in thunderstorm	CRW
	Tactical dec.	flap 5 at 800' AFE on T/O	PTM
	Tactical dec.	flap 25 landing	CRW
	Autopilot	P1 never tries to use	PF CAP
	Other	P3 uses only 1 side of shld. harness	FE
6	Navigation	nav switches in ADF for T/O	PTM
	Communication	P1 fails to contact ATC (tower)	CAP PNF
	Communication	P1 copies wrong squawk	CAP PNF
	Communication	P1 misses T/O clnc	CAP PNF
	Communication	P1 uses wrong call sign	CAP PNF
	Communication	does not report level at 4000'	PTM
	Sys. operation	P2 puts flaps down during start	PF COP
	Sys. operation	no ice protection on T/O	CRW
	Sys. operation	P3 reduces power as EPR increase	CRW
	Sys. operation	P2 selects wrong computer for F/D	PTM
	Sys. operation	P2 resets B computer & loses F/D	PF COP
	Sys. operation	P1 difficulty tuning ADFs	CAP PNF
	Tactical dec.	P1 fails to take over unstable app	CAP PNF
	Crew integration	no comm. regarding setting radios	CRW
	Flying skill	P2 follows F/D too late	PF COP
	Flying skill	P2 excessive angle at att. in turn	PF COP
	Flying skill	P2 throttle control on final	PF COP
	Autopilot	P2 put A/P to CMD w/o pause at MAN	PF COP
	Autopilot	in CMD during turbulence	PTM

TABLE 27 (Contd.)

Run No.	Ruffell Smith Categories	Description	By-Operator Categories
8	Navigation	P2 tunes wrong OM at JFK	PNF COP
	Navigation	ILS mode not selected	PTM
	Navigation	P1 misreads navaid frequency	PF CAP
	Communication	P2 copies wrong frequency	PNF COP
	Sys. operation	no ice protection on T/O	CRW
	Flying	low A/S and high rate of descent on final	PTM
	Flying	270K at 5000' in climb	PTM
	Flying skill	P1 throttle control on final	PF CAP
10	Navigation	P2 sets ADF incorrectly	PNF COP
	Communication[b]	P2 uses wrong call sign	PNF COP
	Sys. operation	P2 selects wrong computer for F/D	PTM
	Flying[c]		
	Tactical dec.	flap 25 landing	CRW
	Autopilot	TURB mode not selected	PTM
12	Navigation	P1 problems w/ radials after T/O	CAP PNF
	Navigation	P1 does not understand way pt chg	CAP PNF
	Communication[d]	P1 talks to cabin instead of ATC	CAP PNF
	Flying	over rotation on takeoff	PTM
	Flying	neither pilot has control	PTM
	Flying	excessive hand flying in climb	PF COP
	Tactical dec.	flap 25 landing	CRW
13	Navigation[e]		PTM
	Communication	P1 does not call tower after FAF	PTM
	Communication	P1 calls NY Center on wrong freq.	CAP PNF
	Communication	P1 does not report Southgate	PTM
	Communication	does not squawk when requested	PTM
	Sys. operation	P3 sets #1EPR higher than others	CRW
	Flying	flap 5 too early	PTM
	Tactical dec.	P2 wants to make flap 25 landing	PF COP
	Flying skill	P1 rough	CAP PNF
	Flying skill	P2 throttle control on approach	PF COP
	Autopilot	not used in climb	PF COP
	Autopilot	P2 puts to CMD while in ALT HOLD	PF COP
14	Navigation	P2 sets wrong VOR frequency	PNF COP
	Communication	P2 does not use call sign	PNF COP
	Communication	P2 uses wrong call sign	PNF COP
	Communication	P2 asks for repeat of heading	PNF COP
	Autopilot	TURB mode not used	PTM
	Other	altimeter errors not noticed	CRW

TABLE 27 (Contd.)

Run No.	Ruffell Smith Categories	Description	By-Operator Categories
15	Flying	326K at 9000'	PTM
	Flying	flaps 20 too early	PTM
	Tactical dec.	Descent Check started late	CRW
	Autopilot	P1 uses wrong A/P	PF CAP

[a]Error found during crew coordination procedures analysis.

[b]Error found during crew coordination procedures analysis.

[c]Error could not be verified by the data.

[d]Error found during crew coordination procedures analysis.

[e]Second segment error improperly listed for first segment.

APPENDIX E

EVALUATION GUIDES

Crew Coordination

In the main the Crew Coordination Procedures occur in a sequence determined by the experimental scenario. However, they are intertwined with numerous other verbal communications including ATC clearances, ATIS recordings, messages to or from Operations, passenger announcements, and general conversation. Crew members frequently interrupt or preempt one another. When prescribed verbalizations are seemingly omitted, extra vigilence must be maintained to guarantee that a required statement is not masked by other communications. Also, proceduralized information may be literally correct but may occur at the wrong time and/or in the wrong sequence. Hence, in recording occurrences of compliance with Crew Coordination Procedures it is essential to note specific declarations, the spokesman, and the sequence of operational events. Table 28 shows procedure names, scored compliance activity, and appropriate operators in an idealized sequence. The Transfer of Aircraft Control procedure is timely whenever it does not interfere with the accomplishment of other tasks.

TABLE 28

CREW COORDINATION COMPLIANCE SCORING

Procedure Name	Prescribed Verbalizations	Prescribed Operators
Pre-Start Checklist	Command	PF
	Announcement	PNF
	Challenges and responses	PNF, PF, FE
	Completion statement	PNF
Start Checklist	Command	PF
	Announcement	PNF
	Challenges and responses	PNF, PF, FE
	Completion statement	PNF
Pre-Taxi Checklist	Command	PF
	Announcement	PNF
	Challenges and responses	PNF, PF
	Completion statement	PNF
Transfer of EGT Monitor	Acceptance	FE
	Relinquishment	PF
Taxi Checklist	Command	PF
	Ammouncement	PNF
	Challenges and responses	PNF, PF, FE
	Completion statement	PNF
Takeoff Checklist	Command	PF
	Announcement	PNF
	Challenges and responses	PNF, PF, FE
	Completion statement	FE
Takeoff Callouts	Airspeed	PNF
	80 knots	PNF
	V1 [safe decision speed]	PNF
	VR [rotation speed]	PNF
	V2	PNF
	Positive rate [of climb]	PNF
Gear Retraction	Command	PF
	Acknowledgement	PNF
Takeoff Callout	800 feet	PNF

TABLE 28 (Contd.)

Procedure Name	Prescribed Verbalizations	Prescribed Operators
Flap Retraction	Command [flaps 5]	PF
	Acknowledgement	PNF
	Command [flaps 1]	PF
	Acknowledgement	PNF
	Command [flaps up]	PF
	Acknowledgement	PNF
Altitude Callout	1000 to go [at 3000' MSL]	PNF
After Takeoff Checklist	Command	PF
	Completion statement	FE
Altitude Callout	1000 to go [at 14000' MSL]	PNF
Transfer of Aircraft Control	Acceptance	PNF
	Relinquishment	PF
	Acceptance	PF
	Relinguishment	PNF
Descent Checklist	Command	PF
	Announcement	FE
	Challenges and responses	FE, PF, PNF
	Completion statement	FE
Approach Checklist	Command	PF
	Announcement	FE
	Challenges and responses	FE, PF, PNF
	Completion statement	FE
Altitude Callout	1000 to go [at 5000' MSL]	PNF
Approach Flap Extension	Command [flaps 1]	PF
	Acknowledgement	PNF
	Command [flaps 5]	PF
	Acknowledgement	PNF
	Command [flaps 10]	PF
	Acknowledgement	PNF
	Command [flaps 20]	PF
	Acknowledgement	PNF

TABLE 28 (Contd.)

Procedure Name	Prescribed Verbalizations	Prescribed Operators
Landing Gear/Landing Flap Extension	Command [gear down]	PF
	Acknowledgement	PNF
	Command [flaps 25]	PF
	Acknowledgement	PNF
	Command [flaps 30]	PF
	Acknowledgement	PNF
Landing Checklist	Command	PF
	Announcement	FE
	Challenges and responses	FE, PF
	Completion statements	FE
Precision Approach Callouts	Outer marker	PNF
	500 feet AFE	PNF
	200 feet ADH	PNF
	100 feet ADH	PNF
	Minimums	PNF
Landing Roll Callouts	All in reverse	FE
	100 knots	PNF
	90 knots	PNF
	60 knots	PNF
	All out of reverse	FE

For each of the above procedures an instance of noncompliance is recorded whenever the required verbalization is omitted, uttered out of sequence, or spoken by other than the prescribed operator. In the case of callout procedures, statements which do not concur with actual aircraft parameters (e.g., an early or late declaration of "1000 feet to level off") are also counted as cases of noncompliance.

Cockpit Management

In every type of aviation pilots are obliged to undergo recurrent subjective evaluations of their flight management skills. For general aviation pilots, a biennial flight review from an FAA examiner or a certified flight instructor is required. For Air Force pilots a minimum of two standardization/evaluation flights per year is normally mandatory; in most military units periodic evaluations in a simulator are also required. Airline pilots receive semi-annual flight checks and simulator evaluations from FAA inspectors or designated company examiners.

Although specific tasks and procedures may vary greatly from one aircraft to another and from one operating environment to another (e.g., single pilot general aviation flying, military bombardment, and transcontinental passenger flight), all pilot evaluations involve one aviator's subjective assessment of another's composite airmanship. During every rating the management principles of continuity and discipline are judged, sometimes implicitly but often explicitly. Likewise, in any cockpit occupied by more than one crew member the precept of cooperation can hardly be overlooked. The need for cooperation is perceptible in every multi-place aircraft. In short, the type of subjective assessments of cockpit management which are shown in Chapter V are made hundreds of times each day throughout the whole spectrum of aviation.

This author's faculty for judging other pilots' management skills rests upon seventeen years of affiliation with the United States Air Force, including four years of formal education and over twelve years of piloting. Flight training and operational experience have been accumulated in six different aircraft flying with sundry crew sizes under a variety of environmental conditions. The judgments contained herein could reasonably have been made by any aviator with similar training and experience. However, just as no two flight examiners have exactly the same perceptions and biases, no two surrogate evaluators of the experimental data should be expected to produce identical assessments.

APPENDIX F

PROBABILITY PLOTS

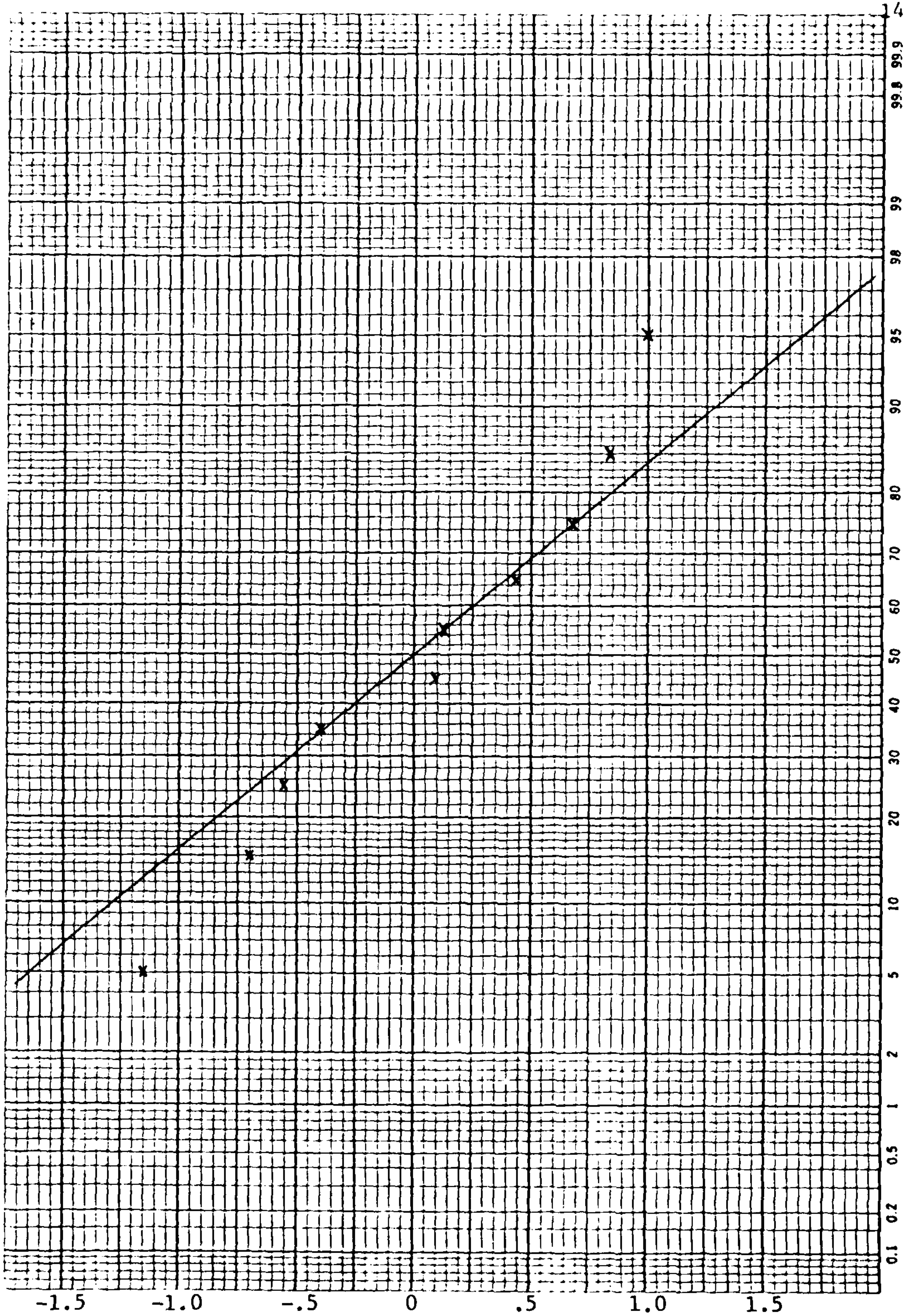


Figure 4. Normal Probability Plot of Test Statistic for TPF Distribution.

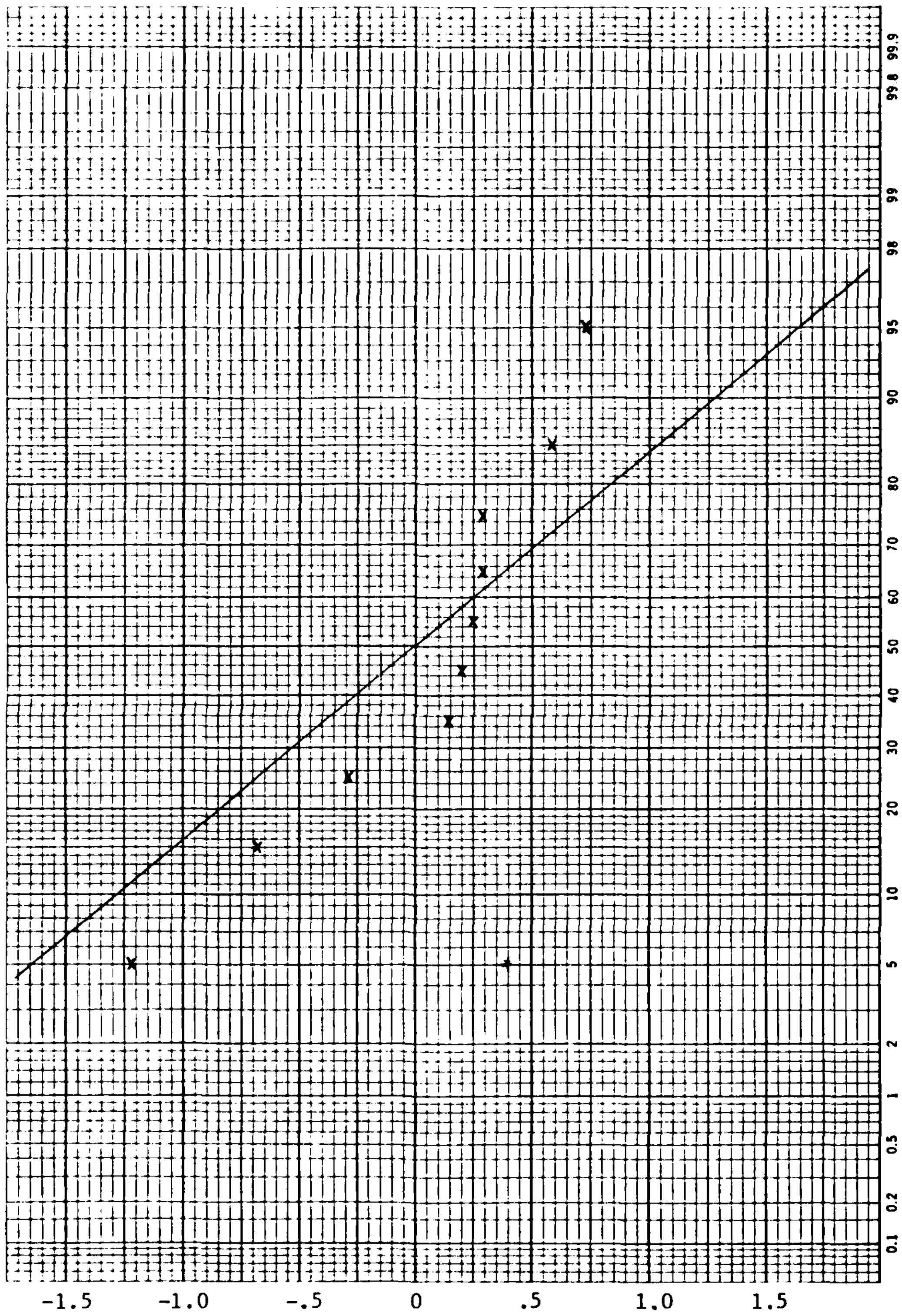


Figure 5. Normal Probability Plot of Test Statistic for TCAP Distribution.

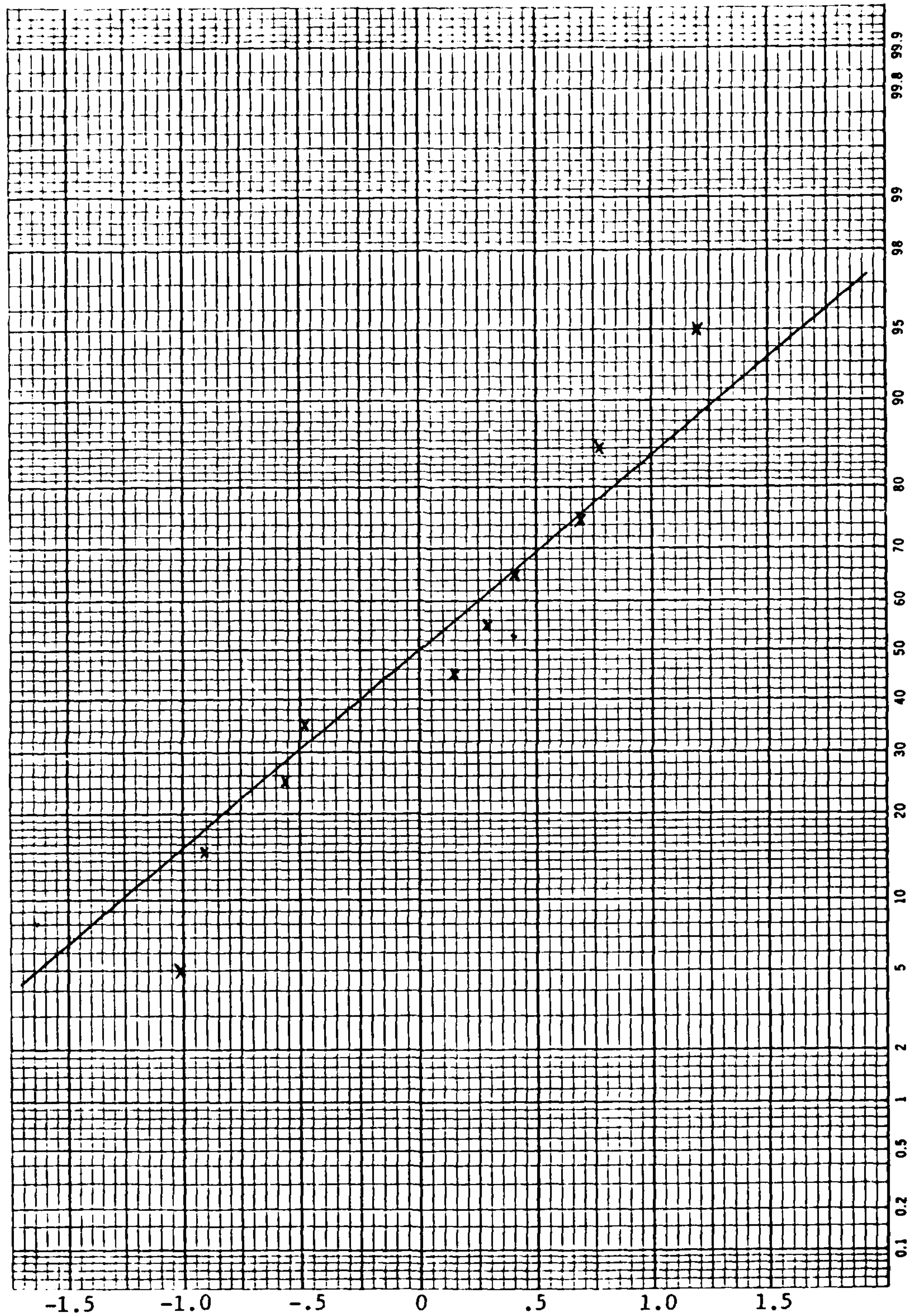


Figure 6. Normal Probability Plot of Test Statistic for CPF Distribution.

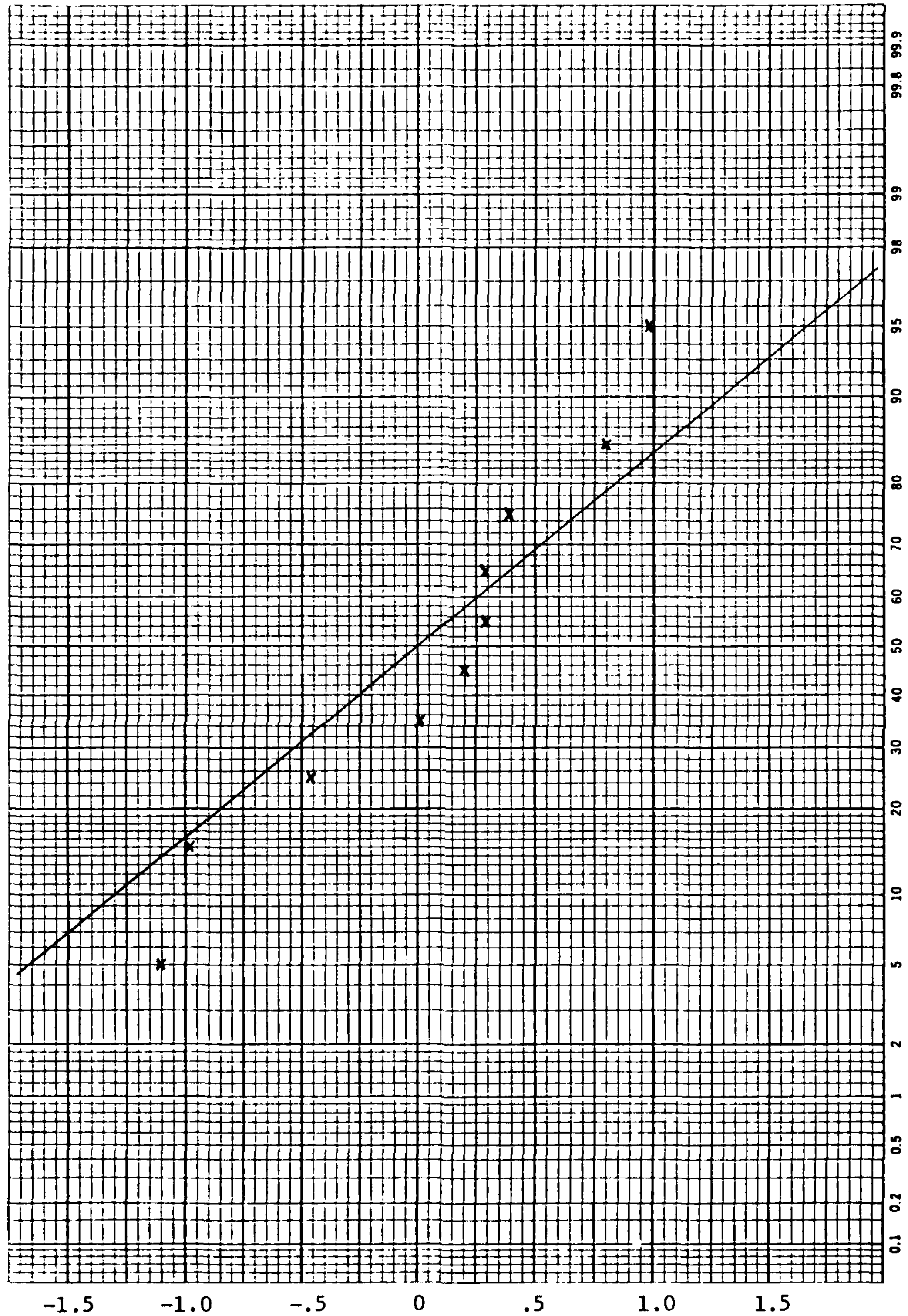


Figure 7. Normal Probability Plot of Test Statistic for CCAP Distribution.

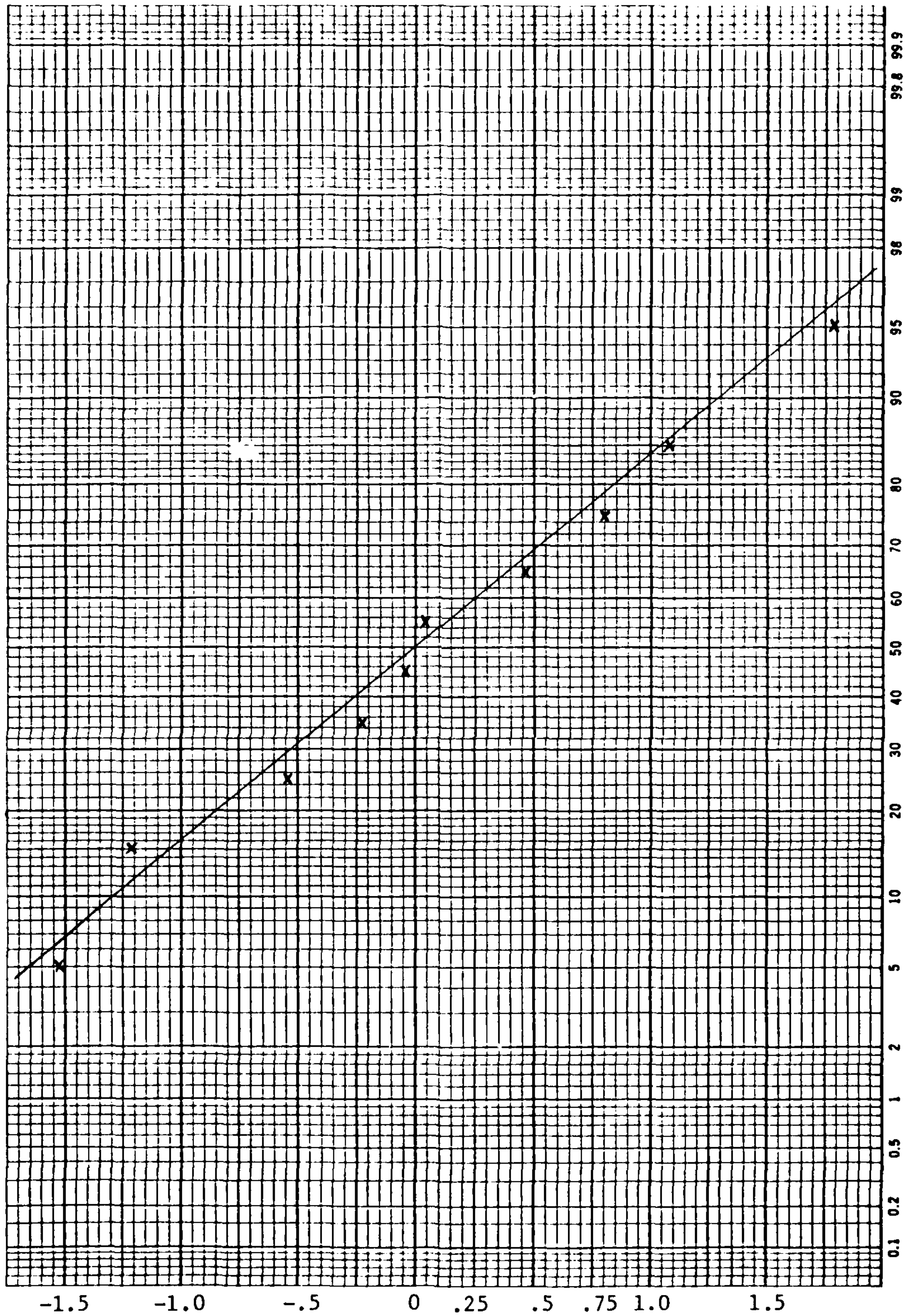
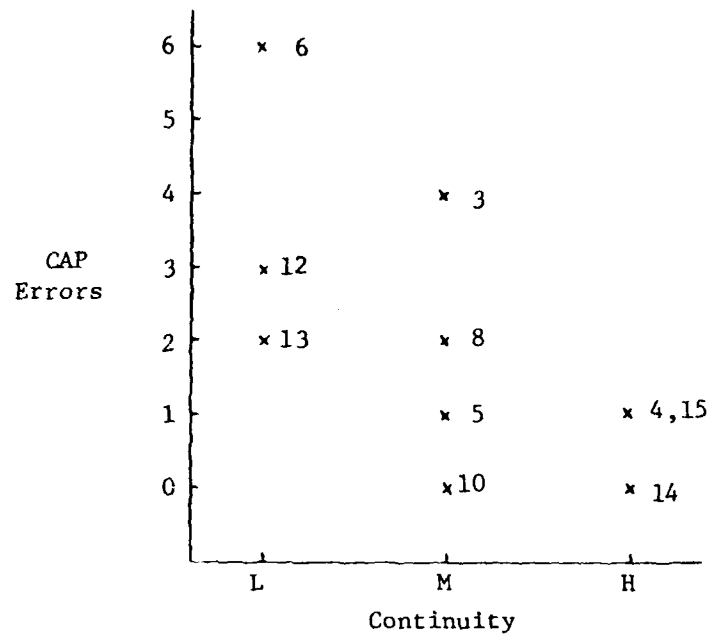


Figure 8. Normal Probability Plot of Test Statistic for PLTS Distribution.

APPENDIX G

SUBJECTIVE ASSESSMENT DIAGRAMS



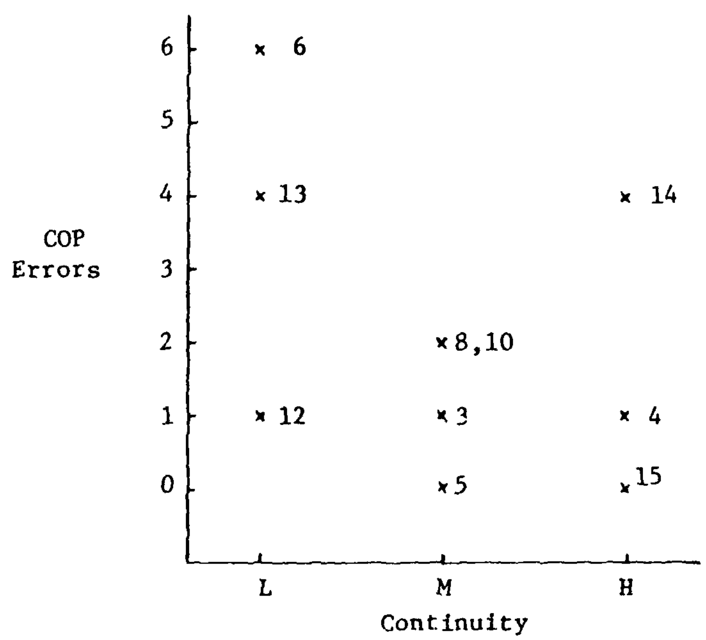
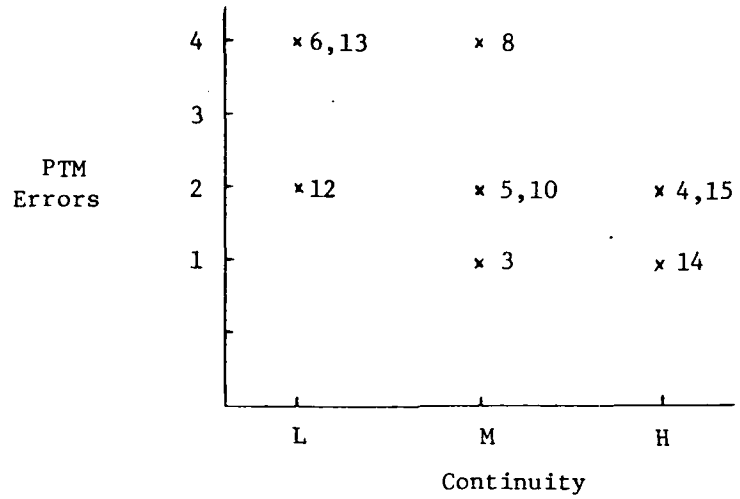
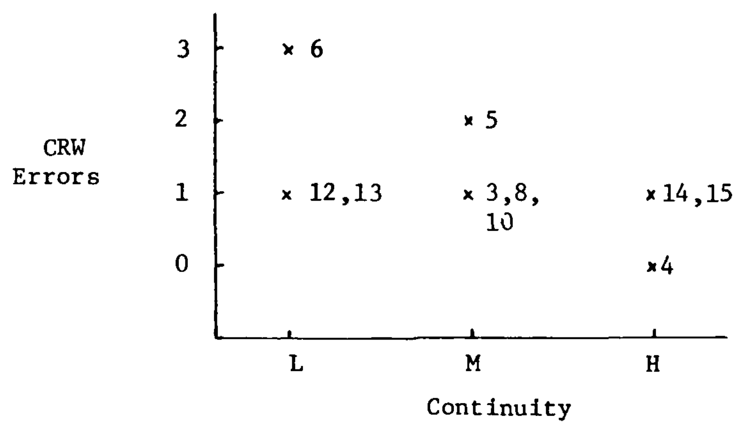


Figure 9. Continuity Plots.





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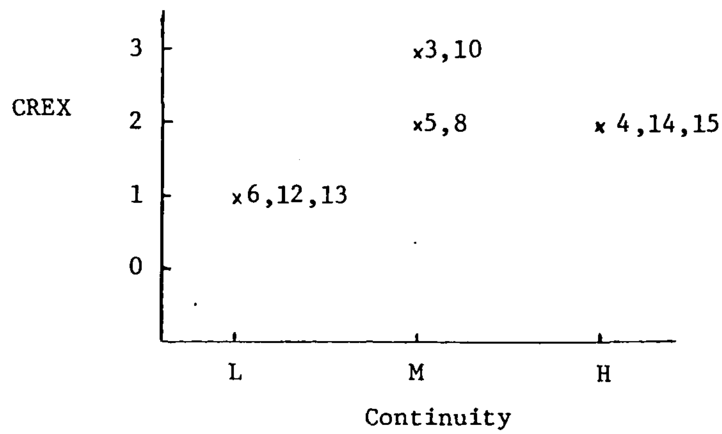

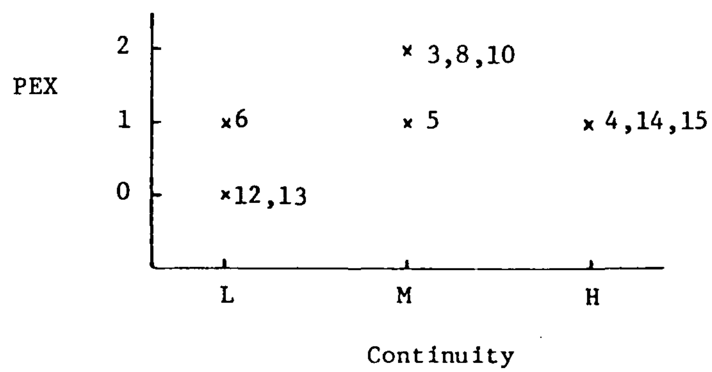

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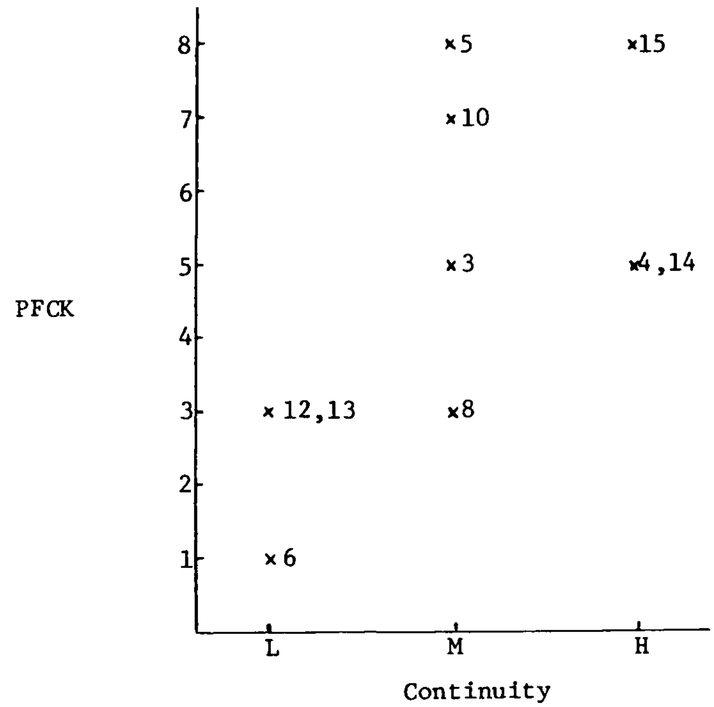

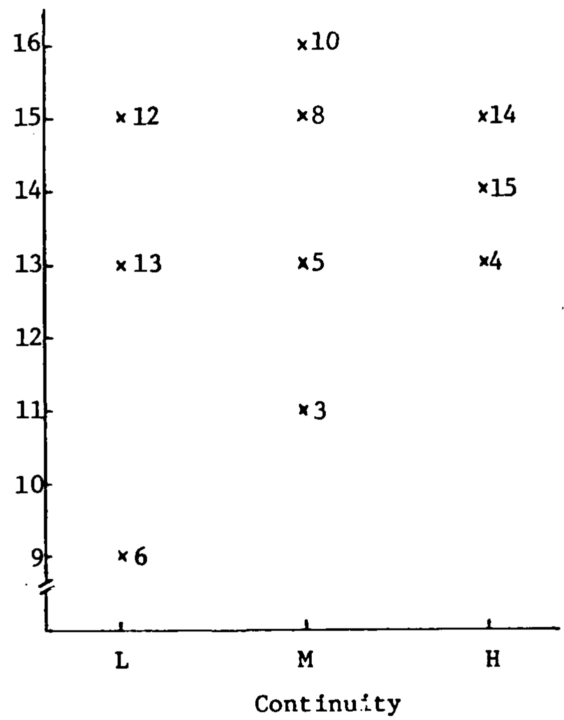

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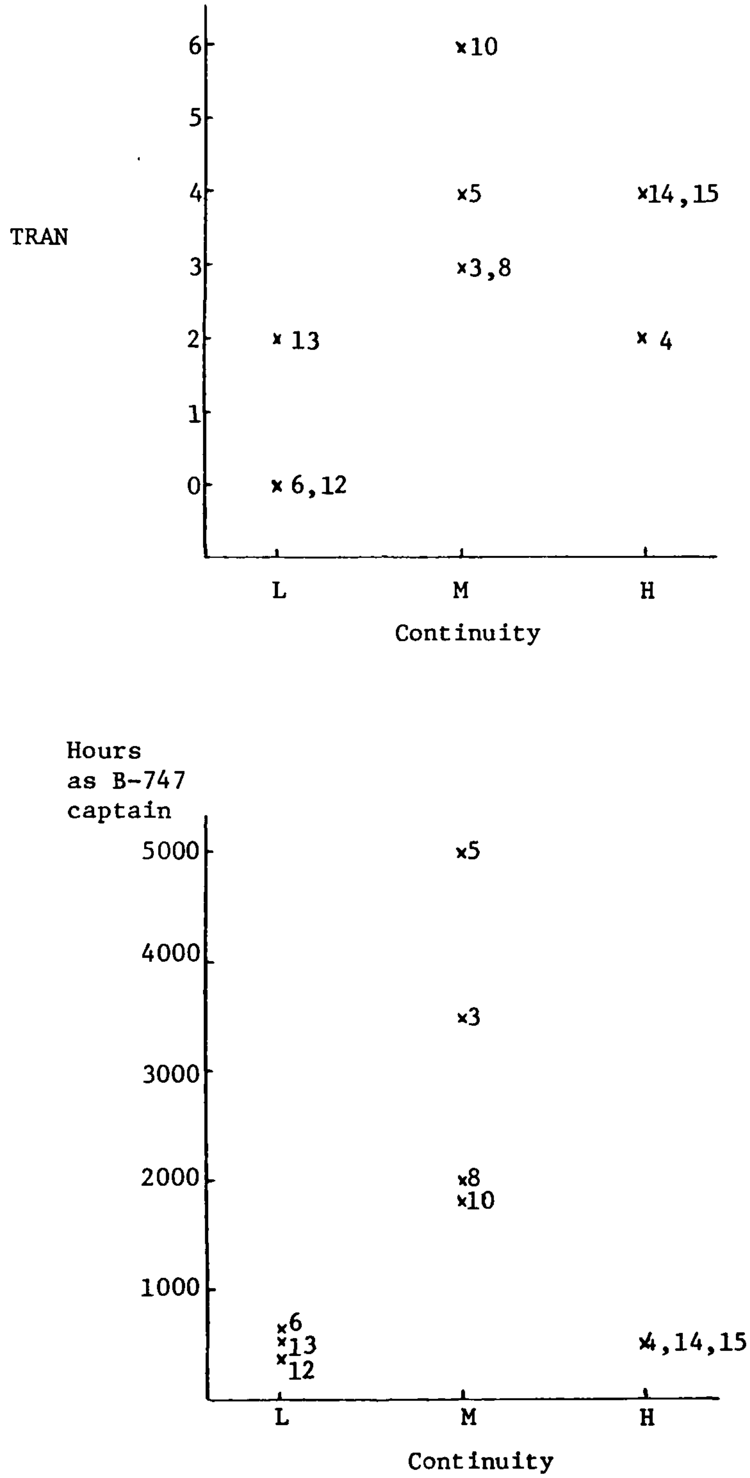

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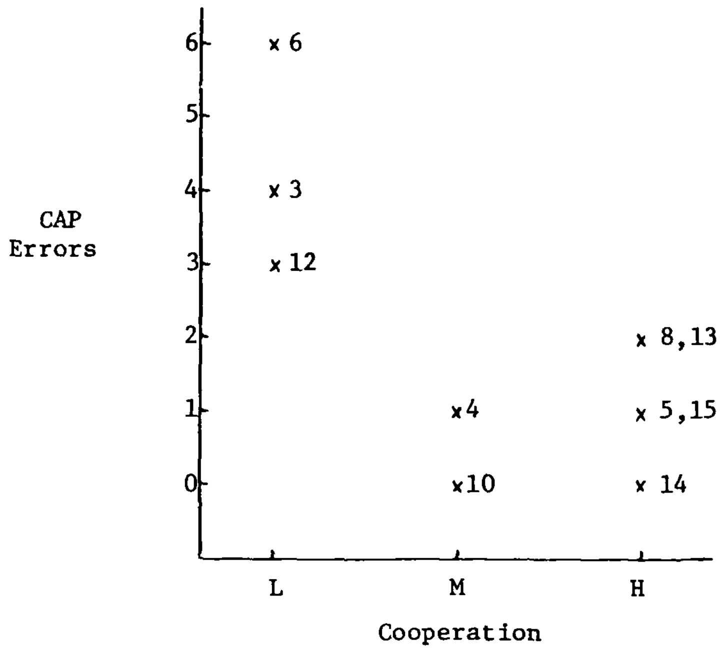


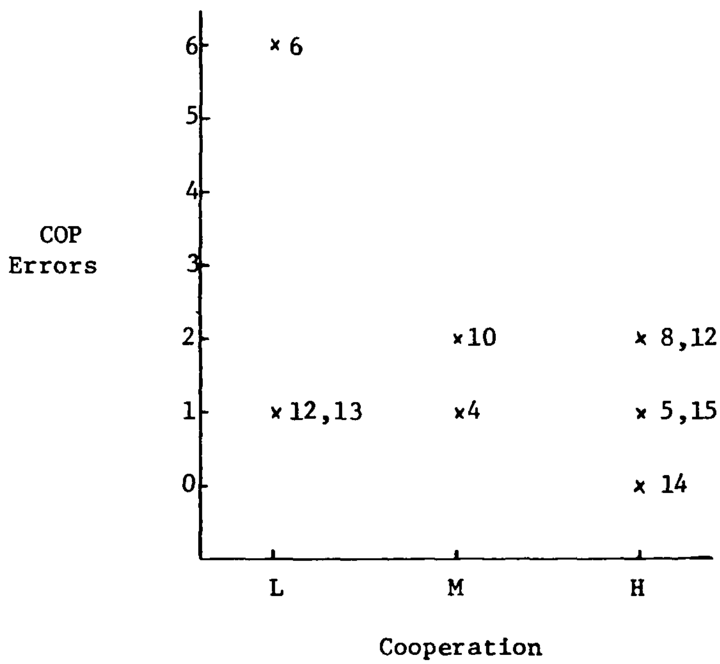


Figure 10. Cooperation Plots.

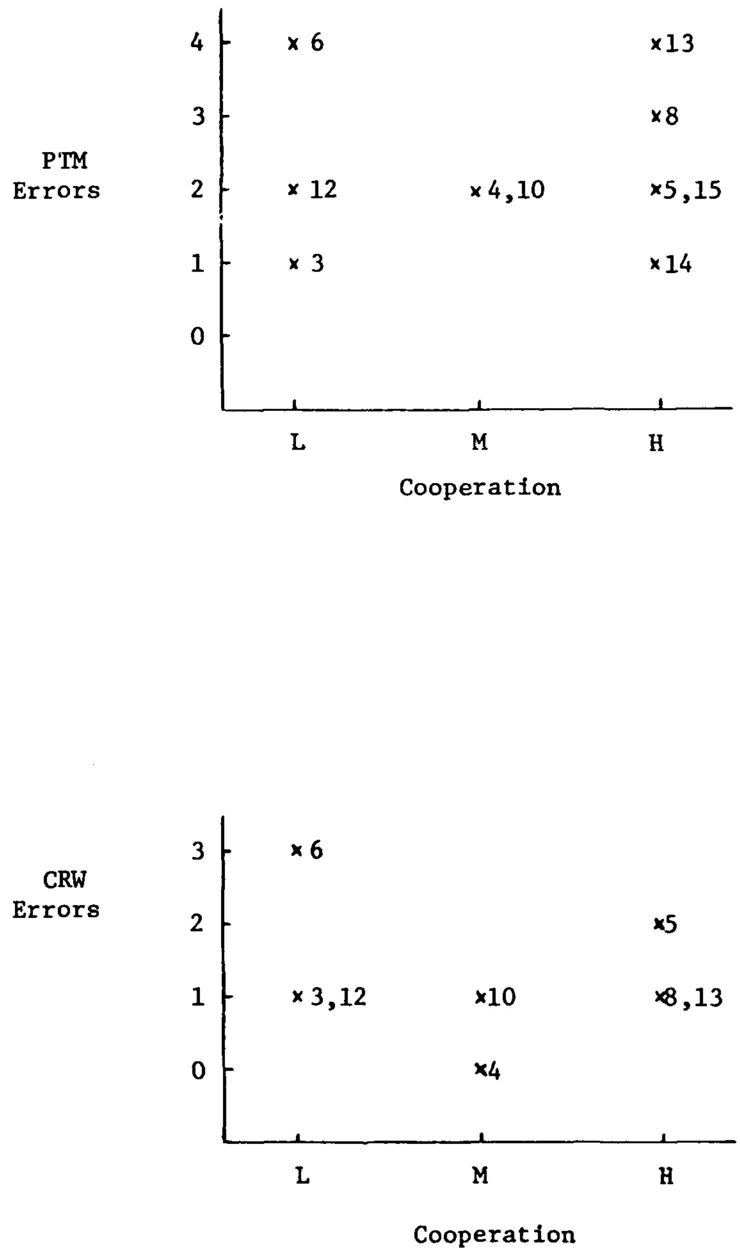
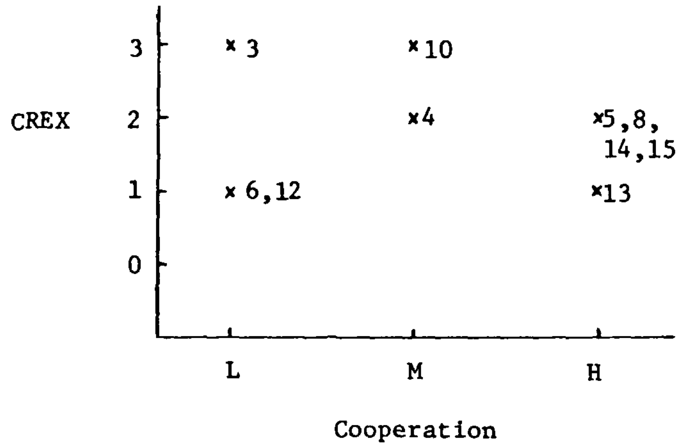

PTM Errors
4
3
2
1
0
x 6
x 12
x 3
x 4,10
x13
x8
x5,15
x14
L
M
H
Cooperation
CRW Errors
3
2
1
0
x 6
x 3,12
x10
x4
x5
x8,13
L
M
H
Cooperation

Fig. 10. (Contd.)


CREX
3
2
1
0
× 3
× 10
× 4
× 5,8, 14,15
× 6,12
× 13
L
M
H
Cooperation

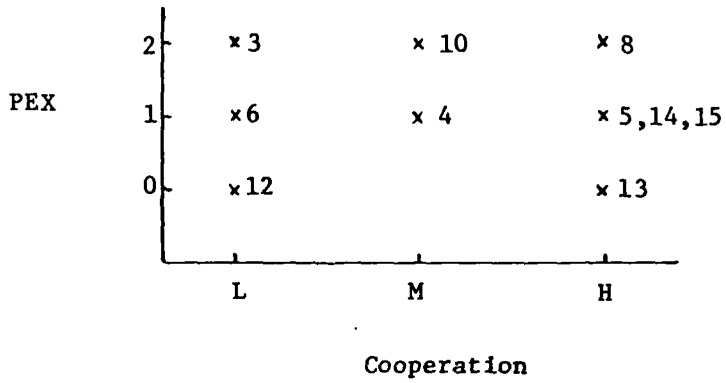
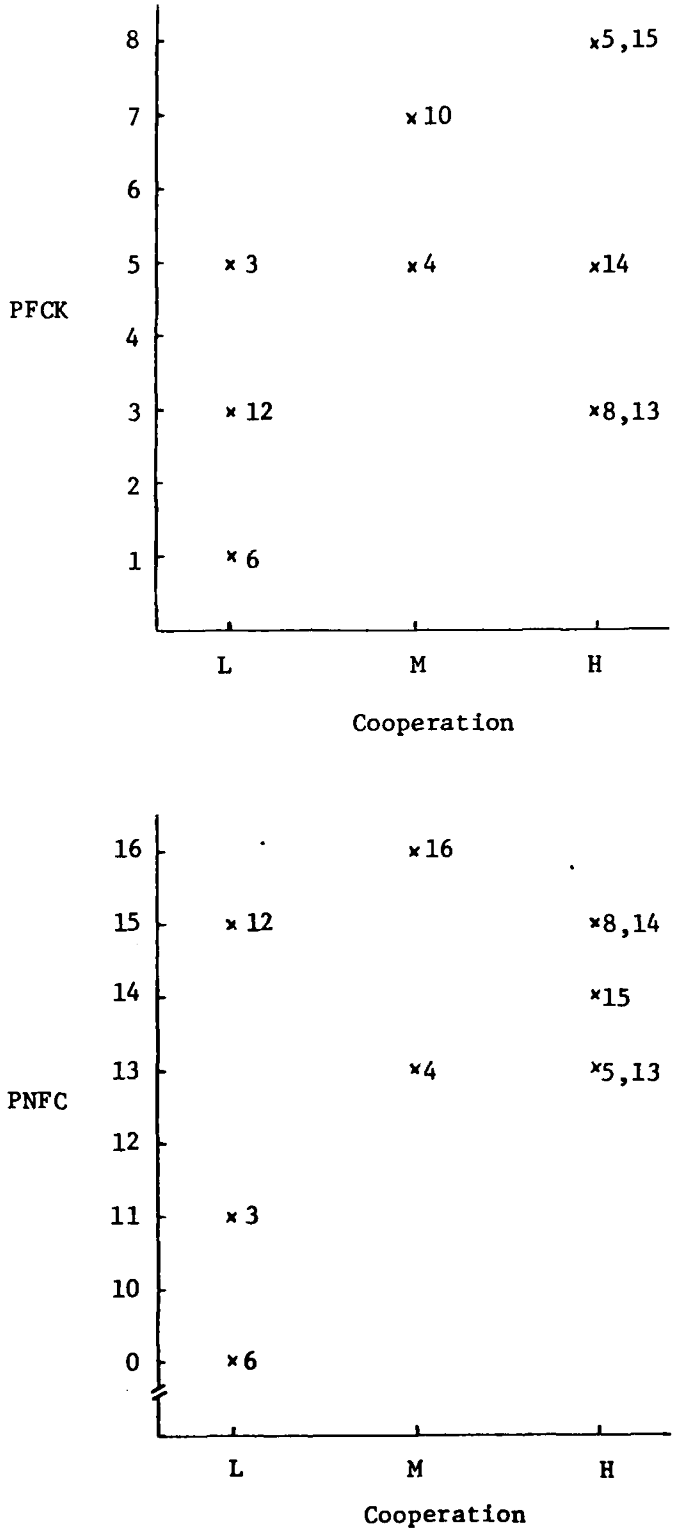

PEX
2
1
0
× 3
× 10
× 8
× 6
× 4
× 5,14,15
× 12
× 13
L
M
H
Cooperation

Fig. 10. (Contd.)



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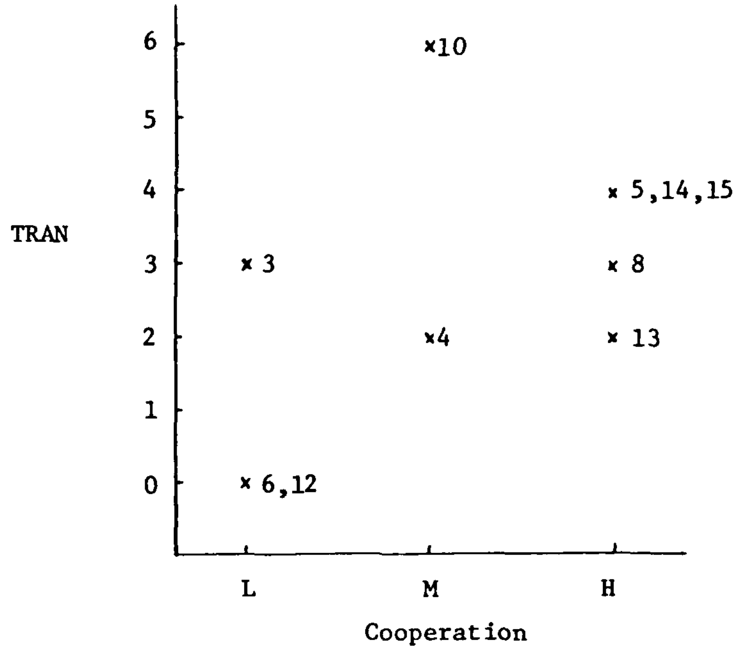

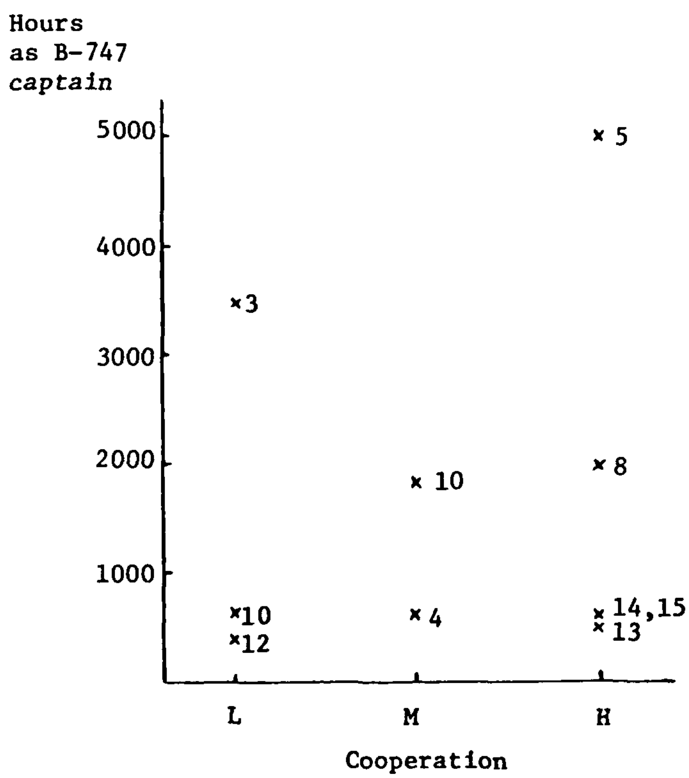

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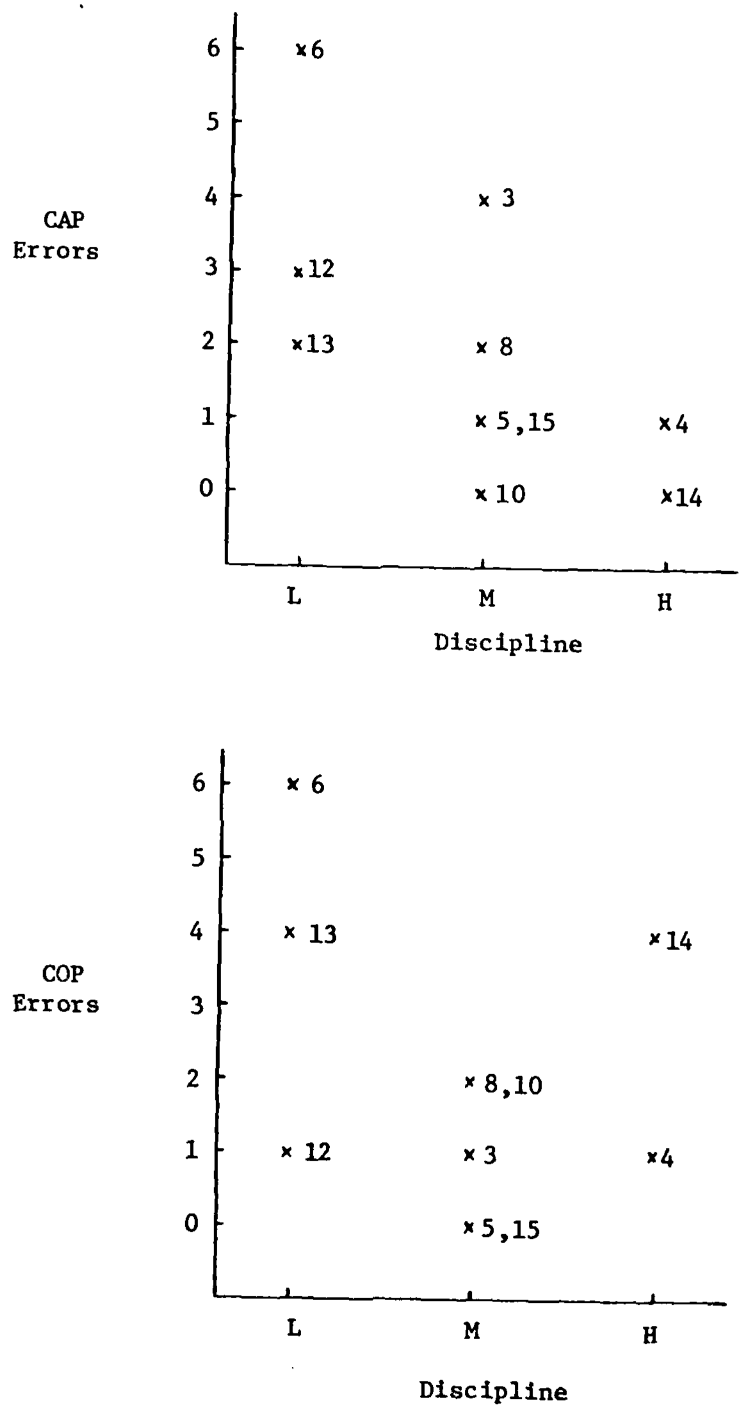
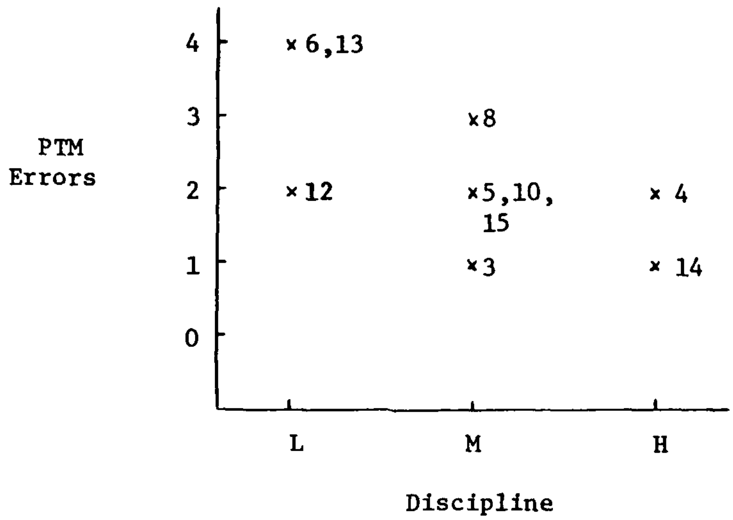
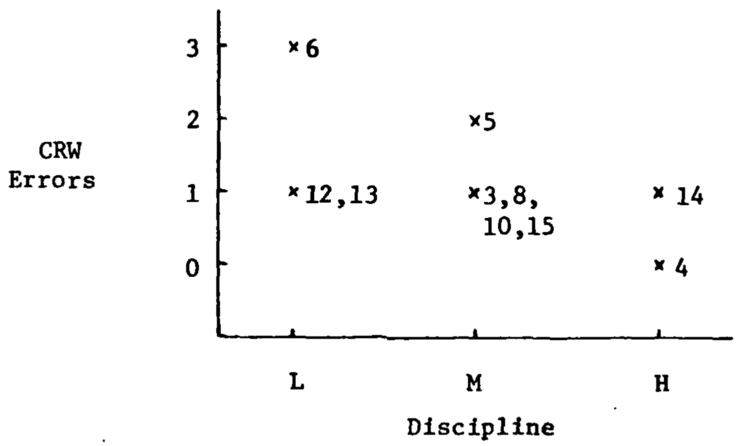


Figure 11. Discipline Plots.





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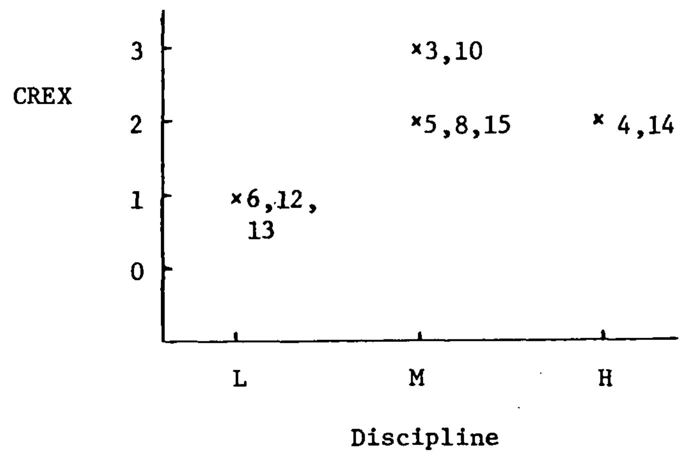

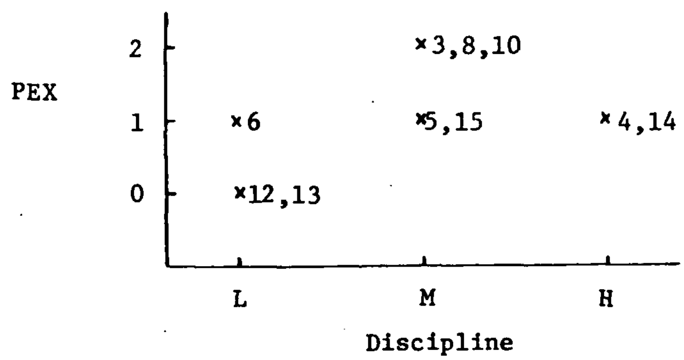

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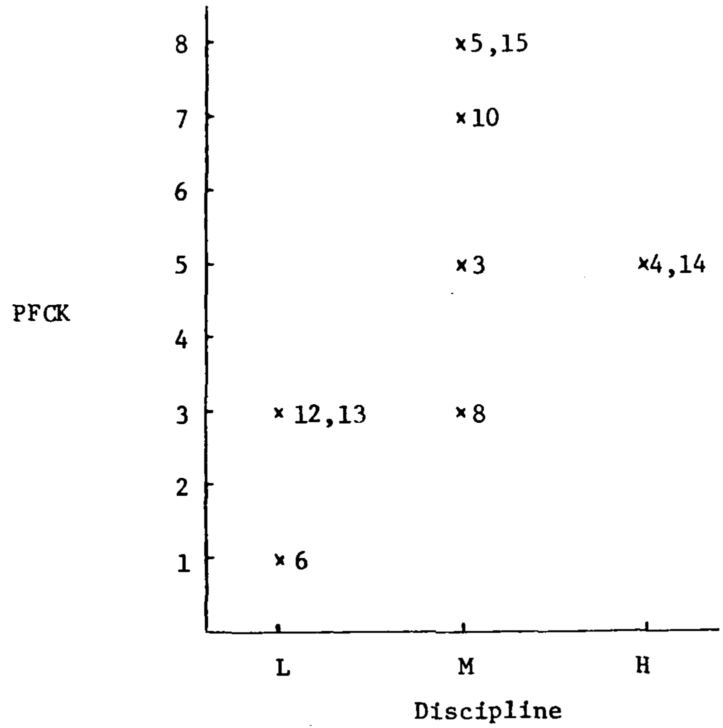

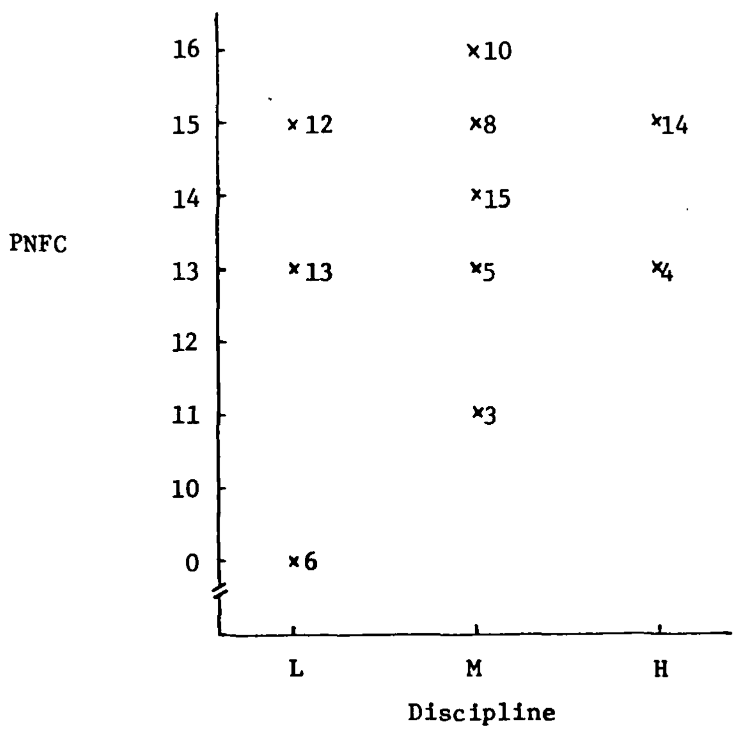

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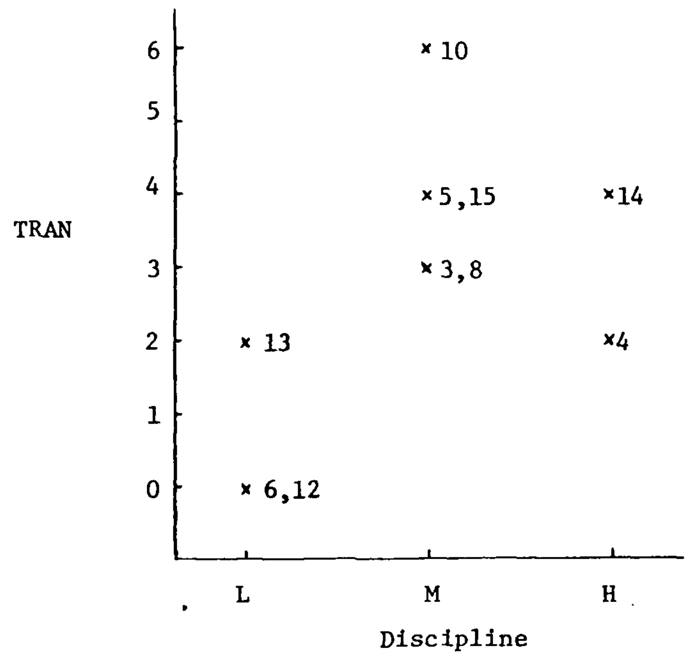

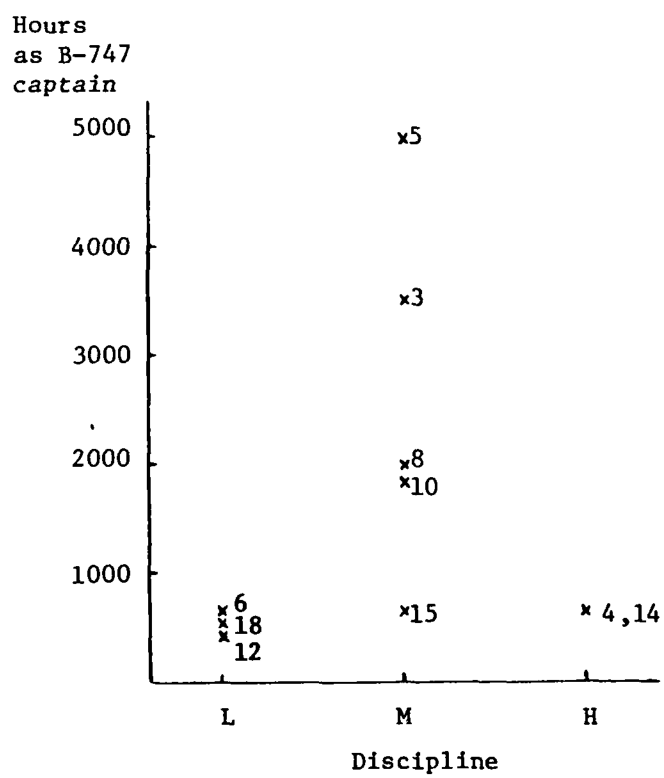

Figure 11. (Contd.)

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