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AIRCREW COORDINATION AND DECISIONMAKING:
Peer Ratings of Video Tapes made during a Full Mission Simulation

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Abstract: Six professionally active, retired captains rated the coordination and decisionmaking performances of sixteen aircrews while viewing videotapes of a simulated commercial air transport operation. The videotapes displayed a composite of four views of crewmembers, and the cockpit, from cameras located inside the simulator. The scenario featured a required diversion and a probable minimum fuel situation. Seven point Likert-type scales were used in rating variables on the basis of a model of crew coordination and decisionmaking. The variables were based on concepts of, for example, decision difficulty, efficiency, and outcome quality; and leader-subordinate concepts such as person- and task-oriented leader behavior, and competency motivation of subordinate crewmembers. Five-front-end variables of the model were in turn dependent variables for a hierarchical regression procedure. The variance in safety performance was explained 46%, by decision efficiency, command reversal, and decision quality. The variance of decision quality, an alternative substantive dependent variable to safety performance, was explained 60% by decision efficiency and the captain's quality of within-crew communications. The variance of decision efficiency, crew coordination, and command reversal were in turn explained 78%, 80%, and 60% by small numbers of preceding independent variables. A principle component, varimax factor analysis supported the model structure suggested by regression analyses. Crewmembers for this study were diverse with respect to airline of origin and recency, or currency on the Boeing 707 - the aircraft simulated. Some retired personnel were used. The results should be interpreted accordingly.

INTRODUCTION

The aircrew interaction process has been implicated as contributing to numerous recent air transport accidents and incidents (Cooper, White, & Lauber, 1979; Murphy, 1980; NTSB, 1976). And many interpersonal factors have been suggested as causes of ineffective crew performance {lack of decisive command, strained social relations, and pilot-copilot role relationships (Murphy, 1977)}. Problematic pilot-copilot role issues include the command responsibility of the captain when the first officer is flying, and the responsibility of the first officer when the captain deviates from safe or legal practices (Wiener, 1977).

Flightcrew communications patterns have been related to performance outcomes in a study of simulator data (Foushee and Manos, 1981). Mitigation level, a linguistic indication of tentativeness and indirectness in speech, has been identified as a factor in failures of crewmembers to get new topics discussed or suggestions ratified by the captain (Goguen, Linde, and Murphy, 1984). In their study of air transport accident transcripts they also showed mitigation level to vary with command and situation dimensions. Finally, a full mission simulator study of crew performance (Ruffell-Smith, 1979) related ineffective management of both human and material resources to increased decision times. Generally, however, suggested causal factors in air crew performance effectiveness have not been well defined through systematic study or research. One reason for this could be the lack of adequate methods for isolating and quantifying crew interaction factors and for relating these factors to flight task performance (Foushee, 1984; Murphy, 1977) - a situation comparable to that for small group performance generally (Hackman and Morris, 1975).

The major objective of this rating study was to initiate development of a hierarchical process model of aircrew coordination and decisionmaking. A secondary objective was to develop reliable measures of the crew interaction process that could be related to other substantive measures, such as flight task error measures, or to measures developed with coded communications data. This will be addressed in future reports.

This study used videotapes of aircrews performing a full mission simulation of a commercial air transport operation (Murphy, Randle, Tanner, Frankel, Goguen, and Linde, 1984). Such videotapes have been used in studying medical team-patient interactions (Frankel & Beckman, 1982). Leadership style and crewmember competency variables, included in the model of crew performance presented below, reflect findings from recent critical reviews of the leadership literature (House, 1984; House & Baetz, 1979; Kerr, 1984). Design of the rating scales and procedures (including rater training), reflect findings from recent reviews of rating literature (Landy & Farr, 1983; Landy & Farr, 1980). The single dimension , Likert-type scales and anchoring methods were justified on the bases that the study is exploratory, and research findings have shown little gain in performance when more complex scales are used.

METHOD

The Model

Crewmember Behavioral Variables: Variables of major interest were based on some focal concepts. Task-oriented, person-oriented, and participatory leadership behaviors were rated for both the captain and first officer. These variables were differentiated on the basis of specific behaviors. Task-oriented leadership behaviors were those concerned with establishing goals, clarifying responsibilities, defining subordinate (others for the first officer) roles and task requirements, coaching subordinates and providing task related feedback. Person-oriented leadership behaviors included those evidencing concern with establishing and maintaining positive crewmember relationships, providing psychological support, and enabling feelings of satisfaction.

Participatory leadership was rated in regard to supervision/resources management on the basis of behavior that encouraged subordinates (or other crewmembers, for first officer) to make suggestions regarding accomplishment of tasks, independently analyze problems, give feedback, and question the leader. Participatory leadership was also rated in regard to decisionmaking. The criterion was behavior concerned with ensuring that all crewmembers for whom a decision was relevant had a chance to influence that decision. Relevance was indicated if a crewmember had significant and pertinent information related to the decision, responsibility for implementing the decision, or significant ego involvement for other reasons.

To address the question of interaction between a captain's leadership effectiveness and a subordinate's capacity and willingness to participate, the first officer and flight engineer were rated on a dimension of competency-motivation. The criterion was evidence of a crewmember being knowledgeable, skillful, and motivated with respect to fulfilling the requirements of his position.

Within-crew communications quality was rated for all three crewmembers with respect to both specific decisionmaking processes and participation in the more general crew coordination process. Behavioral criteria were 1) hearable, understandable, appropriate (in style and content), accurate, and timely messages; 2) being a good listener who makes an effort to understand; and 3) achieving a reciprocal indication that understanding was reached.

Command Reversal - An Interactive Variable: Command reversal was also rated with respect to both specific decisionmaking processes and the more general crew process. If, for example, a first officer performed much of what would normally be the captain's general leadership function, a high rating for that crew on the variable "command reversal" would be expected. Similarly, if a first officer performed much of what would generally be the captain's decisionmaking function, a high rating for that crew on "decision command reversal" would be expected. No attempt was made to distinguish whether such command reversals were due to acquiescence of the captain or dominance of the first officer or whether the actions and decisions were or were not appropriate.

Intermediate Performance Measures: Command reversal was expected to negatively affect crew coordination and decision efficiency, two other focal variables of the hypothesized hierarchical process model (shown in part in Figure 1). A high rating on crew coordination would indicate strong rater agreement that, over a mission segment: individual crewmember knowledge and skills were allocated in an effective and timely manner to meet task and situation demands. A high rating on decision efficiency would indicate strong rater agreement that, for a particular decision process all significant information was acquired at an opportune time, adequately evaluated, and appropriately utilized.

Dependent Variables: Decision quality and safety performance, also shown in Figure 1, are alternative, primary dependent variables for this study. Like decision efficiency and some other variables mentioned above, decision quality was rated for eight decision processes that occured during the mission. A high rating on decision quality would indicate strong rater agreement that a choice made was "the best considering safety of flight and/or the attainment of all other mission goals". Unlike the 15 crew process and nine decisionmaking variables, safety performance was rated on the basis of relatively factual data after raters had observed all 16 crews. Safety performance ratings were essentially based on an assessment of risk in a crew's solution or attempted solution to the major scenario problem.

Data entering into safety performance included the airport where landing occured, fuel on board at landing, and altitudes reached during approaches below minimums when the runway could not be seen.

Other Variables: In addition to the focal variables discussed above, three variables of more peripheral interest were rated: crew cohesiveness, crew friendliness, and decision difficulty.

Identification and Definitions of Variables: All variables are identified with their concepts, referents, and instrument by which they were measured, in Table 1. Attaching the prefix "decision" to a concept such as participatory leadership distinguishes a variable referring to participatory behavior in decisionmaking as opposed to that in supervision/resources management. Attaching the suffix (P1), (P2), or (P3) to a concept distinguishes a behavioral variable, such as communications quality, as to whether reference is to captain, first officer, or flight engineer behavior, respectively. Definitions for all variables can be synthesized from the scale and criterion statements of Appendix A, presented so as to mirror concept presentation in Table 1.

The model will be further discussed below - including those assumptions leading to the partial formulation shown in Figure 1.

The Data

The primary data for the study were sixteen high quality, quad image tapes showing interaction and performance of sixteen three-man flight crews. The crews flew a full mission scenario in a Boeing 720B flight training simulator, a late version of the Boeing 707. Figure 2 shows a typical quad image videotape frame: captain and first officer (upper left and right quadrants, respectively); flight engineer (lower right quadrant); and a context image shot from the back of the simulator that preserved the same relative locations of crewmembers (lower left quadrant). This combined view was made from four small video cameras located in the simulator, out of sight of the crewmembers.

A current, professional air traffic controller was used in the simulation. The controller also participated with another member of the experimental team in simulating conversations with other aircraft, to provide background conversations on the Air Traffic Control (ATC) network.

Crewmembers: The crewmembers were paid volunteers. Their experience represented a wide range of airline of origin and recency, or currency on B-707 line operations. Some were current on the B-707. Many had recent B-707 line experience but were currently flying other jet aircraft in line operations. Some were retired from the line. Thus crew composition ranged from one in which all members were retired from the line to one currently flying the B-707 as an intact crew. The major objective of the overall simulation study was to develop methods for quantifying crew coordination and decisionmaking factors, and their relationships to flight task performance. Thus, this diversity in experience was considered of some importance as an aid in evaluating the sensitivity of candidate performance measures.

All crewmembers received six hours of classroom differences training and four to eight hours of simulator differences training. The number of hours of simulator differences training that a crewmember received was based on recency. Subjects were formed into crews prior to simulator training and were instructed in coordinated procedures during this training.

Scenario: Simply, the overall scenario represented a flight from Tuscon, continuing to Los Angeles (LAX) after a short stopover at Phoenix, with a forced diversion to an alternate upon reaching LAX. Each crew flew the scenario only once, without prior knowledge of the scenario problem. The intent of this procedure was to maximize a valid description of natural crew performance. The crew's enactment of the scenario began with a Captain's Briefing in the simulated operations room at Tuscon and ended upon stopping on the runway at the selected alternate {either Palmdale (PMD) or Ontario (ONT)}. This rating study used videotapes from the longer, problem-leg only - beginning as all three crewmembers entered the cockpit at Phoenix.

The scenario was designed to evoke a series of decisions about where to proceed following a missed approach at LAX due to nose gear not-down-and-locked indication. This situation was exacerbated because it occured at a time when the Los Angeles basin (which includes the planned alternates Ontario and Long Beach) was experiencing low and deteriorating ceiling and visibilities due to coastal fog. Following the missed approach and upon going through a complete gear check procedure that takes several minutes, the crews had to insure that the gear was down and pinned so they could assume that the panel light indication was faulty.

Eight Decisions: While on the ground at Phoenix the crew was given weather information indicating some degradation at LAX. During the latter part of the cruise to LAX, they would be given direct information and other cues about further deterioration of ceiling and runway visual range (RVR) at LAX. Cues included being given an enroute hold due to traffic back-up and an ATC-net conversation regarding another aircraft's missed approach and return for a second attempt. If weather conditions at possible alternates were requested a crew could realize that conditions at other coastal airports such as Long Beach were similar to LAX; that ONT located inland from LAX, was lagging LAX in deterioration; and that PMD, located just over a mountain range out of the Los Angeles basin, was experiencing clear weather with good visibility. The decisionmaking behavior of the crews with respect to whether unusual contingency planning was required and what that planning should be was the first of eight decision processes to be rated in this Crews were cleared to approach LAX, from hold, when their fuel remaining was 14,000 lbs. This decision process was evaluated at the point of calling for gear down, a short time thereafter and near the outer marker at LAX.

The other decisions concerned: 2) whether to go around on the first approach to LAX - a decision that is essentially procedural in that attempts to recycle the gear did not extinguish the failure indication; 3) whether to reapproach LAX - some crews chose to proceed to an alternate and work the gear problem enroute 4) whether to go around (including early interruption) on the second approach to LAX - somewhat less procedurally based, depending on fuel remaining, for example; 5) the choice of ONT or PMD as an alternate; 6) whether to bring the nose gear up during cruise for fuel conservation; 7) whether to select another alternate after receiving company information on relative weather conditions at PMD and ONT and the companies' preference for ONT for passenger handling; and 8) what arrival status to declare.

The last decision, like the first, is a complex decision or planning process, and has components involving whether to declare an emergency or problem situation (due to the nose gear indication or for low fuel) and whether to request emergency equipment (if an emergency is not declared). The timing of information given by the company for decision process seven was designed to require crews to reconsider their alternate, but to maintain their original decision for a prudent outcome.

The Rating Procedure

Rating Scales and Administration: Figure 3 shows the eight videotape stop points at which decision processes were rated. At each point, raters marked nine decisionmaking (DM) scales like that presented in figure 4 - each occupying one page of a booklet. A criterion statement shown below a scale defines the underlined modifier in the scale statement at the top. Thus a <u>very efficient</u> decision process (see Figure 4) is one in which "all significant information was acquired at an opportune time, adequately evaluated and appropriately utilized."

The criterion statements tended to anchor scales at the top (7) scale value. During interactive rater training the kinds of outcomes that would merit rating at the other extreme (1) value and/or intermediate values, were discussed. A blackboard beside the video playback unit contained complete rater instructions and a large scale with anchor descriptions for scale numbers two through six: neutrality for four and incrementally equal interval tendencies toward strong agreement or disagreement for the others. Except for decision difficulty and decision quality scales, presented in that order at the beginning of each booklet, scales were presented in different random orders for each of the eight decisions.

Figure 3 also shows that stop points one, five, and eight and the point at which all three crewmembers had entered the cockpit, defined the boundaries of three mission segments: 1) pre-problem, 2) major problem, and 3) secondary problem. At these three stop points, following administration of the DM instrument, the 15-scale crew process (CP) instrument was administered. As contrasted to the DM instrument the CP instrument assessed qualities based on behavior of individual crewmembers, or the crew, throughout each segment. Examples are task- and person- oriented leadership qualities and crew coordination. The 15 scales were presented in different random orders for each segment.

As noted previously,the first videotape stop was made as "gear-down" was called at LAX. The eighth stop was made over the outer marker at the alternate. The other stops were keyed to completions of decision processes - usually signaled by the start of implementation. After stop point eight, the videotape was continued until the aircraft had stopped on the runway. At this time a fourth CP booklet was administered. These ratings on CP variables over the complete operation were made for comparison with average ratings over the three segments.

All 25 scales were identical to that shown in Figure 3 except for those that assessed first officer leadership styles. These contained a n/a position after number seven. N/a (not applicable) was to be circled only if <u>no</u>

opportunity arose for leader behavior.

As has been noted, the safety performance (SP) instrument was administered in a session after raters had completed all other ratings on the sixteen crews. The raters were not told that they would provide the SP ratings until the other rating sessions were completed.

Airport, airway, and simulator performance information was available to raters during the rating process. Calculated fuel requirements under emergency flight conditions, for both ideal and less-than-ideal aircraft configurations (e.g. gear down) were made available during rating of safety performance - for go-around at ONT and PMD and for flights between airports. During all rating sessions, the videotape would be stopped at a rater's request to clarify a crewmember utterance or other factual information. The raters took notes throughout the flights, and were particularly encouraged to do so during the cruise from Phoenix to LAX. A monitor was present during all rating sessions to insure independence of ratings.

Scenario conditions (or contextual events) were not entirely consistent over the 16 crews. These inconsistencies as well as how they were dealt with are discussed in (Appendix B).

Raters: The raters were six retired captains, all maintaining professional experience as analysts or researchers with the NASA-Aviation Safety Reporting System. All had experience on the Boeing 720B and/or 707. Their combined airline experience totaled 224 years. Four airlines were represented. Year of retirement ranged from 1978 to 1984.

Rating Design: The raters were formed into two balanced groups of three raters, an A- and B-group, based on ASRS research experience, airline of experience, and recency of retirement. Two raters who worked in proximity to each other at their ASRS position were assigned to different groups - all agreed not to discuss completed ratings with members of the other group.

The A-group rated the videotapes, and hence crews, in order one through 16. This crew identification order represented a randomization of the order that crews performed in the simulator. On each rating day, A-group rated two crews - one in a morning and one in the afternoon. The B-group rated crews in the general order of nine through 16 followed by one through eight - except that morning and afternoon videotapes were reversed. Their actual order was: 10,9,12,11.... The latin square type design provided control for time of day effects, partial control for unanticipated sequential effects, and the possibility of examining data for such effects.

Rater Training: All raters received three 2-hour initial training sessions. In session one, the DM and CP rating booklets were presented and discussed. Feedback on these instruments was solicited and utilized when appropriate. A lecture was also given on rating theory - discussing, for example, assumptions of multidimensionality of jobs and situations; effectiveness levels, or degrees of qualities within dimensions; the rater as a measuring instrument; rating accuracy; need to reduce errors of halo, leniency, and midpoint cluster; rating skill components; and the desired end result of independent but reliable ratings. During sessions two and three accuracy and error reduction discussions were repeated. Also, DM and CP scales were utilized repeatedly on videotapes made during "shakedown" simulator runs. These were non-data runs made by crews that were not included in the study. Following each rating effort, ratings were posted and discussed. A-group received an added training session prior to starting ratings of crews nine through 16 due to an unplanned 1-week interruption of their rating activity.

RESULTS AND CONCLUSIONS

Inter-rater Reliabilities

Variable reliabilities were computed by use of the Spearman-Brown formula for multiple raters. These multiple r reliabilities are presented in Table 2. The average reliability over all variables is .92.

Variable Means and Standard Deviations

Crew Process Variables: Means and standard deviations were computed for the 15 crew process variables for each of the three segments. The means for each variable were compared with Fisher's "protected t" test. Differences between segments 2 and 3 means were not significant ($p > .10$). Differences were significant ($p < .05$) for all variables - except competency-motivation (for P2 and P3), command reversal, and task-oriented leadership (P2) - between the pre-problem segment and each of the problem segments (see Table 3). Thus, performance ratings declined on five of the six leadership behavior variables, on communications quality for all crewmembers, and on the three crew referenced variables (cohesiveness, coordination, and friendliness) as the difficulty of the scenario was increased. These effects, apparently due to being in a less structured problem situation, could have implication for remedial training. Table 3 also presents the overall mean and SD for each of the 15 crew process variables. An identical "t" test procedure also revealed no differences between an average rating on CP variables over the three segments and the overall rating made on the ground at the alternate.

The standard deviations for the crew process variables across segments were fairly consistent within and between variables. The range of standard deviations within each of these variables across the three segments was approximately equal to the average range of .13.

Decisionmaking Variables: Means for each of the nine decision variables are presented for each of the eight decisions in Table 4. The overall mean and standard deviation for each variable is also presented in Table 4.

The standard deviations for the decisionmaking variables across decision points were fairly consistent within and between variables. The range of standard deviations across the eight decision points within each of these variables was approximately equal to the average range of .41. Variables 16 and 17 had larger ranges (.72 and 1.01, respectively). Inspection revealed that these larger ranges were due to the low standard deviations at decision point two (the first go-around) for these two variables.

Safety Performance: The overall mean for safety performance (V25) was 3.53, and the overall standard deviation was 1.85.

Multiple Regression/Correlation Analyses

Correlation Matrix: An interpair correlation matrix was obtained (n=96; 6 raters x 16 crews) (Table 5). The six raters made independent ratings. However, in that each rater rated each of the 16 crews, crews cannot be considered truly independent. Rather, there is a relative independence among the 96 points and some bias due to non-independence had to be accepted. The correlations of Table 5 that are at or above .267 are significant ($p < .01$) for 90 degrees of freedom.

The correlations between variables representing concepts assessed for both crew process and and decisionmaking are of interest for methodological reasons. Command reversal (V9) is seen to correlate .92 with decision command reversal (V24). The possibility of combining these two variables for modeling purposes is suggested. The communications quality variables (V13-15) correlated .79, .73, and .78 with their decisionmaking counterparts (V21-23). The participatory leadership variables (V5,V6) correlated .83 and .77 with their decisionmaking counterparts (V19,V20).

Crew Cohesiveness (V10) and Crew Coordination (V11) are significantly correlated (r=.93). There was evidence that a few raters had some difficulty in distinguishing these two variables conceptually - and it is easy to conceive of difficulty in distinguishing them operationally. The expressed problem was in separating crew cohesiveness conceptually from crew coordination - not in rating crew coordination. For the prior reasons the high correlation may be, in part, an artifact.

Regression Analyses: The partial model in Figure 1 is based on a set of assumptions that would determine the order for entering variables into a hierarchical regression analysis. These assumptions include the usual assumptions for establishing causal priority. Also, based on the hierarchical command structure it is assumed that captain leadership and communications qualities would have larger effects than those of other crewmembers. This assumption accounts for captain quality variables, and not other crewmember variables, being included in the front-end, partial model. The rationale for including a task-oriented leadership variable rather than person-oriented or participatory leadership variables was derived from some evidence that a task-oriented leadership style is more effective in problem situations. The curved line between V13 and V21 of Figure 1 indicates correlation but implies no causal relationship, as the directed, signed lines do.

The analytic approach chosen was a hierarchical procedure initiated by a series of stepwise regressions, each subsequent procedure including decreasing numbers of the variables shown in Figure 1. That is, all of the variables except V13 {communications quality(P1)}, which was included only in the last of the five regressions in the series. This was done to reduce the ratio of the k (independent variables - IV's) to the n (96) for the first four regressions. Although these k/n ratios exceed what may be considered prudent for substantive findings, the exploratory nature and predominately predictive interest here, as well as use of an a priori hierarchical model for entry of initial variables is argued to justify the procedure. Through this procedure, k is restricted to small values relative to the large number of possible IVs.

The series of five stepwise regressions were performed in reverse order to that shown in Table 6. Table 6 indicates the dependent variables for these regressions as I) command reversal, II) crew coordination, III) decision efficiency, IV) decision quality, and V) safety performance.

Variables in the partial model that precede a particular dependent variable were the IVs for that regression. Entering order for the IVs were top-down from left to right. The stepwise regression program employed was BMDP2R (BMDP Statistical Software, 1983) with a minimum acceptable F value (to enter) of 4.00 ($p < .05$) and a maximum acceptable F value (to remove) of 3.90.

Following each of the five basic regression procedures, the partial correlation table for variables not in the equation was consulted to determine which F value to enter above 4, if any. If such a variable was present and logically prior to the dependent variable, another regression, adding this variable, was performed. This procedure was continued until no logically prior variables had an F value above 4 to enter.

Significant IVs were then entered into a final regression by a usual hierarchical procedure - if precedences were strictly established by the model. If not, some alternative paths were usually considered. Regression results are discussed in the order performed. Summary analyses are presented in Tables 6 and 7.

<u>Safety Performance</u> is seen (Table 7) to have 46% of the variance explained. Command reversal - a negatively correlated IV contributes 16%. Decision efficiency contributes 28%. Decision quality contributes 3%.

That decision quality only increments the variance explained by 3% could be due to two considerations. First, the definition of decision efficiency stops not too far short of including decision quality. The second and perhaps most important consideration is based on defining criteria for decision quality versus safety performance and is discussed below.

<u>Decision Quality</u>, considered an alternative substantive dependent variable to safety performance, is seen (Table 7) to have 60% of the variance explained by communications quality (P1) (12%) and decision efficiency (48%).

The suggested rationale for the relative percentages of variance explained for decision quality and safety performance is based on defining criteria for the two variables.

Defining criteria for decision quality were presented at the beginning of the rating effort and considered whether choices were most appropriate based on "safety of flight and/or the attainment of other mission goals." Safety performance ratings were based on the level of safety achieved (or risk avoided) in the end solution for the major scenario problem - or in unsafe attempts to solve the problem by landing at LAX - and criteria were presented only after all the other ratings had been made. Safety performance defining criteria thus excluded any consideration of attaining "other mission goals" - for example that ONT was preferable for passenger handling and was the designated alternate.

Decision Efficiency is seen (Table 7) to have 78% of the variance explained. The explanatory variables and suggested increments in variance explained are decision communications quality (P3) (17%), decision communications quality (P1) (33%), decision command reversal (8%), command reversal (5%), and crew coordination (14%).

This is the first stepwise procedure to be continued beyond the basic regression. Table 6 shows that, prior to these continuations 74% of the variance in decision efficiency was explained by the three variables of the formal partial model - decision communication quality (P1), crew coordination and decision command reversal. The added variables for the entering orders shown, contributed 2% increments of variance respectively. Table 7 however shows that if the flight engineer's decision communications quality were considered logically prior to the other significant variables, it contributes 17% of the variance. The flight engineer's communications concerning the nose gear and fuel is suggested to explain the significance of this variable for decision efficiency.

For most purposes, as will be further discussed below, V9 (command reversal) and V24 (decision command reversal) can be considered to be synonymous - or V24 can be used to assess the generic concept of command reversal, as the model of Figure 1 suggests. In explaining decision efficiency however, V9 increments the variance explained by 5%. Decision command reversal is shown logically prior to command reversal in Figure 7 on the basis of the substantive dependent variables being decision based.

Crew coordination is seen by Table 7 to have 81% of the variance explained. The order of explanatory variables and suggested increments in variance explained is essentially arbitrary. Perhaps the major implication from the regressions in Tables 6 and 7 is that crew coordination has most of its variance explained by a quality variable for each of the three crewmembers: Communications quality (P1), competency-motivation (P2), and competency-motivation (P3). Comparing the regressions in Tables 6 and 7 also indicates that the effect of the communications quality variable essentially nullifies that of task-oriented leadership (P1). For reasons discussed previously, crew cohesiveness, highly correlated with crew coordination, was excluded from entering the stepwise regression equations.

Decision command reversal is shown by Table 6 to have 60% of the variance explained by five variables. In decreasing order of contribution, for the variable order shown, the IVs are task-oriented leadership (P2), decision difficulty, task-oriented leadership (P1), communications quality (P1), and decision participatory leadership (P1). The alternative order shown in the hierarchical procedure in Table 7 has no less an arbitrary variable order than the stepwise procedure of Table 6 and does not contradict the major suggestions from Table 6: The behavioral variables of most importance are the task-oriented leadership variables for the first officer and captain, correlated positively and negatively respectively with command reversal, and accounting for about 28% and 15% increments in variance explained respectively. Considering also the 10% increment of variance explained by decision difficulty, the suggestion is that a combination of low task-oriented captain leader behavior with high task-oriented first officer behavior fosters command reversal, and that this is particularly so as crews get themselves into difficult situations. The other two IVs together account for an 8% increment in variance explained; five percent of which is attributable to the communications quality of the captain, also negatively correlated with command reversal.

As mentioned above, decision command reversal (V24) correlated significantly (.92) with a more general leadership-associated measure of command reversal (V9). Some analyses including a case in which V24 was an independent and a dependent variable, were repeated with V9 substituted for V24. For example, repetition of the preceding stepwise regression, with V9 substituted for V24, produced similar results; All the variance explained was attributable to the first officers' and captains' task-oriented leadership behaviors and decision difficulty: about 35%, 11%, and 5% increments in multiple R squared respectively. A repetition of hierarchical Regression V of Table 7 also produced similar results with V9 substituted for V24. V24 in conjunction with decision efficiency and decision quality explained 46% of the variance in safety performance as opposed to 45% when V9 was substituted -- with 16% contributed by V24 as opposed to 9% contributed by V9. The overall evidence is that V9 and V24 differ little as currently defined and measured.

Although it may be appropriate in this study to consider these two variables as essentially synonymous, such is not necessarily recommended for future work - and improvements in definition may be appropriate.

A summary suggestion from the above series of regression analyses is that major differences for coordination versus decisionmaking pathways in the model are associated with the effect of command reversal for decisionmaking and competency-motivation of the first officer and flight engineer for coordination.

Factor Analysis

A factor analysis with principal components extraction and varimax rotation was performed using BMDP4M (BMDP Statistical Software, 1983). The number of factors was limited to the number of eigenvalues greater than one. Rotated factor loadings for the five orthogonal factors and variance explained by each factor are shown in Table 8.

The highest loadings for factor one (ranging from .844 to .923) clearly cluster captain participatory and person-oriented leadership variables, and captain communications quality variables. Crew cohesiveness, crew coordination, and decision efficiency loadings group separately and load on factor one (.590 to .641) but also load substantially on factors two, three, and four. Task-oriented leadership (P1) is clearly grouped with these three crew variables and also loads substantially on factor 4.

Factor two shows a similar pattern to factor one in that the highest loadings clearly cluster first officer participatory and person-oriented leadership variables, and first officer communications quality variables. Competency-motivation (P2) and task-oriented leadership (P2) group together somewhat separately from the above cluster.

Factor three shows a similar pattern, loading most heavily for flight engineer communications quality and the competency-motivation variables.

Factor four has its highest loadings on the command reversal variables (.842 and .727). The only other positive loading (.619) is for decision difficulty. The important negative loadings are for the substantive dependent measures, flight safety and decision quality; the intermediate performance measures, crew coordination and decision efficiency; and task-oriented leadership (P1).

Factor five loads most heavily on crew friendliness (.574) followed by task-oriented leader behavior of the first officer (.390) and captain (.369), and the negative loading for the first officer's participatory leader behavior in decisionmaking (-.312). It is also of some interest that crew friendliness loads (.522) on factor one - thus at about the same level as does task-oriented leadership (P1).

The outcome of the factor analysis tends to confirm the model structure suggested by regression analysis; adding knowledge concerning the clustering of communications quality variables and other-than-task-oriented leadership variables; and identifying a factor that loads most heavily on crew friendliness. Further factor analyses, and regression analyses using factors, may be appropriate.

Crew Differences

Figure 5, graphically displays the means and SDs for the 16 crews on each of the variables of the partial model - and also for task-oriented leadership (P2). The crew presentation order is on the basis of ratings on safety performance. Table 9 indicates where each crew landed and the amount of fuel on board at landing.

The following two conversations are presented only as examples of communications related to the crew coordination process and to decisionmaking. They are from the crews rated highest and lowest on safety performance (numbers 13 and eight), and exemplify successful coordination and unsuccessful decisionmaking, respectively.

> Captain: Don't forget to fly the airplane
> First officer: Yeah, I am (sounding slightly defensive).
> - pause -
> First officer: Everything's under control.
> Captain: That's your main responsibility.
> First Officer: Yep.

An exchange like the above occured six times between the captain and first officer of crew 13 during this flight leg. This particular clarification of responsibility occured while both the captain and first officer were copying weather.

> Captain: (On approach to LAX) We're going to land this way. Tell him to get the fire trucks,

we're probably going to smear the nose wheel.
First officer: (To ATC) We-ah-could have a problem with our nose gear, so be aware of that please.
Captain: (continues approach)
First officer: We don't have the green light on our nose gear. Ah we'll continue the approach.
Captain: If that 12K (referring to 12,000 lbs of fuel) is realistic, we don't need to smear this thing.

This conversation occurred within crew eight, a crew for which members appeared to function very independently of each other (see their low coordination rating on Figure 5). In this conversation the last stated insight of the captain received no support from other crewmembers and the aircraft was landed unsafely at LAX.

Concluding Statement

A start has been made on the development of a model of crew coordination and decisionmaking. The inclusion of decision efficiency and command reversal as variables in the model appear to be useful advances in conceptualizing the crew performance process. Some insight was suggested on the dynamics of command reversal: Relatively low and high task-oriented leader behavior of the captain and first officer respectively - especially as the situation becomes difficult appears to be the leading impetus to the occurrence of command reversal. Task-oriented leadership thus appears to be distinguished some from person-oriented or participatory leadership. The latter leader behavior variables are shown by factor analysis to cluster closely with communications quality variables.

Both regression and factor analyses suggest the important effects of all three crewmember behavioral qualities on crew coordination and, through different pathways, on decision efficiency. Both analyses also suggest the important effects of command reversal in decision pathways - on decision efficiency and quality variables, and on safety performance. As outcome variables decision quality is seen to have more variance explained (60%) than did safety performance (46%). The reason is suggested to be that the defining criteria for decision quality ratings are more inclusive, considering not only safety of flight but also the attainment of other mission goals - and were available to raters throughout the rating effort.

Significant decreases in the ratings of leader behaviors and communications qualities occurred for both the captain and first officer, for the major problem segment as opposed to the pre-problem (take off and cruise to LAX) segment. Similar decreases occured for crew coordination, cohesiveness, and friendliness - but not for command reversal and competency-motivation of the first officer and flight engineer. It is perhaps significant for command reversal that the only leader behavior not rated lower on the major problem (as opposed to the pre-problem) segment was the first officers' task-oriented leadership.

One of the five orthogonal factors loaded most heavily for crew friendliness. However, the validity of crew cohesiveness as a substantial measure as defined and used in this study was questioned.

The rating of videotapes appear to have considerable promise in developing crew performance models. A suggested improvement on this study is the inclusion of a display of systems information, such as airspeed, altitude, fuel remaining, etc., adjacent to the video display. Such a display should reduce error variance in crew process ratings, and permit addition to the model of a variable, paralleling decision quality, assessing flight task execution quality.

Considerable reduction in error variance should also be realized through refinement of variables and/or their defining criteria, through improvements in rater training made possible by these videotapes, and through improvements in data generation and rating procedures.

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References

Cooper, G. E., & White, M. D., & Lauber, J. K. (Eds.). (1980). Resource management on the flight deck. Proceedings of a NASA/Industry Workshop. Moffett Field, Ca.: NASA Ames Research Center.

Dixon, W.J., & Brown, M. B., & Engelman, L., & Frane, J. W., & Hill, M. A., & Jennrich. R. I, & Toporek, J. D. (Eds.). (1983). BMDP Statistical Software (rev. ed.). Berkely: University of California Press.

Foushee, H. C. & Manos, K. L. (1981). Information transfer within the cockpit: Problems in intracockpit communications. In C. E. Billings & E. S. Cheaney (Eds.) Information transfer problems in the aviation system. (Report No. NASA TP-1875). Washington, DC: National Aeronautics and Space Adminstration.

Frankel, R. M., & Beckman, H. B. (1982). Impact: an interaction-based method for preserving and analyzing clinical transactions. In L.S. Pettegrew (Ed.), Explorations in provider and patient interaction (pp. 71-85). Humana Inc.

Goguen, J. Linde, C., & Murphy, M. (1984) Crew communication as a factor in aviation accidents. In E J. Hartzell & S. Hart (Eds.), Papers from the 20th Annual Conference on Manual Control, 2, (pp. 217-248). Moffett Field, CA: NASA, Ames Research Center.

Hackman, J. R. & Morris, C. G. (1975). Group tasks, group interaction process, and group performance effectiveness: A review and proposed integration. In L. Berkowitz (Ed.), Advances in experimental social psychology (Vol. 8, pp 45-99). New York: Academic Press.

House, R. J. (1984). Commentary on management research. In A. P. Brief (Ed.), Productivity research in the behavioral and social sciences (pp. 268-282). New York: Praeger.

House, R. J., & Baetz, M. L. (1979). Leadership: Some empirical generalizations and new research directions. Research and organizational behavior (Vol. 1, pp. 341-423). JAI Press Inc.

Kerr, S. (1984). Leadership and participation. In A. P. Brief (Ed.), Productivity research in the behavioral and social sciences (pp. 229-251). New York: Praeger.

Landy, F. J., & Farr, J. L. (1980). Performance rating.

Psychological Bulletin, *87*, 72-107.

Landy, F. J., & Farr, J. L. (1983). *The measurement of work performance*. New York: Academic Press.

Murphy, M. R. (1977). Coordinated crew performance in commercial aircraft operations. *Proceedings of the 21st Human Factors Society Annual Meeting*, 416-420.

Murphy, M. R. (1980). Analysis of eighty-four commercial aviation incidents: implications for a resource management approach to crew training. *1980 Proceedings Annual Reliablility and Maintainability Symposium*, 298-306.

National Transportation Safety Board, Special Study. (1976). *Flight crew coordination procedures in air carrier instrument landing system approach accidents* (Report No. NTSB-AAS-76-5). Washington, DC: National Transportation and Safety Board.

Ruffell Smith, H.P. (1979). *A simulator study of the interaction of pilot workload with errors, vigilance, and decisions* (Report No. NASA TM-78482). Washington DC: National Aeronautics and Space Adminstration.

Table 1

Concept-Variable Relationships

Concept	*Referent	Var. No.	**Instrument
a. Task-Oriented Leadership	P1,P2	1,3	CP
b. Person-Oriented Leadership	P1,P2	2,4	CP
c. Participatory Leadership	P1,P2	5,6	CP
		19,20	DM
d. Competency-Motivation	P2,P3	7,8	CP
e. Command Reversal	P1-P2	9	CP
		24	DM
f. Crew Cohesiveness	Crew	10	CP
g. Crew Coordination	Crew-Task	11	CP
h. Crew Friendliness	Crew	12	CP
i. Communications Quality	P1,P2,P3	13,14,15	CP
		21,22,23	DM
j. Decision Difficulty	Situation	16	DM
k. Decision Quality	Crew Outcome	17	DM
l. Decision Efficiency	Crew-Task	18	DM
m. Safety Performance	Crew Outcome	25	SP

*P1 = Captain, P2 = First Officer, P3 = Flight Engineer
**CP = Crew Process, DM = Decision Making, SP = Safety Performance

Table 2

Variable Reliabilities Determined by Spearman-Brown Formula for Multiple r

No.	r	No.	r	No.	r	No.	r	No.	r
1	.91	6	.87	11	.96	16	.88	21	.89
2	.93	7	.93	12	.90	17	.93	22	.86
3	.78	8	.96	13	.94	18	.94	23	.92
4	.90	9	.96	14	.92	19	.88	24	.95
5	.92	10	.96	15	.96	20	.84	25	.99

Table 3

Changes in Crew Process Variable Means Across Segments

No.	Name	Means for Segments 1	2	3	~Decrease 1 to 2	1 to 3	Overall Mean	SD
1	Task-Oriented Leadership (P1)	5.08	4.71	4.56	*.37	**.52	4.79	1.28
2	Person-Oriented Leadership (P1)	4.48	3.93	3.91	**.55	**.57	4.11	1.32
3	Task-Oriented Leadership (P2)	4.97	4.91	4.86	ns	ns	4.92	1.01
4	Person-Oriented Leadership (P2)	4.72	4.34	4.30	*.38	**.42	4.46	1.09
5	Participatory Leadership (P1)	4.71	3.91	3.84	**.80	**.87	4.16	1.47
6	Participatory Leadership (P2)	4.91	4.13	4.38	**.78	**.53	4.48	1.18
7	Competency-Motivation (P2)	5.10	4.87	4.98	ns	ns	4.99	1.29
8	Competency-Motivation (P3)	4.50	4.15	4.42	ns	ns	4.36	1.34
9	Command Reversal	3.60	3.86	3.81	ns	ns	3.76	1.59
10	Crew Cohesiveness	4.56	3.89	4.02	**.67	*.54	4.16	1.56
11	Crew Coordination	4.49	3.86	3.83	**.63	**.66	4.07	1.57
12	Crew Friendliness	4.83	4.35	4.49	**.48	*.34	4.55	1.03
13	Communications Quality (P1)	4.82	4.17	4.06	**.65	**.76	4.36	1.51
14	Communications Quality (P2)	4.97	4.53	4.53	*.44	*.44	4.68	1.23
15	Communications Quality (P3)	4.53	4.14	4.44	ns	ns	4.37	1.19

*Difference significant ($p<.05$)
**Difference significant ($p<.01$)
~Differences between segments 2 and 3 means were not significant ($p>.10$)

Table 4

Means of Decisionmaking Variables for the Eight Decisions

No.	Name	Decision Number 1 Mean	2 Mean	3 Mean	4 Mean	5 Mean	6 Mean	7 Mean	8 Mean	Overall Mean	SD
16	Decision Difficulty	3.11	2.21	4.23	3.24	3.89	3.41	2.49	2.54	3.16	1.45
17	Decision Quality	4.54	6.11	3.97	5.10	4.71	4.77	5.65	4.29	4.86	1.65
18	Decision Efficiency	3.84	4.52	3.18	3.32	3.18	3.43	4.38	3.48	3.65	1.72
19	Decision Participatory Leadership(P1)	4.65	4.05	3.78	3.75	3.77	3.55	3.63	3.53	3.86	1.42
20	Decision Participatory Leadership(P2)	4.65	4.24	4.26	4.11	4.20	3.75	3.70	4.27	4.20	1.25
21	Decision Communications Quality(P1)	4.52	4.50	3.85	3.96	4.01	3.97	3.97	3.77	4.08	1.42
22	Decision Communications Quality(P2)	4.83	4.44	4.23	4.18	4.39	3.88	4.22	4.36	4.34	1.22
23	Decision Communications Quality(P3)	4.26	4.19	4.00	3.74	3.81	4.04	3.92	4.07	4.01	1.21
24	Decision Command Reversal	3.53	3.36	3.58	3.78	3.69	3.05	2.82	3.54	3.45	1.56

Table 5

Correlation Matrix

		1	2	3	4	5	6	7
1	Task-Oriented Leadership (P1)	1.0000	0.4768	0.2226	0.1267	0.4425	0.0883	0.2476
2	Person-Oriented Leadership (P1)	0.4768	1.0000	0.2164	0.1652	0.8170	0.1622	0.3990
3	Task-Oriented Leadership (P2)	0.2226	0.2164	1.0000	0.4983	0.1629	0.6470	0.6412
4	Person-Oriented Leadership (P2)	0.1267	0.1652	0.4983	1.0000	0.1857	0.6880	0.5766
5	Participatory Leadership (P1)	0.4425	0.8170	0.1629	0.1857	1.0000	0.2756	0.4206
6	Participatory Leadership (P2)	0.0883	0.1622	0.6470	0.6880	0.2756	1.0000	0.6969
7	Competency-Motivation (P2)	0.2476	0.3990	0.6412	0.5766	0.4206	0.6969	1.0000
8	Competency-Motivation (P3)	0.2311	0.2353	0.5283	0.4028	0.2783	0.4666	0.6182
9	Command Reversal	-0.3241	-0.1315	0.5005	0.2427	-0.0368	0.4061	0.2668
10	Crew Cohesiveness	0.5528	0.6368	0.4442	0.4076	0.6549	0.4730	0.7436
11	Crew Coordination	0.5453	0.6145	0.4031	0.3523	0.6693	0.4490	0.6816
12	Crew Friendliness	0.5144	0.6676	0.4290	0.5288	0.5224	0.3034	0.4509
13	Communications Quality (P1)	0.5785	0.7998	0.1434	0.1581	0.7992	0.2367	0.4499
14	Communications Quality (P2)	0.2790	0.3028	0.6137	0.6432	0.3012	0.7007	0.8098
15	Communications Quality (P3)	0.1310	0.1635	0.4760	0.3340	0.1988	0.3686	0.4803
16	Decision Difficulty	-0.2881	-0.0472	-0.1302	-0.0734	0.0171	-0.0074	-0.0581
17	Decision Quality	0.3888	0.2913	0.1722	0.1186	0.3210	0.2309	0.3343
18	Decision Efficiency	0.5639	0.5157	0.2518	0.2533	0.5957	0.3701	0.5638
19	Decision Participatory Leadership (P1)	0.3334	0.6917	0.1798	0.2087	0.8276	0.3105	0.3989
20	Decision Participatory Leadership (P2)	-0.0892	0.0716	0.5180	0.6101	0.2010	0.7667	0.5593
21	Decision Communications Quality (P1)	0.4759	0.7191	0.1516	0.1716	0.7559	0.3080	0.4683
22	Decision Communications Quality (P2)	0.0263	0.2107	0.5025	0.5399	0.2720	0.7214	0.6524
23	Decision Communications Quality (P3)	-0.0085	0.1907	0.3125	0.2250	0.2330	0.3393	0.4156
24	Decision Command Reversal	-0.3853	-0.0992	0.4257	0.1760	-0.0242	0.2978	0.2035
25	Safety Performance	0.4094	0.2673	0.0935	0.1517	0.2988	0.1998	0.2358

	8	9	10	11	12	13	14	15	16
1	0.2311	-0.3241	0.5528	0.5453	0.5144	0.5785	0.2790	0.1310	-0.2881
2	0.2353	-0.1315	0.6368	0.6145	0.6676	0.7998	0.3028	0.1635	-0.0472
3	0.5283	0.5005	0.4442	0.4031	0.4290	0.1434	0.6137	0.4760	-0.1302
4	0.4028	0.2427	0.4076	0.3523	0.5288	0.1581	0.6432	0.3340	-0.0734
5	0.2783	-0.0368	0.6549	0.6693	0.5224	0.7992	0.3012	0.1980	0.0171
6	0.4666	0.4061	0.4730	0.4490	0.3034	0.2367	0.7007	0.3686	-0.0074
7	0.6182	0.2668	0.7436	0.6816	0.4509	0.4499	0.8098	0.4803	-0.0581
8	1.0000	0.1852	0.6868	0.6674	0.3927	0.2925	0.5268	0.8686	-0.1803
9	0.1852	1.0000	-0.1056	-0.0744	-0.0973	-0.2549	0.1687	0.2174	0.2703
10	0.6868	-0.1056	1.0000	0.9337	0.6295	0.7539	0.6731	0.5342	-0.2410
11	0.6674	-0.0744	0.9337	1.0000	0.5603	0.7427	0.6035	0.5090	-0.2232
12	0.3927	-0.0973	0.6295	0.5603	1.0000	0.5777	0.5048	0.3409	-0.2322
13	0.2925	-0.2549	0.7539	0.7427	0.5777	1.0000	0.4069	0.1687	-0.0831
14	0.5268	0.1687	0.6731	0.6035	0.5048	0.4069	1.0000	0.4085	-0.1853
15	0.8686	0.2174	0.5342	0.5090	0.3409	0.1687	0.4085	1.0000	-0.0999
16	-0.1803	0.2703	-0.2410	-0.2232	-0.2322	-0.0831	-0.1853	-0.0999	1.0000
17	0.3928	-0.1437	0.4780	0.5461	0.2237	0.3488	0.2307	0.3937	-0.2500
18	0.5054	-0.1928	0.7727	0.8206	0.4375	0.6528	0.4606	0.4115	-0.2305
19	0.2867	0.0970	0.5673	0.5362	0.4385	0.6437	0.3062	0.2471	0.0185
20	0.4559	0.4838	0.3379	0.2861	0.1641	0.1188	0.5573	0.4000	0.0772
21	0.2915	-0.1446	0.6917	0.6836	0.4168	0.7938	0.4040	0.1928	-0.1462
22	0.4775	0.3584	0.4748	0.4160	0.2638	0.2916	0.7287	0.4394	-0.0189
23	0.6974	0.2541	0.4362	0.4025	0.1611	0.1368	0.2508	0.7797	0.0571
24	0.1534	0.9198	-0.1259	-0.1286	-0.1112	-0.2500	0.0934	0.1851	0.3729
25	0.2707	-0.3049	0.4166	0.4589	0.2828	0.2891	0.1591	0.2059	-0.3415

	17	18	19	20	21	22	23	24	25
1	0.3088	0.5639	0.3334	-0.0892	0.4759	0.0263	-0.0085	-0.3853	0.4094
2	0.2913	0.5157	0.6917	0.0716	0.7191	0.2107	0.1907	-0.0992	0.2673
3	0.1722	0.2518	0.1798	0.5180	0.1516	0.5025	0.3125	0.4257	0.0935
4	0.1186	0.2533	0.2087	0.6101	0.1716	0.5399	0.2250	0.1760	0.1517
5	0.3210	0.5957	0.8276	0.2010	0.7559	0.2720	0.2330	-0.0242	0.2988
6	0.2309	0.3701	0.3105	0.7667	0.3080	0.7214	0.3393	0.2978	0.1998
7	0.3343	0.5638	0.3989	0.5593	0.4683	0.6524	0.4156	0.2035	0.2358
8	0.3928	0.5054	0.2867	0.4559	0.2915	0.4775	0.6974	0.1534	0.2707
9	-0.1437	-0.1928	0.0970	0.4838	-0.1446	0.3584	0.2541	0.9198	-0.3049
10	0.4780	0.7727	0.5673	0.3379	0.6917	0.4748	0.4362	-0.1259	0.4166
11	0.5461	0.8206	0.5362	0.2861	0.6836	0.4160	0.4025	-0.1286	0.4589
12	0.2237	0.4375	0.4385	0.1641	0.4168	0.2638	0.1611	-0.1112	0.2828
13	0.3488	0.6528	0.6437	0.1188	0.7938	0.2916	0.1368	-0.2500	0.2891
14	0.2307	0.4606	0.3062	0.5573	0.4040	0.7287	0.2508	0.0934	0.1591
15	0.3937	0.4115	0.2471	0.4000	0.1928	0.4394	0.7797	0.1851	0.2059
16	-0.2500	-0.2305	0.0185	0.0772	-0.1462	-0.0189	0.0571	0.3729	-0.3415
17	1.0000	0.7533	0.3305	0.1409	0.4453	0.2104	0.3852	-0.2444	0.5795
18	0.7533	1.0000	0.5490	0.2096	0.6876	0.3484	0.4180	-0.2963	0.6204
19	0.3305	0.5490	1.0000	0.4071	0.8041	0.4429	0.4047	0.1368	0.2742
20	0.1409	0.2096	0.4071	1.0000	0.3301	0.8384	0.4975	0.4817	0.1215
21	0.4453	0.6876	0.8041	0.3301	1.0000	0.4762	0.3554	-0.1437	0.4184
22	0.2104	0.3484	0.4429	0.8384	0.4762	1.0000	0.5020	0.3382	0.0959
23	0.3052	0.4180	0.4047	0.4975	0.3554	0.5020	1.0000	0.2871	0.2649
24	-0.2444	-0.2963	0.1368	0.4817	-0.1437	0.3382	0.2871	1.0000	-0.3979
25	0.5795	0.6204	0.2742	0.1215	0.4184	0.0959	0.2649	-0.3979	1.0000

Correlations at or above .267 are significant for n=90 df.

Table 6

Stepwise Regression Analysis Summaries

Step	Variable Entered	Variable Removed	Multiple R	RSQ	Change in RSQ
I DECISION COMMAND REVERSAL (V24)					
1	13.Communications Quality(P1)		.2500	.0625	.0625
2	1.Task-Oriented Leadership(P1)		.3867	.1496	.0871
3		13	.3853	.1485	-.0011
4	3.Task-Oriented Leadership(P2)		.6509	.4237	.2752
5	16.Decision Difficulty		.7216	.5207	.0970
6	19.Decision Participatory Leadership(P1)		.7441	.5537	.0330
7	13.Communications Quality(P1)		.7774	.6043	.0506
II CREW COORDINATION (V11)					
1	1.Task-Oriented Leadership(P1)		.5453	.2973	.2973
2	21.Decision Communications Quality(P1)		.7279	.5299	.2325
3	7.Competency-Motivation(P2)		.8313	.6910	.1611
4	8.Competency-Motivation(P3)		.8794	.7734	.0824
5	24.Decision Command Reversal		.8857	.7844	.0110
6	13.Communications Quality(P1)		.9053	.8196	.0352
7		24	.9024	.8144	-.0053
8		21	.8991	.8083	-.0060
III DECISION EFFICIENCY (V18)					
1	1.Task-Oriented Leadership(P1)		.5639	.3180	.3180
2	21.Decision Communications Quality(P1)		.7384	.5452	.2272
3	11.Crew Coordination		.8461	.7158	.1706
4	24.Decision Command Reversal		.8591	.7380	.0221
5		1	.8577	.7357	-.0023
6	23.Decision Communications Quality(P3)		.8720	.7604	.0247
7	9.Command Reversal		.8849	.7831	.0228
IV DECISION QUALITY (V17)					
1	1.Task-Oriented Leadership(P1)		.3888	.1512	.1512
2	21.Decision Communications Quality(P1)		.4886	.2387	.0875
3	11.Crew Coordination		.5627	.3167	.0779
4		21	.5568	.3101	-.0066
5		1	.5461	.2983	-.0118
6	24.Decision Command Reversal		.5737	.3291	.0308
7	18.Decision Efficiency		.7638	.5834	.2543
8		11	.7536	.5680	-.0154
9		24	.7533	.5675	-.0005
10	13.Communications Quality(P1)		.7766	.6031	.0356
V SAFETY PERFORMANCE (V25)					
1	1.Task-Oriented Leadership(P1)		.4094	.1676	.1676
2	21.Decision Communications Quality(P1)		.4819	.2323	.0646
3	24.Decision Command Reversal		.5539	.3068	.0745
4		1	.5400	.2915	-.0152
5	11.Crew Coordination		.5841	.3412	.0496
6		21	.5721	.3274	-.0138
7	18.Decision Efficiency		.6610	.4369	.1095
8		11	.6597	.4352	-.0017
9	17.Decision Quality		.6795	.4617	.0266

Table 7

Hierarchical Regression Analysis Summaries

Variable Entered	Multiple R	RSQ	Change in RSQ
I DECISION COMMAND REVERSAL (V24)			
16. Decision Difficulty	.3729	.1391	.1391
19. Decision Participatory Leadership(P1)	.3949	.1559	.0169
3. Task-Oriented Leadership(P2)	.6080	.3697	.2137
13. Communications Quality(P1)	.7323	.5363	.1660
1 .Task-Oriented Leadership(P1)	.7774	.6043	.0680
II CREW COORDINATION (V11)			
13. Communications Quality(P1)	.7427	.5516	.5516
1. Task-Oriented Leadership(P1)	.7561	.5717	.0201
7. Competency-Motivation(P2)	.8515	.7251	.1534
8. Competency-Motivation(P3)	.8991	.8083	.0833
III DECISION EFFICIENCY (V18)			
23. Decision Communications Quality(P3)	.4180	.1747	.1747
21. Decision Communications Quality(P1)	.7122	.5073	.3326
24. Decision Command Reversal	.7680	.5898	.0825
9. Command Reversal	.8012	.6419	.0520
11. Crew Coordination	.8849	.7831	.1412
IV DECISION QUALITY (V17)			
13. Communications Quality(P1)	.3488	.1216	.1216
18. Decision Efficiency	.7766	.6031	.4814
V SAFETY PERFORMANCE (V25)			
24. Decision Command Reversal	.3979	.1583	.1583
18. Decision Efficiency	.6597	.4352	.2769
17. Decision Quality	.6795	.4617	.0266

Table 8

Factor Analysis Using Principal Components and Varimax Rotation

VARIABLES	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5
5. Participatory Leadership (P1)	Ø.923	Ø.	Ø.	Ø.	Ø.
2. Person-Oriented Leadership (P1)	Ø.888	Ø.	Ø.	Ø.	Ø.
13. Communications Quality (P1)	Ø.882	Ø.	Ø.	Ø.	Ø.
21. Decision Communications Quality (P1)	Ø.846	Ø.	Ø.	Ø.	Ø.
19. Decision Participatory Leadership (P1)	Ø.844	Ø.	Ø.	Ø.	Ø.
10. Crew Cohesiveness	Ø 641	Ø.393	Ø.4Ø9	-Ø.3Ø6	Ø.252
11. Crew Coordination	Ø.639	Ø.333	Ø.43Ø	-Ø.327	Ø.
18. Decision Efficiency	Ø.59Ø	Ø.	Ø.4Ø6	-Ø.517	Ø.
1. Task-Oriented Leadership (P1)	Ø.5Ø5	Ø.	Ø.	-Ø.479	Ø.369
6. Participatory Leadership (P2)	Ø.	Ø.882	Ø.	Ø.	Ø.
20. Decision Participatory Leadership (P2)	Ø..	Ø.812	Ø.	Ø.	-Ø.312
14. Communications Quality (P2)	Ø.	Ø.812	Ø.	Ø.	Ø.
22. Decision Communications Quality (P2)	Ø.	Ø.8Ø1	Ø.	Ø.	Ø.
4. Person-Oriented Leadership (P2)	Ø.	Ø.794	Ø.	Ø.	Ø.
7. Competency-Motivation (P2)	Ø.356	Ø.711	Ø.324	Ø.	Ø.
3. Task-Oriented Leadership (P2)	Ø.	Ø.657	Ø.341	Ø.	Ø.39Ø
15. Communications Quality (P3)	Ø.	Ø.255	Ø.889	Ø.	Ø.
23. Decision Communications Quality (P3)	Ø.	Ø.	Ø.836	Ø.	Ø.
8. Competency-Motivation (P3)	Ø.	Ø.368	Ø.814	Ø.	Ø.
24. Decision Command Reversal	Ø.	Ø.315	Ø.	Ø.842	Ø.
9. Command Reversal	Ø.	Ø.4Ø8	Ø.	Ø.727	Ø.
25. Safety Performance	Ø.254	Ø.	Ø.258	-Ø.671	Ø.
16. Decision Difficulty	Ø.	Ø.	Ø.	Ø.619	Ø.
17. Decision Quality	Ø.3ØØ	Ø.	Ø.482	-Ø.528	Ø.
12. Crew Friendliness	Ø.525	Ø.3Ø8	Ø.	Ø.	Ø.574
VARIANCE EXPLAINED	6.Ø83	5.393	3.513	3.3Ø4	1.483

Loadings less than 0.2500 have been replaced by zero

Table 9

Airport of Landing and Fuel Remaining at Landing

Crew No.	Airport	*Fuel Klbs	Crew No.	Airport	*Fuel Klbs
1	PMD	6.2	9	PMD	2.9
2	PMD	7.9	10	ONT	2.0
3	ONT	3.5	11	PMD	7.5
4	ONT	4.6	12	PMD	8.9
5	ONT	3.4	13	PMD	7.7
6	PMD	6.0	14	PMD	2.8
7	ONT	4.0	15	PMD	9.8
8	LAX	8.8	16	PMD	5.4

* Accuracy of fuel remaining = +/- 10%

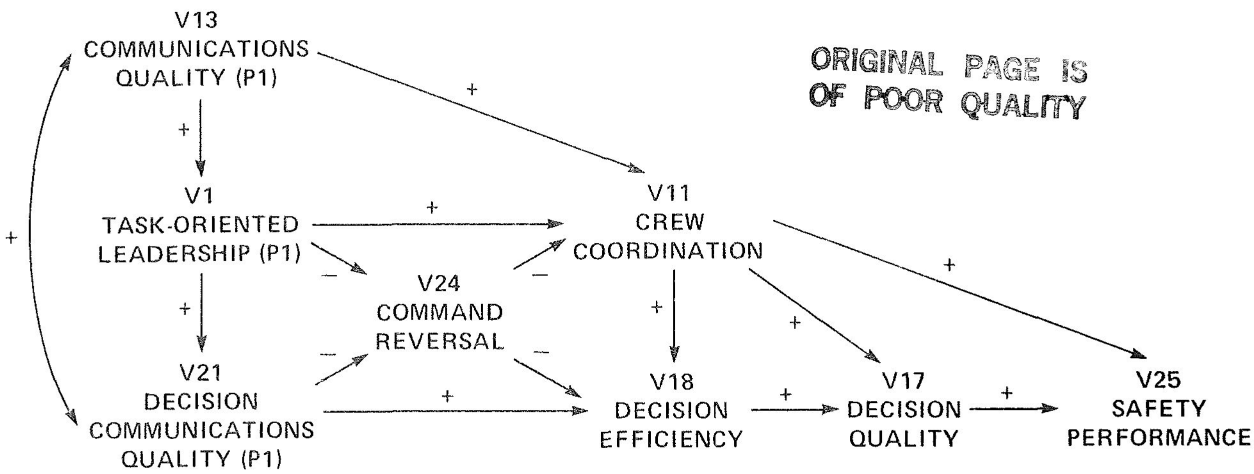

Fig. 1 Partial Model of Crew Coordination and Decisionmaking

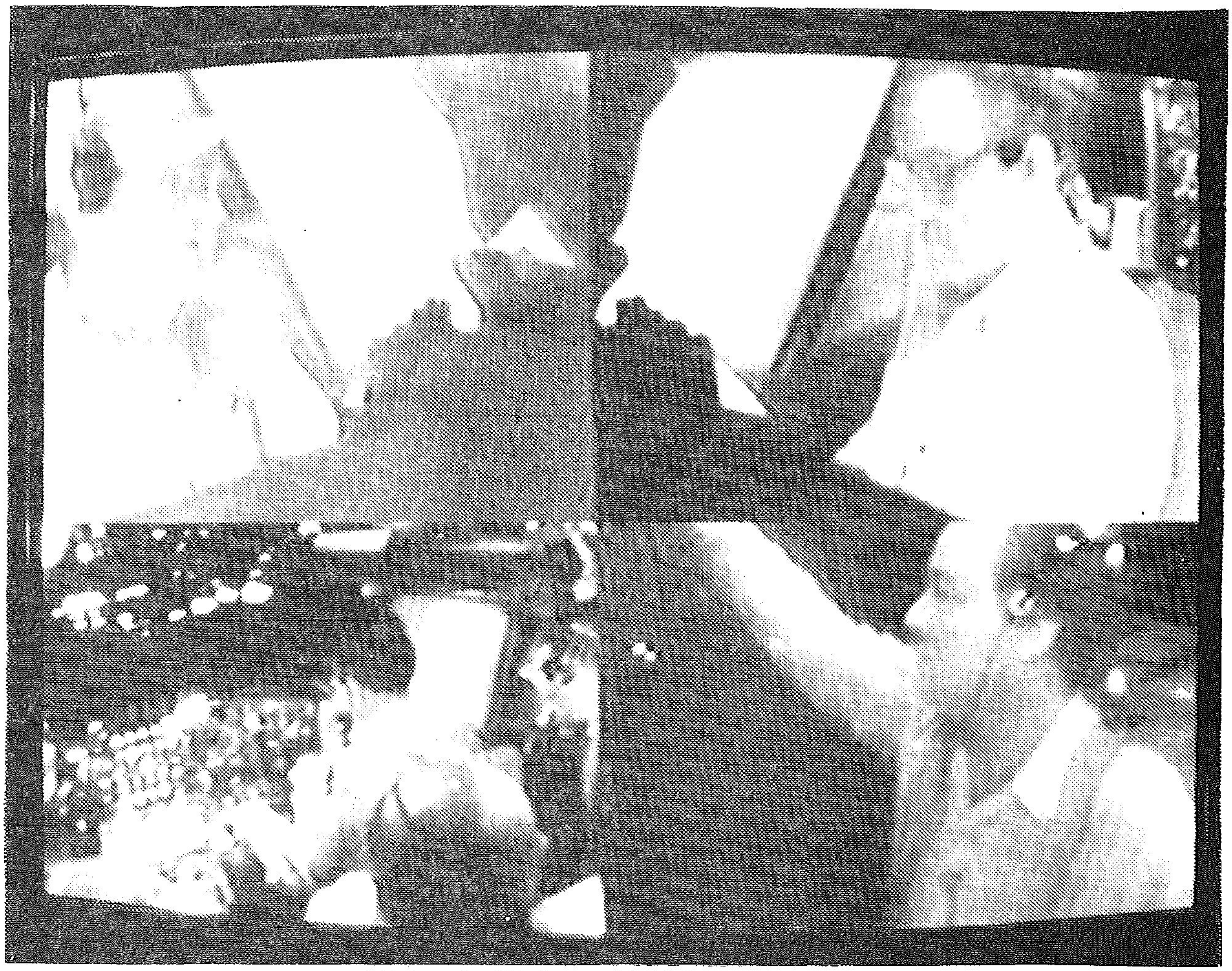

Fig. 2 Video Still Frame

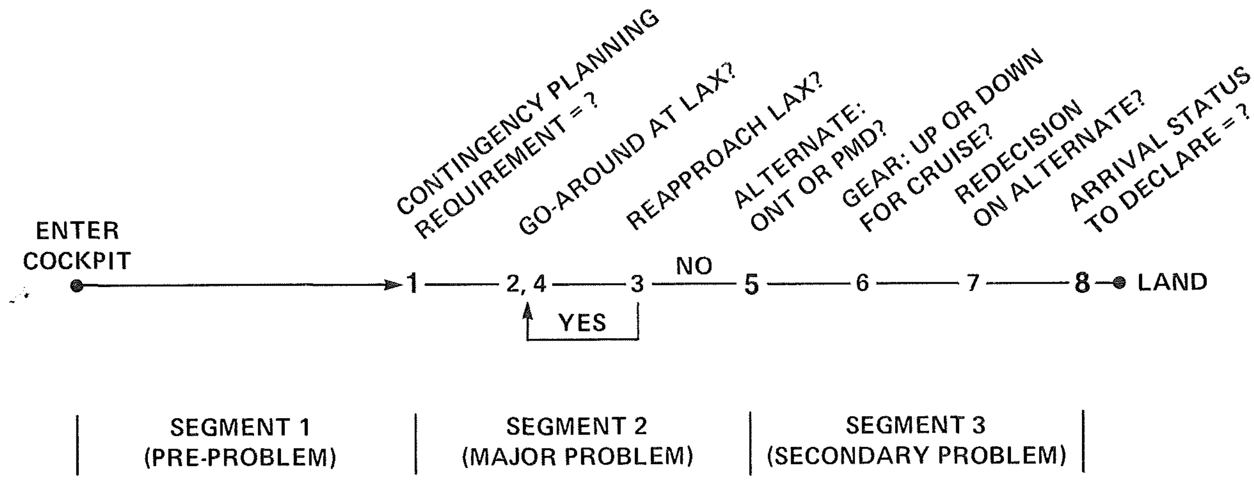

Fig. 3 Videotape Stopping Points for Decisionmaking and Crew Process Ratings

THE DECISION PROCESS WAS VERY EFFICIENT

STRONGLY DISAGREE 1 2 3 4 5 6 7 STRONGLY AGREE

(ALL SIGNIFICANT INFORMATION WAS ACQUIRED AT AN OPPORTUNE TIME, ADEQUATELY EVALUATED, AND APPROPRIATELY UTILIZED)

COMMENT:

Fig. 4 Rating Scale Example

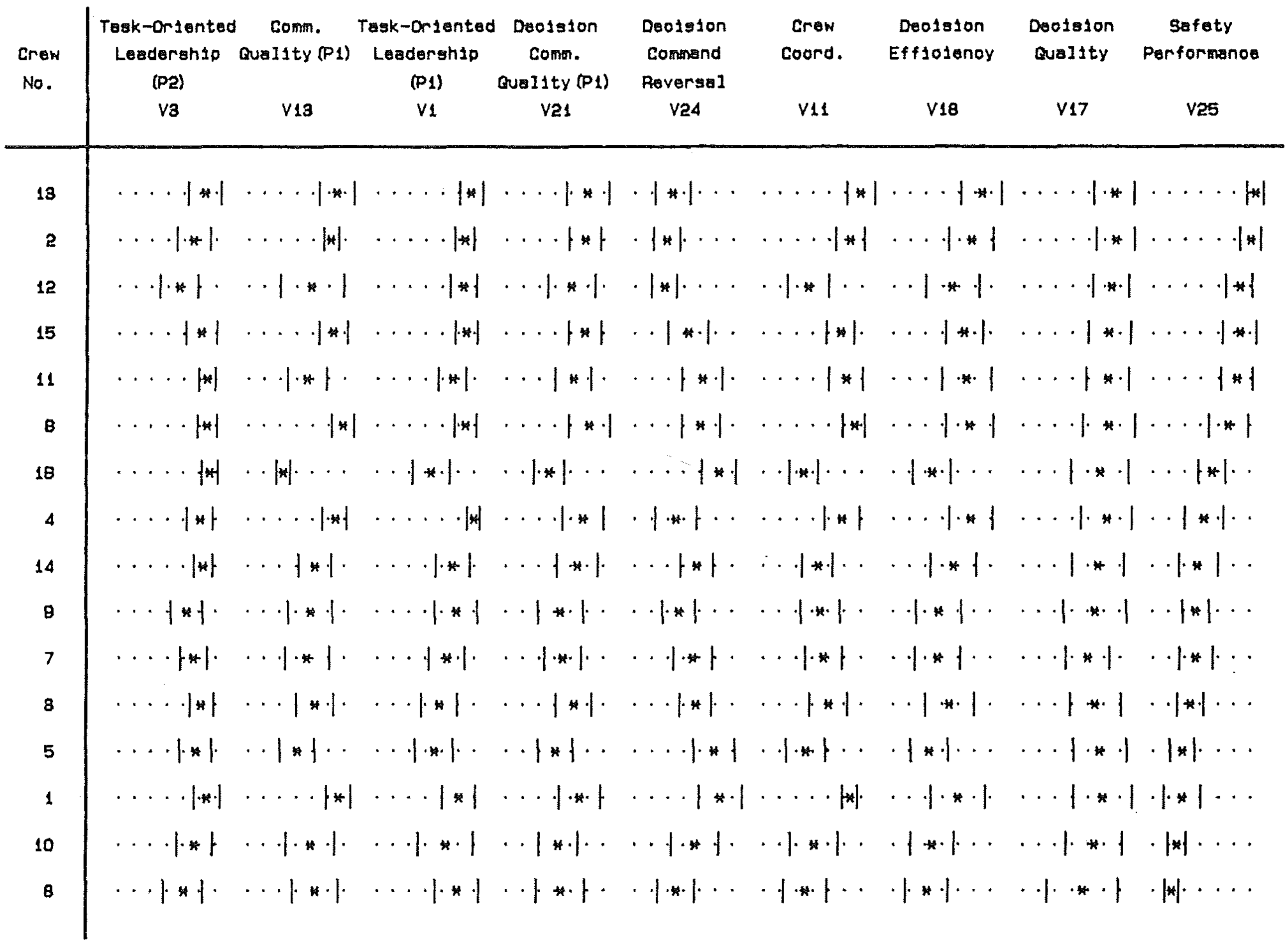

Fig.5 Means and Sds of Sixteen Crews on Variables of Model - Descending Order of Performance on V25 (Safety Performance)

Appendix A

Scale and Criterion Statements for Variables - Ordered by Concepts

a. Task-Oriented Leadership/Variables 1 and 3:
The CAPTAIN'S (FIRST OFFICER'S) leader behavior was highly task-oriented. (His behavior was highly concerned with establishing goals, clarifying responsibilities, defining *subordinate roles and task requirements, coaching subordinates and providing task related feedback and evaluation)

b. Person-Oriented Leadership/Variables 2 and 4:
The CAPTAIN'S (FIRST OFFICER'S) leader behavior was highly sociomotively-oriented. (His behavior was highly concerned with establishing and maintaining positive crewmember relationships, providing psychological support, enabling feelings of satisfaction, making tasks interesting or enjoyable)

c. Participatory Leadership/Variables 5 and 6:
The CAPTAIN'S (FIRST OFFICER'S) leader behavior was highly participative in regard to supervision/resources management. (His behavior was highly concerned with encouraging subordinates to make suggestions regarding accomplishment of tasks, to independently analyze problems, to give feedback, and to question the leader)

Participatory Leadership/Variables 19 and 20:
The CAPTAIN'S (FIRST OFFICER'S) leader behavior was highly participative in regard to decisionmaking. (His behavior was highly concerned with ensuring that all crewmembers for whom a decision was relevant had a chance to influence that decision -i.e. those crewmembers who had significant and pertinent information, responsibility to implement the decision, or significant ego involvement for other reasons)

d. Competency-Motivation/Variables 7 and 8:
The FIRST OFFICER (FLIGHT ENGINEER) exhibited high competence and willingness to be responsible with respect to fulfilling the requirements of his position. (appeared highly knowledgeable, skillful, and motivated in his behavior and task performance)

e. Command Reversal/Variable 9:
The FIRST OFFICER performed much of what would generally be the captain's leadership function. (whether due to acquiescence of the captain or dominance of the first officer)

Command Reversal/Variable 24:
The FIRST OFFICER performed much or what would generally be the captain's decisionmaking function. (same criterion statement)

f. Crew Cohesiveness/Variable 10:
The CREW functioned in a highly cohesive manner. (showed high crew solidarity or harmony; i.e. appeared well integrated into a unit)

g. Crew Coordination/Variable 11:
ACTIVITIES OF CREWMEMBERS were well coordinated to task and situation demands. (individual crewmember knowledge and skills were allocated in an effective and timely manner to meet task and situation demands)

h. Crew Friendliness/Variable 12:
The CREWMEMBERS related in a highly friendly manner. (interactions were most usually accompanied by verbal and/or non-verbal signs of friendliness, or warmth)

i. Communications Quality/Variables 13,14,15:
The CAPTAIN (FIRST OFFICER,FLIGHT ENGINEER) exhibited very good within-crew communications. (highly hearable, understandable, appropriate - in style and content, accurate and timely messages; good listener who made effort to understand; achieved reciprocal indication that understanding was reached)

Communications Quality/Variables 21, 22, 23:
The CAPTAIN (FIRST OFFICER,FLIGHT ENGINEER) exhibited very good within-crew communications in regard to decisionmaking. (same criterion statement)

j. Decision Difficulty/Variable 16:
The DECISION was a very difficult one. (involved complex, interacting operational factors - some of which may have been contingent on uncertain future events; or conflicting goals of safety, operational efficiency, company and/or ATC requirements - or preferences)

k. Decision Quality/Variable 17:
The CHOICE (or outcome of the decision process) was most appropriate. (the best choice considering safety of flight and/or the attainment of other mission goals)

l. Decision Efficiency/Variable 18:
The DECISION PROCESS was very efficient. (all significant information was acquired at an opportune time, adequately evaluated, and appropriately utilized)

m. Safety Performance/Variable 25:
The LEVEL OF SAFETY achieved through this crew's performance, considering the major scenario problem and any **special circumstances(s), was very high.(based on: safety of approach (es) to LAX; the airport of landing - considering differential risks of LAX,ONT,and PMD; fuel-on-board at touchdown - considering go-around and go-to-another-alternate fuel requirements, as well as additional fuel for a reasonable margin of safety)

*The word "subordinate" was used in referring to "other crewmembers" only in reference to the captain's leadership role. The latter phrase, or a derivative, was used throughout in reference to the first officer's leadership role.
**See Appendix B for a discussion of these special circumstances.

Appendix B

Data Quality

For many reasons scenario conditions or (contextual events) were not entirely consistent over the 16 crews for these long data runs. Simulator failures, crew generated events, experimenter team errors, planned interventions to reduce possibilities of crashes (for example, from remaining too long in the LAX area) contributed to such inconsistencies. An advantage of ratings are that contextual effects can be taken into consideration. During the rating procedure all such inconsistencies were identified and discussed with the raters. For the safety performance ratings such inconsistencies were documented, by crew, on fact sheets.

Simulator problems included stabilizer chatter that led crew one to assume a runaway stabilizer and declare and emergency prior to arrival at LAX. This necessitated clearing their flight to approach LAX with 17,500 lbs of fuel on board. Crews three, seven, and nine were cleared for but did not execute the enroute hold prior to fuel levels reaching 14,000 lbs, and their subsequent clearance to LAX. Although varying time-in-hold was planned (to compensate for usual crew differences in fuel burn), simulator burn rates were determined to be high for these flight segments. A few crews were given runway visual ranges that were below the minimum 2400 ft. on their second approach to LAX. Although the crews could and some did, legally continue their approach across the outer marker by declaring an emergency, bias toward early interruption of approach could be present for some crews. Finally, the flight engineer of crew two had some prior knowledge of the major scenario problem. All experimenters and raters agreed however that his role play as a naive crewmember was successful and should result in little bias for that crew's performance.