AN INVESTIGATION OF TRANSITIONAL MANAGEMENT PROBLEMS FOR THE NSTS

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ANNUAL REPORT

BY

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AN INVESTIGATION OF TRANSITIONAL MANAGEMENT PROBLEMS FOR THE NSTS AT NASA

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ANNUAL REPORT (JAN. 15, 1986 - JAN. 15, 1987)

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I. PRELIMINARY CONSIDERATIONS

1.0 INTRODUCTION

This document, Investigation of Transitional Management Problems for the NSTS at NASA, is the final report summarizing the research carried out in 1986 under a one year contract between the National Space Transportation System (NSTS) and the Department of Industrial Engineering at the University of Houston - University Park (UHUP). The main purpose of this research is to provide analysis and recommendations to the NSTS on managing the transition from a research and development (R/D) structure to an operational structure. This contract represents a continuation of work originally begun in 1985 and seeks to take a closer look at specific transition management problems utilizing the knowledge gained in preparing the 1985 report.

2.0 PERSONNEL

Two professors and two graduate students performed the research for this grant. The principal investigator was Dr. John L. Hunsucker, Associate Professor of Industrial Engineering and Assistant Dean of the College of Engineering at UHUP. In addition, Dr. Hunsucker also serves as the Director of the Engineering Management Graduate Program. The co-principal investigator was Dr. Japhet Law, Assistant

Professor of Industrial Engineering and Director of the Industrial Engineering Graduate Program at UHUP. Two industrial engineering graduate students, Mr. Shaukat Brah and Mr. Randal Sitton, have been involved in this project from its inception.

3.0 DEFINITIONS

- Operations or Operational Era - At NASA, the term "operations" is normally used in a somewhat different sense than is used NASA has considered the shuttle program to be operational once it completed its four scheduled test flights. However, when we refer to operations here, we mean an organizational structure set up to insure routine, timely performance. In the sense it is used here, operations is synonymous with production.
- Research and Development (R/D) - The term R/D includes research, development, design, testing, and evaluation (DDTE). It is also synonymous with the term "design".
- Strategic Planning - Long-range planning.
- Tactical Planning - Short term planning.
- Goal - A desired future state, oftentimes stated in philosophical terms.
- Objective - A specific action whose accomplishment will help obtain a goal.

- POP - Program Operating Plan. A budgeting process done every six months using a 5-year planning horizon.
- OPF - Orbiter Processing Facility. A building at the Kennedy Space Center (KSC) where the orbiter is made ready before launching back into space.
- VAB - Vehicle Assembly Building. A building at KSC where the Orbiter is mated with the ET and the SRBs.
- ET - External Tank which contains the fuel and the oxidizer for the liquid fuel orbiter engines.
- SRB - Solid Rocket Booster.
- PAD - Launch pad.
- Experience Envelope - The body of knowledge consisting of the various shuttle component design parameters such as minimum and maximum temperatures, or maximum load, etc.
- Flight Rate - The number of flights per year.
- Workloading - The work load or amount of work required to complete a job.
- Maquiladoras - "Twin plant industry". A concept whereby a U.S. Company designs and fabricates a portion of a product and then ships the unfinished product to its plant in Mexico where the labor intensive portion of the process is carried out.
- SR/QA - Safety, reliability, and quality assurance.
- Hanger Queen - Normally, an aircraft that spends an inordinate amount of time in the hanger being repaired. However, NASA uses the term to denote an

Orbiter incapable of flight, e.g. the Enterprise.

- NRC - National Research Council.
- Closet Management - Top level management making top level decisions with little or no input from the lower echelons, almost as if the decision is made in a closet.
- FMEA/CIL HA - Failure Modes and Effects Analysis / Critical Systems List Hazard Analysis.
- SPC - Shuttle Processing Contractor. The consolidated contract at KSC, presently held by Lockheed.

4.0 WORK EFFORT

The work effort for this project consisted of five parts:

1. A literature search and analysis with particular emphasis on applications of interest to NSTS, i.e. R/D to operational transition management.

2. Interviews and analysis of organizations which have undergone transitions.

3. Based on literature searches and interviews, identification of techniques which are applicable to the transition of NSTS and the presentation of them to management.

4. Adaptation of the results to the NSTS program.

5. Interaction of the contractor with NASA management to advise them on transition management.

The results of the first four parts are contained in this report. The last part involved day-to-day interaction with various levels of NASA management, the results of which are interspersed throughout the report.

5.0 STRUCTURE

This report is comprised of eight chapters, each of which can stand alone with the exception of the last chapter which relies on the previous chapters to support its recommendations and conclusions. Chapter II contains additional summaries of published literature on the theory and applications of transition, or change management. Chapter III includes the results of interviews with additional industry personnel whose organizations either have gone through or are now going through change. The issues of flight rates and the flight decision process are addressed in Chapter IV. This chapter also discusses the use of a computer simulation model to analyze the effect of varying different parameters on the flight rate.

Chapter V delves further into the issue of NASA's changing demographics and why this may be cause for concern. The impact of the whole shuttle system structure on the Challenger accident along with highlights of the Rogers Commission Report are presented in Chapter VI. Chapter VII deals with the proposed reorganization of the NSTS management structure and how this transition from R/D to operations can be brought about. Finally, Chapter VIII summarizes the year's work and presents the conclusions of the study.

6.0 OVERVIEW

Parts of this report may seem to dwell excessively on the theoretical. However, in order to fully appreciate the magnitude of the task at hand, some understanding of the theory is important. An in-depth reading of the complete report is therefore advised.

The intent of this report is to stimulate the problem-solving environment at NASA. The change from an R/D to an operational era will be most effective if implemented by NASA itself and not by an outside source.

7.0 ACKNOWLEDGEMENTS

The principal investigator would like to express his sincere appreciation for the diligence of the University of Houston research team, without whose efforts this work would not have been accomplished. In addition, thanks are also due to the Flight Production Office of the NSTS, which not only provided the funding for this study, but whose involvement and support made possible most of the valuable ideas contained in this report.

CHAPTER II

LITERATURE SEARCH

1.0 INTRODUCTION

2.0 SUMMARIES OF THE LITERATURE

3.0 LITERATURE SEARCH CONCEPT MATRIX

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CHAPTER II. LITERATURE SEARCH

1.0 INTRODUCTION

The work on a search and review of the literature was intended to generate a comprehensive information base on the subject of R/D to Operations Transition Management, which forms the foundation of our research effort for NASA's NSTS. Previous work by the authors has identified a void in the literature specifically addressing transition from R/D to Operations. In order to fill this void, it was necessary to research two major areas, namely the characterization of R/D and Operations Management, and the area of Transition Management in general.

The work on the characterization of R/D and Operations Management has resulted in a comprehensive comparison of the two management environments. Thus, our attempts were directed towards further search of the literature in the area of Transition Management based on the major topics of interest identified in our previous work. This includes an updated computer search of the available material since our last search effort, and a 'chaining process' through the references of articles reviewed in the previous grant. The results of this effort are seventy-four article summaries, which are presented in Section 2 of this chapter, along with a one to four star rating of the articles based on their relevance to our work.

It is obvious that most of the articles reviewed this year are somewhat less current than our previous work due to the generation of the majority of the articles through the 'chaining process'. They did not reveal any new insight into transition management or the issue of transition from R/D to Operations; however, they did reinforce the findings from last year's research. The areas of strongest concurrence dealt with the issues of corporate culture and employee resistance to change.

Corporate culture was cited as a powerful force to contend with during a transition. Also, it is one that is difficult, time-consuming, and expensive to change. Several consulting firms have methods for attempting cultural change, but they are exceptionally expensive, slow, and have low success rates. Concerning change resistance, several repeating themes have been noted. One of these is the necessity for employee participation in the change effort. Another is the consideration of corporate culture during the planning and implementation phases of the transition effort. Also, two-way communication before, during, and after the change effort has taken place is vitally necessary.

Resistance to change was another prominent topic of discussion. The various types of resistance that may be experienced during the transition process can be placed in three categories, based on who makes the change, what kind of change is involved, and how the change is conducted.

Similarly, the persistence or institutionalization of change was discussed. It was found by several authors to be related to the type of organizational reward systems, unanticipated consequences of change, discrepancies between the actual and anticipated future states, upper management commitment for the program, group forces, and the nature of the external environment.

Also, they did offer numerous axioms and other "rules-of-thumb" for change agents and Organizational Development (OD) practitioners. Other noteworthy subjects examined in this set of papers were the use of change agents, the Lewin three-phase model of transition (unfreeze, change, freeze), the presence of a catalyst to initiate the transition process, and the systems approach to organizational analysis and problem diagnosis.

Several notable transition management programs were presented and discussed. It was found that these programs are mainly concerned with the aspects of planning, use of power, types of interpersonal relationships, and rate of change. Moreover, they may be focused either at individuals, groups of individuals, or organizational structural variables such as division of labor or reward systems. The change programs most often discussed in this set of articles were OD and Action Research (AR). Some of the OD methods discussed included Confrontation, Team Building, Laboratory Training, Encounter Groups, Behavior Modification, and Transactional Analysis. Action Research was described as a change technique in which the scholarly researchers that are studying an organization actively take part in the transition process by enhancing the organization's own capacity for problem diagnosis and correction. AR involves preliminary diagnosis, data collection, presentation of collected data to the organization, data analysis by the organization, action planning, and action.

Finally, in order to adequately summarize the results of this literature search, a cross-correlation matrix that shows relevant transition management concepts and the articles that support them is presented.

2.0 SUMMARIES OF THE LITERATURE

PAPER USEFULNESS LEGEND:

* NO DIRECT RELEVANCE
** SEEMS TO HAVE SOME RELEVANCE
*** SEEMS TO HAVE A MODERATE AMOUNT OF RELEVANCE
**** SEEMS TO HAVE QUITE A BIT OF RELEVANCE

[1] (**) Ackoff, R. L., Redesigning the Future (New York: Wiley, 1974).

Ackoff acknowledges the importance of employee participation in the organizational transition process. Thus, he proposes a "circular" organizational structure that gives workers at every level in an organization the ability to participate in decisions that will directly affect them. A typical organizational structure is given in Figure 2.1, and an example of a circular structure is given in Figure 2.2. In this structure, a board is placed at each level in the organization, which establishes policies and monitors performance of the managers reporting to it. Each manager operating in the circular organization is a member of the board to which he reports, the board to which his superior reports, and the chairman of the boards to which each of his immediate subordinates reports. Thus, the author claims that he makes every unit of the system - except the lowest element - participate in the management of both the larger system of which it is part and the smaller systems that are part of it.

[2] (**) Alderfer, C. P., "Change Processes in Organizations," in M. D. Dunnette (Ed.) Handbook of Industrial and Organizational Psychology (Chicago: Rand McNally, 1976).

The author presents the following axioms for change agents to follow when attempting organizational change:

(1) In deciding where to start and with whom to work, a consultant should keep in mind the tendency for both the openness and closedness of boundaries between groups to be self-sustaining.
(2) An optimal structure for changing organizations consists of establishing a team (or series of teams) including insiders and outsiders.
(3) The team needs to have optimally open boundaries and relationships of mutuality among team members and between the team and the system.
(4) Permanent change in systems (or subsystems) is most likely to be achieved and sustained if programmed through a series of cycles including diagnosis,

action, and evaluation which are carried out by both insiders and outsiders.

(5) Since knowledge depends on having access to information and closed systems restrict the flow of information, change agents can increase the probability of a successful change program if they move the system toward having more optimally open boundaries with mutual relationships.

[3] (**) Armenakis, A. A., H. S. Feild, and W. H. Holley, "Guidelines for Overcoming Empirically Identified Evaluation Problems of Organizational Development Change Agents," Human Relations, Vol. 29 (1976), 1147-1161.

One of the phases in an OD transition program is the evaluation phase. This phase is important, because data from the evaluation serve as feedback to the organization, as well as a basis for justification of the time and effort expended in the effort. However, the process of evaluation is hindered due to three basic categories of problems: (1) Methodological, (2) Administrative, and (3) Miscellaneous. Methodological problems include the selection and quantitative measurement of "soft" criteria, controlling for extraneous influences, overcoming criterion deficiencies, and dealing with time lags between transition efforts and results. Administrative problems primarily deal with the difficulty in devoting time and financial resources to evaluation of OD efforts. Miscellaneous problems include communicating to managers what OD can and cannot do, and managing conflict between adequate research design and client assistance. These problems are outlined in Table 2.1. In order to overcome these problems, the authors cite various studies and papers that have addressed these issues and present possible courses of action.

[4] (**) Armenakis, A. A., and R. W. Zmud, "Interpreting the Measurement of Change in Organizational Research," Personnel Psychology, Vol. 32 (1979), 709-724.

The detection and measurement of Beta changes (changes due to a recalibration of the measurement scale over time by the subjects) is empirically demonstrated in this article through an experiment conducted with members of a U. S. Army training brigade,. The vehicle used in accessing organizational change is the Survey of Organizations Questionnaire, and the experiment was administered at two points in time with no intervention in between. Present ("how it is now") and ideal ("how I'd like it to be") perceptions of various organizational dimensions were used to establish two scales of measurement. actor analysis was used to consolidate the twenty one perceptions into two distinguishable factors for each measurement scale. After elimination the possibility of the presence of Gamma changes (change of subjects' perception of the criterion being measured) through the use of congruence coefficient tests on the distinguishable factors, comparisons of the scores in the two scales over time were made to establish the presence of Beta change. It was observed that while the difference between ideal versus present scores remained unchanged over time, the actual scores themselves were found to have significantly changed. Further analysis into the sources of internal validity such as testing, maturation, etc. was also presented.

[5] (****) Beer, M., and J. W. Driscoll, "Strategies for Change," in J. R. Hackman and J. L. Suttle (Eds.) Improving Life at Work (Santa Monica, CA: Goodyear Publishing Co., Inc., 1977).

Five conditions required for successful change were outlined: (1) People in the organization must feel pressure in order to change, (2) Participation and involvement of people in reexamining problems and practices are needed to build commitment to change, and to assure that behaviors and attitudes once changed remain changed without surveillance and control, (3) New ideas, models, and concepts must be brought in from the outside to help people in the organization find new approaches that will improve the quality of work life, (4) To ensure successful transition and prevent massive failures that can slow the momentum of change, early innovations leading to improvements should be limited in scope, and (5) A skilled leader or consultant is often needed to bring in new ideas, catalyze the process of reexamination, and support individuals in the process of improving the quality of work life. Also, several considerations for the selection of a proper organization transition strategy were given. These considerations include the amount of power shared between management and subordinates, the appropriate definition of a change-target boundary, the amount of centralization in transition planning and strategy formulation, and the rate of organizational change.

[6] (***) Bennis, W. G., Changing Organizations: Essays on the Development and Evolution of Human Organizations (New York: McGraw-Hill, 1966).

The author identified seven types of change programs: exposition and propagation (use of knowledge to change people and organization); elite-corps (putting the right people in the right places); staff (use of staff personnel to act as an intelligence-gathering agency); scholarly consultations (use of scholarly and academic procedures such as research and investigation to develop change strategies); circulation of ideas to the elite (getting change ideas to the people in power or to those who influence people in power); developmental research (taking theoretical transition theories and developing implementation strategies); and action research (the use of change agents to research and solve client problems, except that the roles of the change agent and the client may change and reverse). In those programs that utilize change agents, a six phase strategy was specified:

Phase 1: Away from the client's plant location, personnel are exposed to behavioral science theory and participate in encounter-type sessions.

Phase 2: Team training is conducted off-site.

Phase 3: Meetings stressing the achievement of better integration between functional groups takes place.

Phase 4: Groups of ten to twelve managers get together and set goals for the total organization. Afterwards, mechanisms for achieving the goals are planned.

Phase 5: The change agent attempts to help the organization realize the goals established in Phase 4.

Phase 6: Stabilization of the changes brought about during the prior phases.

[7] (****) Bennis, W. G., "A Typology of Change Processes," in W. G. Bennis, K. D. Benne, and R. Chin, The Planning of Change (New York: Holt, Rinehart, and Winston, Inc., 1961).

Based upon the persons formulating transition goals and the distribution of power among the members of the organization, eight types of organizational change are presented in this article. These types, presented in Table 2.2, are: (1) Planned change, (2) Interactional change, (3) Technocratic change, (4) "Natural" change, (5) Indoctrinational change, (6) Socialization change, (7) Coercive change, and (8) Emulative change. Planned change involves deliberate mutual goal setting by one or both parties, and an equal power ratio. Indoctrination incorporates mutual goal setting, but has an imbalanced power ratio. Coercive change consists of one-sided deliberate goal setting, and an imbalance in power. Technocratic change relies solely on collecting, interpreting, and disseminating data. Interactional change is a non-deliberate (possibly unconscious) change characterized by mutual goal setting and equal power distribution. Socialized change is non-deliberate, involving mutual goal setting and an imbalance in power. Emulative change is non-deliberate change brought about through a form of identification with and emulation of the "power figures" by the subordinates. Natural change is change with no deliberateness or goal setting on the part of those involved; in other words, this is a "catch-all" category for change occurring inadvertently or by a "quirk of fate".

[8] (***) Cartwright, D., "Achieving Change in People: Some Applications of Group Dynamics Theory," Human Relations, Vol. 4, No. 4 (1951), 381-392.

This article describes the use of the forces operating in groups, or group dynamics, to achieve organizational change. For example, it is shown that when a group as a whole made a decision to have its members change their behavior, this was two to ten times as effective in producing actual change as was a lecture urging members to change. From the application of group dynamics to organizational change, eight principles have been identified by the authors. These are:

(1) Group members who are to be changed and those who are to exert influence for change must have a strong sense of belonging to the same group.
(2) The more attractive the group is to its members, the greater is the influence that the group can exert on its members.
(3) In attempts to change attitudes, values, or behavior, the more relevant they are to the basis of attraction to the group, the greater will be the influence that the group can exert upon the members.
(4) The greater the prestige of a group member in the eyes of the other members, the greater the influence he can exert.
(5) Efforts to change individual or subparts of a group which, if successful, would have the result of making them deviate from the norms of the group will encounter strong resistance.
(6) Strong pressure for changes in the group can be established by creating a shared perception by members of the need for change, thus making the source of pressure for change lie within the group.
(7) Information relating to the need for change, plans for change, and consequences of change must be shared by all relevant people in the group.
(8) Change in one part of a group produces strain in other related parts which can be reduced only by eliminating the change or by bringing about readjustments in the related parts.

[9] (*) Clark, P., Action Research and Organizational Change (London: Harper & Row Ltd., 1970).

The use of Action Research (AR) as a method of transition management was examined. The author cites that AR aims to contribute both to the practical concerns of people in a problematic situation and to the goals of social science by joint collaboration within a mutually acceptable ethical framework. It is a type of applied social research differing from other varieties in the immediacy of the researcher's involvement in the action process. Thus, Action Research must possess an aspect of direct involvement in organizational change, and must simultaneously provide an increase in scholarly knowledge. The book outlines strategies, tactics, and qualifications for action researchers, as well as providing case studies for analysis.

[10] (*) Clark, P., and J. Ford, "Methodological and Theoretical Problems in the Investigation of Planned Organizational Change," Sociological Review, Vol. 18, No. 1 (1970), 29-52.

In this article, the authors raised the issue of questionable methodological and theoretical standings of current research in the area of planned organizational change (POC). After establishing the need for sociological research in the area of POC, they outlined various major models, and elaborated on the weakness of these frameworks. These included the post facto nature of the studies, thus creating a tendency for the research to be dependent on data collected in the POC process. The absence of failures reported also raised the question of how representative these studies were of the population of POC. Another major concern was the issue of what is included and excluded from these studies. In particular, the lack of mentioning of antecedents to POC, resolution of conflicts and resistance, and the analytical frameworks used was noted.

The authors proposed an alternative approach to the study of POC, emphasizing on a tandem relationship between the researcher and the consultants assigned to the POC. They also described some concurrent research they were conducting into POC, and the experience with the simplification of their approach.

[11] (***) Coch, L., and J. R. P. French, "Overcoming Resistance to Change," Human Relations, Vol. 1 (1948), 512-532.

This paper describes an experiment to study the use of group methods to overcome the resistance to change in the work environment. Starting with general observations of past data with respect to changed groups, a preliminary theory was devised to account for the resistance. It was believed that resistance to change is a motivational problem, and that there are two forces involved in the change process. There is a driving force toward the achievement of production goals which increases as one gets closer to the goal, and a restraining force which increases with the level of production. The conflict of these two forces produces frustration, which then results in high turn-over and absenteeism. The amount of 'we-feeling' was also thought to be an important factor in the resistance to change, that strong psychological subgroups with negative attitudes display strong resistance, whereas those with positive attitudes are the best learners in a changed environment.

The experiment was set up with different groups of workers, all of which have similar profiles in their work efficiency rating, amount of 'we-feeling' within the group, and were assigned to new tasks with similar degrees of change. One group was set up so that worker representation was involved in the design of the change, while two other groups have total worker participation in the design of the change program. A control group was included with no worker participation at all. The result from the experiment indicated that the three groups with worker participation were able to recover to the former work efficiency in a short time, and actually proceeded to exceed previous performance levels. The control group have no improvement in their work efficiency, and displayed marked aggression against management and high turn-over in the work force.

Based on the data, it was concluded that the rate of recovery is proportional to the amount of participation, which in turn provided higher morale in the work force during the change process. The use of group techniques in the design of the change process improved the communication for the need of change and increased participation in planning the change. A second experiment was conducted with the control group going through the participative change process, resulting in improvement in the work efficiency as in the first three groups in the first experiment.

[12] (**) Conlon, E. J., "Feedback About Personal and Organizational Outcomes and its Effect on Persistence of Plannned Behavioral Changes," Academy of Management Journal, Vol. 23 (1980), 267-286.

This article addresses the issue of the endurance of change in an organization. Once the decision to change is made, events may occur that cause an individual to reevaluate the newly adopted behavior (see Figure 2.3). Some types of feedback that initiate the reevaluation process include contradictions, unexpected outcomes, and new alternatives. Based upon a study done by the author, three things may be stated concerning feedback and the persistence of change:
(1) Confirming and disconfirming feedback about the

expected outcomes of a behavior affects the decision to persist only when the outcomes are valued.
(2) It is the content of feedback, and not its presence, that affects behavior and beliefs.
(3) Feedback has an impact on the strength of beliefs to which it is targeted and, when no other feedback is available, may transfer beliefs about outcomes that are indirectly related to the instrumental feedback.

[13] (**) "Corporate Culture: The Hard-to-Change Values That Spell Success or Failure," Business Week, 27 October 1980, 148-160.

Due to the pervasiveness of corporate culture, cultural change is one of the most difficult tasks that management can undertake. One of the major problems of cultural change is the relative immutability of culture, along with the fact that that few executives consciously recognize what their company's culture is and how it manifests itself. If cultural change is required, the company needs to examine its existing culture in depth and to acknowledge the reasons for revolutionary change. The change should be marked by a changed structure, new role models, new incentive systems, and new rewards and punishments. Some successful cultural change methods and strategies include the preparation of the organization's current and desired mission, goals and targets, the use of employee participation, and increased organizational communication.

[14] (*) Cronbach, L., and L. Furby, "How Should We Measure Change - Or Should We?," Psychological Bulletin, Vol. 74 (1970), 68-80.

This paper argues that "raw change" or "raw gain" scores, formed by subtracting pretest scores form posttest scores, lead to fallacious conclusions concerning the amount of change made. This is primarily because such scores are systematically related to any random error of measurement. Thus, gain scores are rarely useful, no matter how they may be adjusted or refined. Due to this conclusion, the authors present superior ways of estimating true change and true residual change scores. Also, it develops new and better estimators for measures of change.

[15] (***) Dalton, G. W., "Influence and Organizational Change," in J. B. Ritchie and P. Thompson (Eds.) Organization and People: Readings, Cases, and Exercises in Organizational Behavior (St. Paul: West Publishing Co., 1976).

OD change agents will act more as an adviser and

facilitator of change rather than a change initiator. In order to give structure to the transition process, a four-step sequential model for induced organizational change is presented. In this model (see Table 2.3), the four steps are: (1) Tension occurs in the system, (2) Intervention of a prestigious influencing agent, (3) Individuals attempt to implement the proposed changes, and (4) New behaviors and attitudes are formed, accompanied by decreasing dependence on the influencing agent. This four-step model can be mapped into the familiar Lewin three-step model (Unfreeze, Change, Refreeze) model as shown in Table 2.4. Furthermore, the authors have found four conditions which must occur during the transition process in order for successful transition to occur. First, the organization must move away from generalized goals toward specific objectives. Second, social ties built around previous behavior patterns must be abandoned for new relationships which support the intended changes in behavior and attitudes. Third, self-doubt and a lowered sense of self-esteem must be replaced with a heightened sense of self-esteem. Fourth, an external motive for change must be changed to an internal motive for change. These concepts are presented in Table 2.5.

[16] (***) Davey, N., <u>The External Consultant's Role in Organizational Change</u> (East Lansing, MI: Michigan State University Press, 1971).

Based on the author's research into the external consultant's role in organizational change, a framework for the development of an organization - consultant relationship which will result in a high level of effectiveness was developed. Some of the identified arrangements that should be observed in order to make consultant assistance more effective were:

(1) In considering consultant help, an organization should allow that some changes may be necessary and should reflect this by its identification and engagement of a consultant.
(2) An organization should regard a consultant as an expert resource, and a collaborating equal, and ensure his participation in the consideration of any changes which should be made in the assignment during its progress.
(3) An organization should not closely direct a consultant's work, nor unreasonably constrain him by restricting personal contacts or access to organizational information.
(4) A consultant should work closely and directly with members of the client organization and provide for their participation in the consulting assignment either by assignment to specific working roles, discussion of findings, or an opportunity to

initiate proposals.

(5) An organization should establish a specific point of contact and liaison for a consultant - either the assignment sponsor or other organization member - who can initiate other organization contacts and through whom the consultant can report.

[17] (**) Davis, Shel, "Thoughts on Planned Change and Change Diffusion", Journal of Applied Behavioral Science, Vol. 12 (1976), 230-238.

The author of this paper discussed his opinion on various concepts in change projects :

a. Change projects should not be sheltered; extension both upwards and downwards within the organization should be practiced. Projects that are 'walled-off' get started easier, but one should have long term outlook for the results on change projects.

b. Change projects can get started through productivity issues, through suggestions of the line managers, or through people in the personnel function who's familiar with powerful, proven techniques in changing the pay structure, training methods etc.

c. Involve enough units in the organization with credible managers ('golden boys', with delegated authority), and in a fairly short time (one to two years) to get big payoff in the effort that is visible in the organization. Selection of these 'golden boys' are intuitive and involves trial-and-error. Limited resources in most change projects necessitates careful selection of the target units.

d. Need good, strong inside people with continuity and understanding of the culture. Together with outside consultants, develop and update the 'white paper' (what are we up to, and how are we going to proceed in the change project).

e. Inertia provides resistance to change. Easier to implement plans in new units.

[18] (***) Ernest, R. C., "Corporate Cultures and Effective Planning," Personnel Administrator, March 1985, 49-60.

The author states that effective business planning requires an understanding of not only the external competitive environment, but also the internal corporate culture (see Figure 2.4). Based on the author's research, five orientations were found to be critical in defining a company's culture: (1) Marketing orientation, (2) employee orientation, (3) Problem-solving

orientation, (4) Innovation orientation, and (5) Service / quality orientation. The interrelationships of these five orientations may be summarized by using an "organizational culture grid" (see Figure 2.5). The two dimensions on the grid that define culture are "action" and "people". The amount of corporate "action" may be classified as being "reactive" or "proactive", while the amount of "people" orientation may be from "participative" to "nonparticipative". Based on the action and people dimensions, four culture types may be identified: (1) Interactive, (2) Integrated, (3) Systematized, and (4) Entrepreneurial. The Cultural Grid is useful for strategic planning, organizational development, human resource planning, employee selection, orientation and training, compensation, and performace appraisal and promotion systems.

[19] (***) Fierman, J., "The Corporate Culture Vultures," Fortune, October 17, 1983, 66-72.

Due to the influence of corporate culture, it has been suggested that corporate strategy alone, no matter how well formulated, cannot produce winning results. A number of consulting firms have devised methods to attempt cultural change. The Management Analysis Center (MAC) has developed the CEO's Change Agenda for instituting cultural change. The first three steps focus on planning. Next, the chief executive is to forge a vision of the new strategy and the shared values needed to make it work, then communicate this to employees via speeches, memos, and more informal contacts. Monitoring of the progress of this strategy is an on-going process. The last three MAC items specify methods of creating change. One of these is for the leader to use the budgeting process and internal public relations as levers for change.

Other consultants treat culture less globally, using questionnaires to measure organizational climate, and then use conventional tools such as feedback sessions and team-building techniques to initiate change. Also, hiring, promoting, and terminating systems can effectively be used to build culture and "weed out" incompatibles. However, consultants also state that cultural change is slow and costs too much, and is justifiable only under five conditions: (1) The company has strong values that don't fit a changing environment, (2) The industry is very competitive and moves with lightning speed, (3) The company is mediocre or worse, (4) The company is about to join the ranks of the very largest companies, or (5) The company is small but growing rapidly.

[20] (***) Franklin, J. L., "Characteristics of Successful and Unsuccessful Organization Development," Journal of

Applied Behavioral Science, Vol. 12, No. 4 (1976), 471-492.

It is often important to identify OD approaches which are effective across a spectrum of change situations. This paper, however, addresses the dual to the above problem; namely the identification of characteristics of the organization which are correlated to the success of the change effort regardless of the OD technique used. Twenty five organizations were studied. Questionnaires were conducted both at the beginning and the end of the change effort, which then provides an input in classifying the change effort into 'successful' and 'unsuccessful' categories. Continuous monitoring of the change effort through interviews with key personnel and review of meetings and reports.

Eight major categories of characteristics were investigated, namely: organization's environment, characteristics of the organization, initial contact between the OD team and the members of the organization, formal entry procedures and commitment, data gathering activities, internal change agent characteristics, external agent characteristics, and exit procedures. Statistical tests were applied, and revealed that organization's environment, organization's characteristics, entry and commitment, and internal change agent were significant factors in relation to the success of the OD effort. In particular, successful change efforts were related to organizations that are open and involved in adjusting to the change, with specific and great commitment to the OD efforts. It is interesting to note also that careful selection of internal change agents who possesses assessment-prescriptive skills and has little related experience in change efforts correlates with successful changes in the organizations. Details of the differentiation ability of the eight categories, together with the individual dimensions within each category are provided in Table 2.6. Implications and limitations of these results are also discussed in the paper.

[21] (**) French, Wendell L., and Cecil H. Bell, Jr., Organization Development (Second Edition) (Englewood Cliffs, New Jersey: Prentice Hall, 1978).

This book describes OD as a long-range effort to improve an organization's problem-solving and renewal processes, particularly through a more effective and collaborative management of organization culture - with special emphasis on the culture of formal work teams - with the assistance of a change agent, or catalyst, and the use of the theory and technology of applied behavioral science, including action research (AR). Action research consists of (1) a preliminary diagnosis,

(2) data gathering from the client group, (3) data feedback to the client group, (4) data exploration by the client group, (5) action planning, and (6) action. The use of action research as a change strategy differs from most other strategies in that the AR consultant does not present formal conclusions and recommendations to the client organization; rather, the AR consultant gathers data and assists in the way the client solves problems.

[22] (**) Golembiewski, R. T., K. Billingsley, and S. Yeager, "Measuring Change and Persistence in Human Affairs: Types of Change Generated by OD Designs", Journal of Applied Behavioral Science, Vol. 12 (1976), 133-157.

A discussion of the three types of change generated by OD designs are provided, namely Alpha, Beta, and Gamma changes. Alpha change pertains to a variation in the level of some state within a relatively constant measurement interval. Beta change involves a change due to recalibration of the intervals used to measure the state of interest within the conceptual domain. Gamma change relates to a major shift in conceptualization of the dimensions of reality, or a redefinition of the relevant dimensions being measured. Brief discussions are presented where similar distinction of changes exists in the field of psychological counseling and other sciences.

The authors then elaborated on factorial analysis based methods to demonstrate the existence (or the strong indication of existence) of Gamma changes in an OD structural intervention experiment by Golembiewski, Hilles, and Kagno (1973). Through the use of congruential tests of the factorial structures, the authors concluded that Alpha and Beta changes were inadequate to explain the magnitude of changes present in the data. They further stated that the existence of Gamma changes is difficult to establish. However, the statistical procedures given do provide a reasonable approach to suggest its existence, and that it is very important that attention be devoted to the three different types of changes when dealing with experimental design in behavioral research.

[23] (**) Golembiewski, R. T., and A. Blumberg, "The Laboratory Approach to Organizational Change: Confrontation Design," Journal of the Academy of Management, Vol. 11 (1968), 199-210.

The authors propose that confrontation between groups may be used as a method of organizational change. There are several prerequisites for the use of confrontation design as a transition method. First, there must be participants that are hierarchically and/or funcitonally involved in some common flow of work. Second, confrontations involve two or more organizational entities whose members have real and unresolved issues with one another. Third, confrontation designs involve the mutual development of images as a basis for attempting to highlight unresolved issues. These images are usually three-dimensional in nature, along the lines of: (1) How do we see ourselves in relation to the Relevant Other?, (2) How does the Relevant Other see us?, and (3) How do we see the Relevant Other?. Fourth, confrontation designs must provide for the sharing of 3-D images created by the groups in confrontation. Fifth, confrontation designs assume that significant organizational problems often are caused by blockages in communication. Sixth, confrontations should be short-cycle affairs. Seventh, confrontation designs typically are seen as springboards for organizational action. The authors note that confrontation design seems widely applicable, but some potential host organizations are not culturally prepared for it.

[24] (*) Golembiewski, R., and S. Carrigan, "The Persistence of Laboratory Induced Changes in Organization Styles," Administrative Science Quarterly, Vol. 15 (September, 1970), 330-340.

The authors reported the results of a follow-up study to an earlier experiment, in which a learning design based on a laboratory approach induced changes in interpersonal and intergroup styles in a small sales organization. In this work, two more observations were obtained subsequent to the earlier experiment using the Likert profile of organizational characteristics to gauge the changes. The major finding was that the laboratory-induced changes in interpersonal and intergroup styles had a sustaining effect over the eighteen month time frame.

[25] (**) Goodman, P. S., M. Bazerman, and E. Colon, "Institutionalization of Planned Organizational Change," in B. M. Shaw and L. L. Cummings (Eds.) Research in Organizational Behavior (Vol. 2) (Greenwich, Conn: JAI Press, 1980).

This article outlines the factors that contribute to the institutionalization or persistence of organizational change. Some of these factors include the type and nature of the organization's reward allocation system, unanticipated consequences of change, discrepancies between the actual and anticipated future states, amount of sponsorship of the change program by upper management, group forces, commitment, publicity of the change program, internal intergroup dependencies, and the nature of the organization's external environment.

[26] (**) Greenwald, R., "Companies Need to Establish Climate That Fosters Innovation," Industrial Engineering, April 1985.

The author notes that there are three major barriers to innovation: (1) Too little or too much structure, (2) An organizational culture that discourages innovation, and (3) Lack of employee responsibility for implementation of their ideas. Today, it is recognized that innovation is not a luxury, but a life-or-death issue for business. Innovation can flourish in an organization that has enough structure to impose order on chaos, but not so much that creativity is stifled. Also, while structure allows a company to function smoothly, a bureaucratic organization resists change and is slow to accept new ideas due to the large amount of inertia that exists in such organizations. Furthermore, ideas may never be developed if inter-departmental rivalry is very intense, since departmental interests will be pursued at the expense of the company as a whole.

[27] (**) Greiner, L. E., "Patterns of Organizational Change," Harvard Business Review, Vol. 45 (May/June 1967), 119-130.

This article discusses various means to initiate transition. The concepts the author introduces are grouped into three categories: (1) Unilateral action, (2) Power Sharing, and (3) Delegated Authority. Transition methods involving unilateral action include change by decree, employee replacement, or organizational restructuring. Power sharing techniques include group decision making and group problem solving. Authority delegation methods include case discussion and T-group sessions. T-group sessions, usually used by top management, attempt to increase an individual's self-awareness and sensitivity to group social processes. It was found that most successful transitions occurred when there was strong internal and external pressure toward change. Also, use of shared power techniques or a redistribution of power within the organization contributed to successful transition. Less successful transitions were noted by inconsistency in the change steps and the use of unilateral or delegated authority concepts. From the case studies, the author developed a transition model composed of the following six phases: (1) Pressure and Arousal, (2) Intervention and Reorientation, (3) Diagnosis and Recognition, (4) Invention and Commitment, (5) Experimentation and

Search, and (6) Reinforcement and Acceptance. This model is presented in Figure 2.6.

[28] (**) Greiner, L. E., and L. B. Barnes, "Organization Change and Development," in G. W. Dalton et. al. (Eds.) Organizational Change & Development (Homewood, Ill.: Irwin Dorsey, 1970).

The authors propose that all change programs have four elements in common: planning (ranging from structured to unstructured), use of power (ranging from unilateral to delegated authority), type of interpersonal relationships (from impersonal to personal), and tempo (from revolutionary to evolutionary). Also, a four-phase model for organizational change was proposed. Phase 1 consists of diagnosing organizational problems, Phase 2 involves planning for change, Phase 3 entails the execution of the change plan, and Phase 4 is a analysis of the outcome of the change program.

[29] (*) Hummon, Norman P., Patrick Doreian, and Klaus Teuter, "A Structural Control Model of Organizational Change," American Sociological Review, Vol. 40 (1975), 813-824.

A structural control model relating the size and structure (levels of differentiation) of an organization is proposed. The variables involved were: (1) The number of employees primarily performing output tasks of the organization, (2) The number of divisions functionally differentiating the work force, (3) The number of supervisory employees, and (4) The mean number of hierarchical levels over all divisions. A system of linear equations was formulated to show the structure of the control variables. This was further developed into a system of linear differential equations when the change of state variables over time was considered.

The system was applied to data reported in the literature and found to be interpretable with empirically observed relationships, which provides an alternate view of the organizational change process.

[30] (****) Huse, E., Organization Development and Change (St. Paul, MN: West, 1975).

This book discusses the use of Organizational Development (OD) techniques for change. Some of the methods discussed include Action Research, Confrontation, Management By Objectives, Team Building, Laboratory Training, Encounter Groups, Behavior Modification, Transactional Analysis, and Human Resource Accounting. It also closely examines the types, qualities, and roles of an organizational development

practitioner (i.e., change agent). Selected readings and case studies concerning the role of OD in organizational change are also included.

[31] (**) Jones, G., Planned Organizational Change (New York: Praeger, 1969).

This book notes the importance of change agents and their strategies in the transition process. They serve to identify and clarify the goals of change for the client system, develop useful strategies and tactics to help client systems solve their own problems, and establish and maintain appropriate working relationships between the parties engaged in the change. Three types of change agents were discussed: (1) regular change agents, who can be a person, group, or an organization, that are employed by the client system to assist in achieving improved organizational performance; (2) change catalysts, who may or may not be professional agents, that influences the speed of transition but does not actively participate or undergo change during the transition process; and (3) pacemakers, who are action-oriented and are involved in aspects of stimulation, control, coordination and regulation of organizational behavior (they do not bring about change, but simply guarantees the maintenance of change).

[32] (**) Jones, G., "Strategies and Tactics of Planned Organizational Change," Human Organization, Vol. 23 (1965), 192-200.

Six major elements were identified in the change process: (1) Change Agents, (2) Client system, (3) Goals, (4) Strategies and tactics, (5) Structuring of change, (6) Evaluation. This article primarily focuses on the strategies and tactics of organizational change. Strategy refers to the planning and directing of operations, while tactic relates to the maneuvering of forces into position(s) of advantage. Three classes of strategy were discussed: (1) Coercive strategies, (2) Normative strategies, and (3) Utilitarian strategies. Coercive strategies are characterized by non-mutual goal-setting and an imbalanced power relationship. Normative strategies place emphasis on the use of normative power as a major source of control. The techniques of control are usually the manipulation of symbolic rewards and symbols, employment of leaders, and administration of rituals. Utilitarian strategies are characterized by control over material resources and rewards through the allocation of increased contribution, benefits, and services.

Three useful tactics of organizational change are: (1) The use of Action Research (research personnel actively becoming involved as a manipulator in the change process), (2) Organizational structure modification, and (3) Marginality (the use of facilitators that share the same value systems of both the new and old states).

[33] (**) Kanter, Rosabeth Moss, *The Change Masters: Innovation for Productivity in the American Corporation* (New York: Simon and Schuster, 1983)

This book deals with the topic of increasing employee innovation and initiative through organizational change. Kanter argues that American management has been reluctant to abandon the managerial methods that were successful in the 1950's and 1960's. Thus, many of the organizations that continue to use these outdated methods are currently experiencing low productivity, decreased profits, or overwhelming losses. However, Kanter notes that companies with "progressive" human resource practices, such as IBM, General Electric, and Xerox, have significantly higher long-term profitability and financial growth than companies which do not effectively utilize human resource management techniques to adapt to environmental changes. From this observation, the concept of "Change Masters" was developed. Kanter defined Change Masters as being "people and organizations that are adept at the art of anticipating the need for, and of leading, productive change". In order to more precisely define what practices either stimulate or inhibit innovation and initiative, she closely examined ten companies; some of these included Hewlett-Packard, Wang Laboratories, Polaroid, General Electric, and General Motors. Based on her observations of these companies, she asserts that an American corporate Renaissance is needed which would restore American industry to its former place of leadership and innovation.

[34] (**) Katz, D., and R. L. Kahn, "Organizational Change", in *The Social Psychology of Organizations* (New York: John Wiley & Sons, Inc., 1980), 390-451.

Transition programs may be focused either at individuals, groups of individuals, or organizational structural variables. Individual-oriented programs, such as information dissemination, training, counseling, psychotherapy, employee selection and placement, termination (firing), and behavior modification, have a history of failure due to a disregard on the part of the change agent of the systemic properties of organizations and from the confusion of individual changes with modification in organizational variables. Group approaches to organizational change include sensitivity training, T-groups, surveys, and feedback processes. However, it was noted that the direct manipulation of organizational structural variables, such as the authority structure, reward structure, and the division of labor, is a more powerful approach to producing enduring systemic change.

[35] (*) Kimberly, J. R., and W. R. Nielson, "Organizational Development and Change in Organizational Performance," Administrative Science Quarterly, Vol. 20 (June 1975), 191-206.

This study examined the impact of an OD effort on organizational performance using a model of causal linkages in planned change (see Figure 2.7) which appears to underlie the OD approach to organizational intervention. The transition program consisted of six phases: (1) Initial diagnosis, (2) Team skills training, (3) Data collection, (4) Data confrontation, (5) Action planning, (6) Team building, and (7) Intergroup building. Significant positive changes in target group attitudes and perceptions were found, as was significant positive change in quality of output and in profit. No change in the levels of productivity was found, and a strong positive correlation between those levels and levels for the industry as a whole was interpreted as indicating that this particular index of performance was outside the direct control of plant management and more a function of corporate policy and market conditions.

[36] (*) King, A. S., "Expectation Effects in Organizational Change," Administrative Science Quarterly, Vol. 19, No. 2 (1974), 221-235.

An experiment was conducted in four plants of a clothing pattern manufacturing organization, where it was decided to use job enrichment to improve productivity. Two plants implemented job enlargement while the remaining two implemented job rotation. One plant from each of the above groups was told that productivity was expected to increase as a result of the implemented change, while the remaining plants were told that improved industrial relations rather than increased productivity was expected. Both absenteeism and average daily output per machine crew were recorded in a twelve month period.

While there were no significant differences in absenteeism among the plants, it was observed that productivity is significantly (in a statistical sense) greater as a result of the expectation effect. A follow-up questionnaire was conducted to distinguish between the expectations, perceptions, and evaluations of job enrichment with respect to the alleged effects. The results indicated that the experimentally induced high expectations on productivity affected managers to communicate the expectations more effectively to the employees, and that managerial expectations on performance often serve as self-fulfilling prophecies.

[37] (***) Kotter, J. P., and L. A. Schlesinger, "Choosing Strategies for Change," Harvard Business Review, (March-April 1979), 106-114.

One step in the process of selecting an organizational change strategy is to identify resistances to change. Some of these resistances could be parochial self-interest, employee misunderstanding and lack of trust, and low organizational tolerance to change. In order to overcome these resistances, the authors recommend the use of education and communication, employee participation and involvement, managerial facilitation and support, negotiation and agreement, manipulation and co-optation, and explicit and implicit coercion. These methods are presented in Table 2.7. The use of these techniques should be based on the four following key situational variables shown in Table 2.8: (1) The amount and type of resistance that is anticipated, (2) The position of the change initiators vis-a-vis the resistors (in terms of power, trust, etc.), (3) The locus of relevant data for designing the change, and of needed energy for implementing it, and (4) The stakes involved (e.g., the presence or lack of presence of a crisis, the consequences of resistance and lack of change). A manager can improve his/her chance of transition success by: (1) Conducting an analysis that identifies the possible causes of organizational problems, (2) Conducting an analysis of factors relevant to producing the needed changes, (3) Selecting a change strategy, based on the previous analysis, that specifies key transition variables, such as the speed of change, and (4) Monitoring the implementation process.

[38] (**) Labovitz, S., and J. Miller, "Implications of Power, Conflict, and Change in an Organizational Setting," Pacific Sociological Review, Vol. 17 (1974), 214-239.

This study involved the fragmentation of a research organization into two separate entities due to organizational conflict. This conflict was caused by organizational growth, increasing organizational structuring and bureaucracy, and the widening power differential between executive board members and the research directors. It was found that after the creation of the new company, job satisfaction increased and job tension decreased following the division in the organization. Also, it was determined that increasing size, bureaucratization, differential power, free expression of sentiments, and organizational division led to a decrease in job satisfaction and an increase in job tension.

[39] (*) Lawler, E. E., III, "Pay, Participation, and Organizational Change," in E. L. Cass, and F. G. Zimmer (Eds.) Man and Work in Society (New York: Van Nostrand Reinhold Co., 1975).

The following points concerning pay systems were indicated by the author:
(1) When employees perceive pay and performance are related, they are motivated to perform well,
(2) Pay incentive plans do not always produce higher motivation,
(3) When employees do not trust management, instead of believing that good performance will lead to higher pay they believe that it will lead to higher standards, the abandonment of the incentive plan or some other management "trick" to keep pay down even though performance increases (see Figure 2.8),
(4) Perception of the relationship between pay and performance influences motivation, and
(5) Feelings of satisfaction are important determinants of absenteeism and turnover.
It is noted that pay system changes are highly visible in organizations and as such can produce rapid change. Also, it is usually necessary when structural changes are made to change the pay system. The author notes several disastrous cases that involved the implementation of job enrichment or autonomous work group programs without a change in the pay system to compensate for increased responsibility or work load.

[40] (**) Lawrence, P. R., "How to Deal with Resistance to Change," in G. W. Dalton, P. R. Lawrence, and L. E. Greiner (Eds.) Organizational Change and Development (Homewood, IL: Richard D. Irwin, Inc., 1970), 181-197.

Resistance to change may come in a variety of forms, such as low work output, an increase in employee hostility, resignations and requests for transfer, chronic quarrels, or strikes. This resistance may be lessened through the use of employee participation, an understanding of the true nature of resistance, and the use of concrete steps to deal constructively with resistance caused by staff preoccupation with the technical aspects of new ideas. One of the major points addressed was that change agents often are too concerned with the technical aspects of change to be aware of the social changes they are inadvertently introducing. The suggested method of change is to use a give-and-take, compromise approach, instead of a unilateral, mandate-oriented one. Also, the change agent should utilize employees that have a first-hand knowledge and experience of the organizational area under transition

as a source of ideas and feedback. Another idea is to communicate transition plans and goals in clear, understandable terms to the transition participants.

[41] (*) Leavitt, H. J., "Applied Organizational Change in Industry," in J. G. March (Ed.) Handbook of Organizations (Chicago: Rand McNally, 1965), 1144-1170.

The author views organizations as complex systems involving task, structural, technological, and human variables. These variables may serve as focal points of an organizational change program. However, the human variables are stressed as being the key point that will determine the success or failure of the transition. In particular, the equalization of power between individuals in the organization is very important to the success of a change program.

[42] (*) Lee, J., "Leader Power for Managing Change," Academy of Management Review, Vol. 2 (1977), 73-80.

This paper presents a transition model where the main focus is on the direct assessment of the leader's power, defined as the ability and opportunity to influence others. The model is designed to assess a leader's residual power after accounting for all possible sources that reduce his or her power, such as varieties of subordinate power, task and organizational design power, and power sources extraneous to the immediate system. This model has been used successfully in cases involving a Central American Sugar Mill and a U. S. Copper Mining company.

[43] (*) Linn, R. L., and J. A. Slinde, "The Determination of the Significance of Change Between Pre and Posttesting Periods," Review of Educational Research, Vol. 47 (1977), 121-150.

This article notes some of the problems with the use of various numerical change indicators. For example, difference scores can have negative correlation with the pretest, low reliability, and lack of common trait and scale. Residual scores, which have a zero correlation with the pretest, also suffer from unreliability. The authors conclude by stating that there are numerous problems in measuring change, most notably the main problem of change scores concealing conceptual difficulties and giving misleading results.

[44] (**) Lippitt, G., "Managing Change: 6 Ways to Turn Resistance Into Acceptance," Supervisor Management Magazine, Vol. 11, No. 8, 21-24.

It is noted that the way a supervisor introduces

change, rather than the change itself, may cause transition resistance. Nine supervisory actions may cause resistance: (1) Failing to be specific about the change, (2) Failing to show why a change is necessary, (3) Failing to allow those affected by change to have a say in the planning, (4) Using a personal appeal to gain acceptance of a change, (5) Disregarding a work group's habit patterns, (6) Failing to keep employees informed about a change, (7) Failing to allay employee worries about possible failure, (8) Creating excessive work pressure during a change, and (9) Failing to deal with anxiety over job security. Six ways to reduce resistance are offered by the author: (1) Involve employees in planning the change, (2) Provide accurate and complete information, (3) Give employees a chance to air their objections, (4) Always take group norms and habits into account, (5) Make only essential changes, and (6) Learn to use problem-solving techniques.

[45] (**) Lippitt, R., J. Watson, and B. Westley, <u>The Dynamics of Planned Change</u> (New York: Harcourt, Brace and Co., 1958).

The authors present an expanded, change agent oriented model of change that is based on the Lewin three phase (unfreezing, change, freezing) change model. This model consists of seven phases, which are extensively discussed in the book:

Phase 1: The client system discovers the need for help, sometimes with stimulation by the change agent ("unfreezing").

Phase 2: The helping relationship between the client and the change agent is established and defined.

Phase 3: The change problem is identified and clarified.

Phase 4: Alternative possibilities for change are examined; change goals or intentions are established.

Phase 5: Actual change efforts are attempted.

(Phases 3, 4, and 5 are analogous Lewin's change step.)

Phase 6: Generalization and stabilization of the change program is sought ("freezing").

Phase 7: The helping relationship ends or a different type of continuing relationship is defined.

[46] (*) Lovelady, L., "Planned Change: Problems at the Union / Management Interface," <u>Industrial Relations Journal</u>, Vol. 8, No. 3 (Autumn 1977), 43-58.

This article gives the theoretical background on the process of planned change in organizations that have employees represented by trade unions. As with other organizations, employee involvement, commitment, and participation is essential for a change program to be successful. Other resistances to change noted by the author include the traditional management - union adversary relationship, inflexible union structure and organization, and insufficient time allotment to the change program. These resistances may be overcome by using an extension of the present system of collective bargaining, appointing workers' representatives to the organization's Board of Directors, and involving employees and their representatives in those matters which most closely affect them at the workplace and to which they can contribute.

[47] (*) Lynch, M., Planned Organizational Change: An Analytical Model," *Philippine Journal of Public Administration*, Vol. 14 (January 1970), 31-40.

The author of this paper proposes an alternative analytical typology for the classification of strategies and/or tactics previously proposed by Jones and Niaz (see Figure 2.9). The typology proposed in Lynch's paper consists of three strategy/tactic dimensions: (1) Unit of analysis, (2) Role of unit members, and (3) Position of the unit of analysis. This typology is considered superior to previous strategy/tactic classifications because: (1) This classification uses variables that are relevant to other popular theories such as administrative ecology, power structure analysis, and decision-making, (2) Other classifications are not readily transferable into graphic representation (see Figure 2.10), (3) The other systems is more subjective, and therefore more subjective and less reliable, and (4) the other models do not contain the prime requisite of a valid typology -mutually exclusive categories.

[48] (**) Lynn, G., and J. B. Lynn, "Seven Keys to Successful Change Management," *Supervisory Management*, Vol. 29, No. 11 (November 1984), 30-37.

Although no "cookbook" formulas for change management have been identified by the authors, seven common denominators in the approaches of adaptable companies like Delta Airlines and Hewlett Packard are introduced. These are:

(1) The managers of successful change organizations have a clear picture of exactly where they want their companies to go and what they want them to accomplish,
(2) Successful change managers understand that people, including themselves, naturally resist change,
(3) Management must commit itself in deed as well as word to the accomplishment of the change,
(4) Those responsible for implementing the change in their day-to-day operations should be involved in the change planning process,

(5) Change implementation should be first tested on a small-scale,
(6) The change effort must be evaluated, and
(7) The right time for full-scale implementation of the change effort must be carefully determined.

Also, in order to assist managers in planning a change program, a Change Planning Checklist is presented (see Figure 2.11).

[49] (*) Mangham, I., The Politics of Organizational Change (London: Associated Business Press, 1979).

In this book, the political aspects of change were examined. Five types of change processes were described: unilateral decree, personnel changes, structural rearrangement, group agreement with decisions formulated elsewhere, and collective (participative) decisionmaking. Also, change programs should attempt to structure the organization such that there is team play, sharing of responsibility, expression of feelings and personal needs, collaboration, open and constructive conflict, feedback on performance, flexible leadership, involvement, trust, and adaptiveness.

[50] (***) Mann, F. C., "Studying and Creating Change: A Means to Understanding Social Organizations," in C. M. Arensburg (Ed.) Research in Industrial Human Relations (New York: Harper, 1957).

Based on the author's research, seven psychological and sociological facts must be taken into consideration in attempting to change the attitudes and behavior of and individual or a group of individuals in an organizational setting. These seven facts are:

(1) Change processes need to be concerned with altering both the forces within an individual and the forces in the organizational situation surrounding the individual.
(2) Existing organizational forces such as rights and privileges, reciprocal expectations, and shared frames of reference must first be made pliable, then altered and shifted, and finally made stable again to support the change.
(3) Expectations of the supervisor are more important forces for creating change in an individual than the expectations of the subordinates.
(4) Change processes designed to work with individual supervisors off the job in temporarily created training groups contain less force for initiating and reinforcing change than those which work with an individual in situ.
(5) Change processes organized around objective, new social facts about one's own organizational situation have more force for change than those

organized around general principles about human behavior. The more meaningful and relevant the material, the greater the likelihood of change.

(6) Involvement and participation in the planning, collection, analysis, and interpretation of information initiate powerful forces for change. Own facts are better understood, more emotionally acceptable, and more likely to be utilized than those of some "outside expert". Participation in analysis and interpretation helps by-pass those resistances which arise from proceeding too rapidly or too slowly.

(7) Change processes which furnish adequate knowledge on progress and specify criteria against which to measure improvement are apt to be more successful in creating and maintaining change than those which do not.

[51] (***) Mann, F. C., and F. W. Neff, Managing Major Change in Organizations (Ann Arbor: The Foundation for Research on Human Behavior, 1961).

A five-phase approach to change was proposed: (1) Analysis of the old state, (2) Recognition of the need for change, (3) Planning for change, (4) Taking the action steps to make the change, and (5) Stabilizing the change. Then, case studies of several organizations using this model were presented to validate the authors' claim. Throughout the article, numerous conclusions drawn from the case studies were introduced. Also, a model for understanding an individual's response to change was given (see Figure 2.12).

[52] (***) Margulies, N., and J. Wallace, Organizational Change: Techniques and Applications (Glenview, IL: Scott, Foresman and Company, 1973).

This book presents and examines a range of transition management techniques drawn from applied behavioral science that are considered useful in planned organizational change programs. These techniques include Action Research, Laboratory Training, Role Theory, and the use of Internal Consulting Teams. It also looks at the factors that determine the choice of a transition technique such as context, cost, and appropriateness for given organizational problems. Furthermore, it offers six major propositions for change:

(1) Regardless of initial focus, any change effort in which changes in individual behavior are required must include means for ensuring that such changes occur.

(2) Organizational change is more likely to be met with success when key management people initiate and

support the change process.

(3) Organizational change is best accomplished when persons likely to be affected by the change are brought into the process as soon as possible.

(4) Successful change is not likely to occur following the single application of any technique.

(5) Successful change programs must rely upon informed and motivated persons within the organization if the results are to be maintained.

(6) No single technique is optimal for all organizational problems, contexts, and objectives.

[53] (**) Margulies, M., P. L. Wright, and R. W. Scholl, "Organization Development Techniques: Their Impact on Change," Group & Organization Studies, Vol. 2 (1977), 428-448.

Organizations are composed of technical, management, and human subsystems (see Figure 2.13). It is proposed that each of these subsystems may be changed through the direct application of appropriate OD transition methods. Specifically, it was found that for changes in the human system, organizational sensitivity training, team building, and survey feedback methods should be used. Likewise, job redesign and sociotechnical interventions promote changes in the technical subsystem. Also, management subsystem change may be accomplished by altering the formal structure of the firm and/or by modifying the organizational control method.

[54] (****) McFeely, W. M., "Organization Change Perceptions and Realities," (New York Conference Board, 1972).

Organizations do not seem to initiate major strategic changes until the pain of not making a change is perceived by those in a position to take action as being greater than their perception of the pain of change. Once the decision is made to undergo change, seven highly interdependent organizational elements should be considered: (1) Linkage or networking; (2) Long versus short term emphasis; (3) Paths of decision-making; (4) Reward system; (5) Administrative constraints; (6) Cultural constraints; and (7) Self-correcting mechanisms. Additionally, seven guidelines for change were given:

(1) There can be no major organizational change without a change in management style.

(2) A change in management style requires a change in people.

(3) The time frame of change tends to be much longer if it is to be implemented by the incumbent management group as contrasted with putting new persons in various key positions within the components affected

by the change.

(4) If there is to be a major change with little time for implementation, the odds are against the incumbent team being able to do it.

(5) If a minor change is contemplated with much time in which to carry it out, the probabilities are that the incumbent team can do it.

(6) If the planned change is minor in nature, but there is little time for implementation, the odds still favor the incumbent team, but the flexibility of of that team must be examined more critically and be given substantial weight in the decision.

(7) If the change is of major magnitude with much available time for implementation, the likely situation will be that of a holding action by the incumbent team with the significant "breakthrough" coming at such time as a new chief executive can be moved in graciously.

[55] (***) Micheal, Stephen R., Fred Luthans, George S. Odiorne, W. Warner Burke, and Spencer Hayden, Techniques of Organizational Change (New York: McGraw-Hill, 1981).

This book presents six techniques of organizational change: Organizational Behavioral Modification (OBM), Management By Objectives (MBO), Management Development (MD), Organization Development (OD), Management Auditing (MA), and Control Cycle (CC). These techniques are compared in Table 2.9. OBM involves changes employee behavior through a five-step process: (1) Identification of critical behaviors; (2) Measurement of the behaviors; (3) Functional analysis of the behaviors; (4) Development and implementation of an intervention strategy; and (5) Evaluation to assure performance improvement. MBO is a management and transition method whereby the superior and the subordinate managers in an organization identify major areas of responsibility in which the employee will work, set some standards for good - or bad - performance, and plan for the measurement of results against those standards. MD shapes managerial behavior through the use of internal and external training programs, coaching, and counseling. OD is a planned, organization-wide, and top-level managed program to increase organization effectiveness through planned interventions in the organization's process using behavioral science knowledge. MA consists of a comprehensive audit of an organization's management personnel and procedures. CC, comprised of the managerial processes of planning, implementing, and evaluating projects, is essentially a control mechanism for bringing about organizational change.

[56] (**) Miller, Danny and Peter Friesen, "Structural Change and Performance: Quantum Versus Piecemeal-Incremental Approaches," Academy of Management Journal, Vol. 25, No. 4, 867-892)

Quantum change is said to occur when the anticipated organizational change happens in a concerted and dramatic way (this is also known as dissipative change); otherwise, a slow and gradual change process is said to be incremental in nature. Based on the research of the authors into structural change of organizations, it was found that successful firms generally had a significantly higher percentage of extreme changes along structural variables than unsuccessful firms. It was also found that incremental structural change was less likely to be undertaken by high performing firms.

[57] (**) Moore, M., and P. Gergen, "Risk Taking and Organizational Change," Training and Development Journal, Vol. 39, No. 6 (June 1985), 72-76.

This paper addresses the risk-taking involved in transition management. Four key structural/cultural factors were found to influence risk-taking: (1) Organization expectations, (2) Reward systems, (3) Support systems, and (4) Available resources. Interacting with the structural factors, personal tendencies such as propensity to taking risks, previous experiences, and decision-making skill affect the process (see Figure 2.14). The authors note that organizations can reduce risk through clear organizational expectations, equitable reward systems, effective support systems, and adequate resources.

[58] (**) Morse, N. C., and E. Reimer, "The Experimental Change of a Major Organizational Variable," Journal of Abnormal and Social Psychology, Vol. 52 (1956), 120-129.

A field experiment in an industrial setting was conducted in order to test hypotheses concerning the relationship between the means by which organizational decisions are made and (a) individual satisfaction, and (b) productivity. The experiment involved the measurement of satisfaction and productivity in two separate work environments - one with a high degree of worker participation and autonomy in the decision-making process, the other with low amount of worker participation. The results of this experiment showed that the individual satisfactions of the work group members increased significantly in an autonomous work environment (with increased role in the decision-making process) and decreased significantly in an hierarchically controlled environment (with a decreased role in the decision-making process). Also, contrary to expectation, both decision-making systems had increased productivity, with the hierarchically-controlled program having a greater increase. The authors partially attribute this finding to the Hawthorne effect (i.e., greater attention to the system by the experimenters caused the increase).

[59] (*) Pettigrew, A. M., "On Studying Organizational Cultures," Administrative Science Quarterly, December 1979.

This paper looks at some of the concepts and process associated with the creation of culture within organizations. The subject under investigation was a private British boarding school from the years 1934 - 1975. The author notes that culture is instilled in organizational members through statements of mission, activities, selective recruitment, and socialization. Furthermore, he notes that culture is manifested through symbols, language, ideologies, beliefs, rituals, and myths. One issue that is highly stressed is that commitment is a key factor for cultural change.

[60] (****) Pfeiffer, J. William, and John E. Jones, The 1980 Annual Handbook For Group Facilitators (San Diego: University Associates, Inc, 1980).

This publication presents a variety of tools and knowledge in the field of Organizational Development (OD). Discussions on an Organizational Diagnosis Questionnaire, a nine-step problem solving model (see Table 2.10), accelerating the stages of group development, a strategy for cultural transitions, OD intervention assessment techniques, and a glossary of frequently used terms in OD and planned change were presented.

[61] (*) Schein, V., "Political Strategies for Implementing Organizational Change," Group and Organization Studies, Vol. 2 (1977), 42-47.

The author notes that little is written about the power and political strategies that are used to implement OD interventions. If a change agent cannot contend with these political forces, he is likely to be overpowered by those who perceive his change approaches as endangering their own power. Thus, supervisors, middle managers, the personnel department, and other staff groups, perceiving the change program as a threat to their power, employ a variety of overt and covert tactics to resist the change. In order to overcome these resistances, Schein suggests that change agents align with powerful allies such as top management, have good credentials to increase their referent power, and maintain a non-threatening, neutral appearance.

[62] (**) Sears, L. N. Jr., "Organization and Human Resource Professionals in Transition," Human Resource Management, Vol. 23, No. 4 (Winter 1984), 409-421.

This article discussed the marginal impact of the OD field on strategic business performance. Three reasons for this were noted: (1) OD has had trouble finding a strategic position in most organizations. Usually being a staff position buried several levels down in the human resource or personnel funciton, it has serious political access and legitimacy problems as compared with high level business decision making; (2) OD professionals often are not well versed in the business issues facing their client; (3) The concepts and skills of OD are generally not possessed by the senior human resource managers who are formally closer to the senior line; thus, OD is not used or strongly advocated. Also, the author advocated a systems approach to organizational analysis (see Figure 2.15).

[63] (*) Seashore, S., and D. Bowers, Changing The Structure and Functioning of an Organization (Ann Arbor: Institute for Social Research, University of Michigan, 1968).

This book concerns a change effort in a prominent firm to increase: (1) The emphasis of the company toward the work group as a functioning unit of organization; (2) The amount of supportive behavior on the part of supervisors; (3) Employee participation in decision-making processes within their area of responsibility; and (4) The amount of interaction and influence among work group members. The foci of the change effort included policy change and clarification, change in organizational structure, and interpersonal skills development. While the results of the program were deemed inconclusive, it was found that stresses upon the organization from internal and external sources caused a significant amount of resistance to change.

[64] (*) Seashore, S. and D. Bowers, "Durability of Organizational Change," American Psychologist, Vol. 25 (1970), 227-233.

This article notes the transition of the Weldon Company after it has been purchased by the Harwood Company. Weldon was losing money, experiencing high cost, generating many errors in strategy and work performance, and suffering from high absenteeism and high turnover. The aim of the transition program was to make Weldon a viable and profitable economic unit as quickly as possible. Due to the change strategy used, the change process was very effective and durable. The

change strategy included the concepts of job security based on improved corporate performance, use of employee participation in the planning and decision-making process, and the linking of guidelines to concrete events and to the rational requirements of the work to be done and the problems to be solved.

[65] (**) Skipton, M. D., "Helping Managers to Develop Strategies," Long Range Planning, Vol. 18, No.2 (1985), p. 56-68.

The strategic management process is seen to have four sequential operations, these being analysis, planning, implementation, and control. The analysis process results in a SWOT report, which outlines Strengths, Weaknesses, Opportunities, and Threats. Planning outlines the various methods and means for obtaining the objectives. These objectives and means should be specified in all steps of strategic planning. One consideration in planning is the policy/aims and mission/purpose of the organization. Policy/aims define what the organization wants to be, and mission/purpose defines what the organization wants to do. Based on the organization's overall SWOT analysis, corporate strategy should contain objectives and means that the strategic management group identifies and wishes to pursue in the future. A business strategy matrix that incorporates the concepts of mission/purpose and policy/aims is shown in Table 2.11.

[66] (***) Taylor, J. C., Technology and Planned Organizational Change (Ann Arbor: Institute for Social Research, University of Michigan, 1971)

Based on the research of the author, five conclusions concerning technology and planned organizational change were found:

(1) A measure of production technology sophistication could be developed which had a reasonably high inter-rater reliability and factorial and convergent validity.
(2) The measure of technological sophistication distinguished between groups with different pre-change levels of subordinate perceptions of supervisory and work group behaviors.
(3) Technological sophistication does facilitate or enhance change forces in the direction of participative management or autonomous group functioning.
(4) Technological sophistication seems to operate as a conditioning variable in social change efforts both directly through situational constraint on worker behavior, and indirectly through affecting interconnectedness of social subsystems.

(5) Technological sophistication acts to increase permanence of change efforts by providing a situation where changes in attitudes are strong subsequent effects of changed behaviors. These changed attitudes appear to be reinforcing factors in the continuance of the changed behaviors.

[67] (**) Tichy, N. M., "How Different Types of Change Agents Diagnose Organizations," Human Relations, Vol. 28, No. 12 (1975), 771-800.

In this article, the author discusses four types of change agents: (1) Outside Pressure (OP), (2) Organization Development (OD), (3) Analysis for the Top (AFT), and (4) People Change Technology (PCT). OP's focus primarily on changing the way systems relate to their external environment. OD's focus on internal processes instead of individual functioning. Also, OD's work collaboratively with the client system to help them solve their problems and to improve their system's problem-solving ability. AFT's focus primarily on the system's external relationships with its environment and whose leverage for change is from inside at the top of the organization. AFT's essentially work with business and government units and are interested in improving 'efficiency' and 'output' of the systems they work with. PCT's concentrate their change efforts on individual functioning within organizations. Using behavioral science techniques, they attempt to improve efficiency and output, system problem-solving, and power equalization and responsiveness to the general public interest. The percentage of OP's, AFT's, OD's, and PCT's that employ different types of organizational diagnostic techniques is displayed in Table 2.12.

[68] (**) Toronto, R., "A General Systems Model for the Analysis of Organizational Change," Behavioral Science, Vol. 20, No. 3 (1975), 145-157.

It is proposed that organizations are systems comprised of several elements (see Figure 2.16). Of these elements, there are three key ones: (1) The authority figure, who has the legitimate organizational authority to make decisions which effect the organization below him; (2) The system structure, which is the totality of relations among the components of the system; and (3) The suprasystem structure, which is the structure of relations among different systems that impinge upon the activity, productivity, and the effectiveness of the system being studied. This model of organizations leads to four major propositions concerning organizational change that were supported by the author's research: (1) Changes in the suprasystem induce changes in the system, but not vice-versa; (2)

Changes in structure induce changes in program, but not vice-versa; (3) Permanent change in system activity data requires a change in and the subsequent equilibration of both the system and its suprasystem; and (4) The hierarchy of constraining influence on a system's activity in order decreasing constraint is: suprasystem structure, suprasystem program, system structure, system program.

[69] (**) Tosi, H., J. Hunter, R. Chesser, J. Tarter, and S. Carroll, "How Real are Changes Induced by Management by Objectives," Administrative Science Quarterly, Vol. 21, No. 2 (1976), 276-306.

In order to test how effective Management by Objectives is in facilitating organizational change, the authors used a questionnaire to gather transition data from two organizations. This questionnaire assessed goal, feedback, superior-subordinate characteristics, and end-result variables. After using correlational techniques to draw causal inferences from the various parameters of the transition model, it was shown that no-change had occurred. However, due to some contradictions in the data, the authors recommend that further studies be done to verify this conclusion.

[70] (***) Warmington, A., "Stress in the Management of Change," in D. Gowler and K. Legge (Eds.) Managerial Stress (New York: Halsted, 1975)

This article analyzes the the sources of stress which are inherent in organizational change programs. The most likely kind of stress to be encountered comes from difficulties between members of the change program and the people in the rest of the organization. These difficulties may be in communications, of the perceived legitimacy and acceptability of the program, or from employees who feel that they are under pressure to change their behavior. Also, there may be uncertainties and anxieties among members of the change unit about the nature of their task and the criteria for success. Unit members individually and collectively will suffer personal anxieties about their position in the company, the way they as individuals are being appraised in conditions of unusual vagueness and ambiguity, how they now fit, and will fit in future, into the status and power structure of the organization, and how appointment to the team has affected their chances of advancement. Finally, individuals are likely to experience internal stress and dissonance as their own value systems and perceptions of the wider organization and its behavior patterns change and as they try to resolve some of the external causes of tension. The author offers several methods for reducing stress. One method is for the unit

undergoing change to try to gain the attention of key people in very senior positions in the company, and to organize themselves to play a useful role as staff advisers and assistants to board members on a variety of policy and planning matters in which their newly acquired expertise can manifest itself.

[71] (*) Warmington, Allan, Tom Lupton, and Cecily Gribbin, Organizational Behavior and Performance: An Open Systems Approach to Change (London: Macmillan, 1977).

The authors contend that organizations should be viewed as socio-technical systems comprised of nine elements: product market variables, resource market variables, labor market variables, designed technical variables, designed mediating mechanisms, attitudinal variables, unofficial manipulatory devices, behavioral variables directly influencing performance, and dependent cost and technical performance variables. These elements and their interactions may considered as change levers (see Figure 2.17 and Table 2.13).

[72] (***) Watson, G., "Resistance to Change," in W. G. Bennis, K. F. Benne, and R. Chin (Eds.) The Planning of Change (New York: Holt, Rinehart, and Winston, 1969).

Twelve recommendations for the prevention and minimization of resistance to change are offered. These suggestions are grouped into three categories, based on who initiates the change, what kind of change is being proposed, and specific procedures for instituting change.

Group 1: Who initiates the change

1. Resistance to change will be less if administrators and other key personnel feel that the project is their own - not one devised and operated by outsiders.
2. Resistance will be less if the project clearly has wholehearted support from top officials of the system.

Group 2: What kind of change

3. Resistance will be less if participants see the change as reducing rather than increasing their present burdens.
4. Resistance will be less if the project accords with values and ideals which have long been acknowledged by participants.
5. Resistance will be less if the program offers the kind of new experience which interests participants.
6. Resistance will be less if participants feel that their autonomy and their security is not threatened.

Group 3: Procedures for instituting change

7. Resistance will be less if participants have joined in diagnostic efforts leading them to agree on what

the basic problem is and to feel its importance.

8. Resistance will be less if the project is adopted by consensual group decision.
9. Resistance will be reduced if proponents are able to empathize with opponents; to recognize valid objections; and to take steps to relieve unnecessary fears.
10. Resistance will be reduced if it is recognized that innovations are likely to be misunderstood and misinterpreted, and if provision is make for feedback of perceptions of the project and for further clarification as needed.
11. Resistance will be reduced if participants experience acceptance, support, trust, and confidence in their relations with one another.
12. Resistance will be reduced if the project is kept open to revision and reconsideration if experience indicates that changes would be desirable.

[73] (****) Zaltman, G., and R. Duncan, Strategies for Planned Change (New York: John Wiley & Sons, 1977).

Numerous transition management principles that would be useful to change agents are offered in this book. Facilitative, re-educative, persuasive, and power strategies for change were presented. Cultural, social, organizational, and psychological barriers were discussed. Also, the characteristics of change agents, organization members, and the organizations themselves are extensively examined.

[74] (**) Zander, A., "Resistance to Change - Analysis and Prevention," Advanced Management, Vol. 15-16 (Jan. 1962), 9-11.

The author cites six causes of transition resistance. Resistance can be expected if:

(1) The nature of the change is not made clear to the people who are going to be influenced by the change,
(2) Management does not account for the fact that different people will see different meanings in the proposed change,
(3) Those influenced by the change are caught between strong forces pushing them to make the change (i.e., management) and strong forces deterring them against making the change (i.e., peer pressure),
(4) The change is make on personal grounds rather than impersonal requirements or sanctions, and
(5) The change ignores the already established institutions in the group.

It is proposed that resistance can be prevented to the degree that the changer helps the changees to develop their own understanding of the need for the change, and an explicit awareness of how they feel about it, and what can be done about those feelings. This rule has the following implications:

(1) Two-way communications must be maintained, or negative attitudes will persist and increase in intensity,

(2) Resistance may be less likely if the group participates in making the decisions about how the change should be implemented, what the change should be like, how people might perform in the changed situation, or any other problems that are within their area of freedom to decide, and

(3) Resistance will be less likely if facts which point to the need to change are gathered by the persons who must make the change.

Table I. Major Problems Encountered in Evaluating OD Efforts as Identified by Change Agents[a]

Problem	Frequency	Percent
Methodological		
Selection and quantitative measurement of soft criteria	24	22
Difficulties of employing comparison groups	22	21
Controlling for extraneous influences	21	20
Criterion deficiency	4	4
Problems with time lags	3	3
Administrative		
Difficulty in devoting time and financial resources to evaluation of OD efforts	20	19
Miscellaneous (such as)	13	12
Communicating to managers what OD can and cannot do		
Conflict between adequate research design and helping a client		
Total	107	101%[b]

[a] $N = 101$.

[b] Percentages do not sum to 100 percent due to rounding.

Table 2.1 [3]

PARADIGM FOR CHANGE PROCESSES

Power ratio	*Mutual goal setting*		*Nonmutual goal setting (or goals set by one side)*	
	Deliberate on the part of one or both sides of the relationship	*Nondeliberate on the part of both sides*	*Deliberate on the part of one side of the relationship*	*Nondeliberate on the part of both sides*
.5/.5	Planned change	Interactional change	Technocratic change	"Natural" change
1/0	Indoctrinational change	Socialization change	Coercive change	Emulative change

Table 2.2 [7]

A model of induced change

Tension experienced within the system	Intervention of a prestigious influencing agent	Individuals attempt to implement the proposed changes	New behavior and attitudes reinforced by achievement, social ties, and internalized values—accompanied by decreasing dependence on influencing agent
	Generalized objectives established	Growing specificity of objectives—establishment of subgoals	Achievement and resetting of specific objectives
Tension within existing social ties	Prior social ties interrupted or attentuated	Formation of new alliances and relationships centering around new activities	New social ties reinforce altered behavior and attitudes
Lowered sense of self-esteem	Esteem-building begun on basis of agent's attention and assurance	Esteem-building based on task accomplishment	Heightened sense of self-esteem
	External motive for change (New schema provided)	Improvisation and reality-testing	Internalized motive for change

Table 2.3 [15]

Unfreezing		Change	Refreezing
Tension and the need for change was experienced within the organization.	Change was advocated by the new director.	Individuals within the organization tested out the proposed changes.	New behavior and attitudes were either reinforced and internalized, or rejected and abandoned.

Table 2.4 [15]

Away from:	and	Toward:
Generalized goals	⟶	Specific objectives
Former social ties built around previous behavior patterns	⟶	New relationships which support the intended changes in behavior and attitudes
Self-doubt and a lowered sense of self-esteem	⟶	A heightened sense of self-esteem
An external motive for change	⟶	An internalized motive for change

Table 2.5 [15]

Characteristics of Successful and Unsuccessful Change in Organizations, Including Nondifferentiating Characteristics

Category	*Nondifferentiating characteristics*	*Successful*	*Unsuccessful*
ORGANIZATION'S ENVIRONMENT	Geographical location State of the industry[a] Scope of the market[b]	Expanding market Labor drawn from suburban areas Higher pay rate	Steady market Labor drawn from towns Lower pay rate
ORGANIZATIONAL CHARACTERISTICS	Size[b] Changes in size	More levels of hierarchy Heavy industry organizations Innovative reputation	Fewer levels of hierarchy Office and Sales organizations Noninnovative reputation Nonunion Insurance industry
INITIAL CONTACT	Position of contact person Negotiation period[b]		
ENTRY AND COMMITMENT	Desire to be seen as innovative Commitment for a resurvey[b] Commitment for a restructuring of the organization[b] Commitment to Survey Feedback plus Process Consultation	Interest based on prior contact with research/development staff Commitment to Survey Feedback Strategy Greater support from top management Research/development staff introduced as part of general presentation Expression of a specific problem	Interest not based on prior contact with research/development staff No commitment to Survey Feedback Strategy Lesser support from top management Self-introductions by research/development staff Expression of a general problem Not motivated by a desire to experiment with new ideas
DATA GATHERING	Total population data collections Sample data collections Time between waves of data collection Reasons for second wave of data collections[a] Credibility of the survey instrument[b]	More recent initiation of development/research effort	
INTERNAL CHANGE AGENTS	ICA selection Knowledgeability of organizational functioning and change agentry[b] Skill levels Value orientations[b] Non-change-agent experience[b] Previous change-agent experience Research posture Change-agent style	ICAs possessed assessment-prescriptive skills More care taken in ICA selection	Did not possess assessment-prescriptive skills Less care taken in ICA selection Previous ICA training More previous work experience in a personnel department
EXTERNAL CHANGE AGENTS	ECA selection[a] Care of ECA selection[a] Knowledge base[b] Value orientation[b] Skill levels Types of skills[b] Non-change-agent experience Previous change-agent experience Change-agent style Research posture		
TERMINATION PROCEDURES	Pace and planning of termination Reasons for termination (includes several dimensions)[a,b] Attitude toward effort at termination		

[a]Indicates limited variance among organizations included in this study
[b]Indicates the existence of trends (not statistically significant) suggesting differences between successful and unsuccessful organizations

Table 2.6 [20]

Methods for dealing with resistance to change

Approach	Commonly used in situations	Advantages	Drawbacks
Education + communication	Where there is a lack of information or inaccurate information and analysis	Once persuaded, people will often help with the implementation of the change	Can be very time-consuming if lots of people are involved
Participation + involvement	Where the initiators do not have all the information they need to design the change, and where others have considerable power to resist	People who participate will be committed to implementing change, and any relevant information they have will be integrated into the change plan	Can be very time-consuming if participators design an inappropriate change.
Facilitation + support	Where people are resisting because of adjustment problems.	No other approach works as well with adjustment problems	Can be time-consuming, expensive, and still fail
Negotiation + agreement	Where someone or some group will clearly lose out in a change, and where that group has considerable power to resist.	Sometimes it is a relatively easy way to avoid major resistance.	Can be too expensive in many cases if it alerts others to negotiate for compliance.
Manipulation + co-optation	Where other tactics will not work, or are too expensive.	It can be a relatively quick and inexpensive solution to resistance problems	Can lead to future problems if people feel manipulated.
Explicit + implicit coercion	Where speed is essential, and the change initiators possess considerable power.	It is speedy, and can overcome any kind of resistance.	Can be risky if it leaves people mad at the initiators.

Table 2.7 [37]

Fast	Slower
Clearly planned.	Not clearly planned at the beginning.
Little involvement of others.	Lots of involvement of others.
Attempt to overcome any resistance.	Attempt to minimize any resistance.

Key situational variables

The amount and type of resistance that is anticipated.

The position of the initiators vis-à-vis the resistors (in terms of power, trust, and so forth).

The locus of relevant data for designing the change, and of needed energy for implementing it.

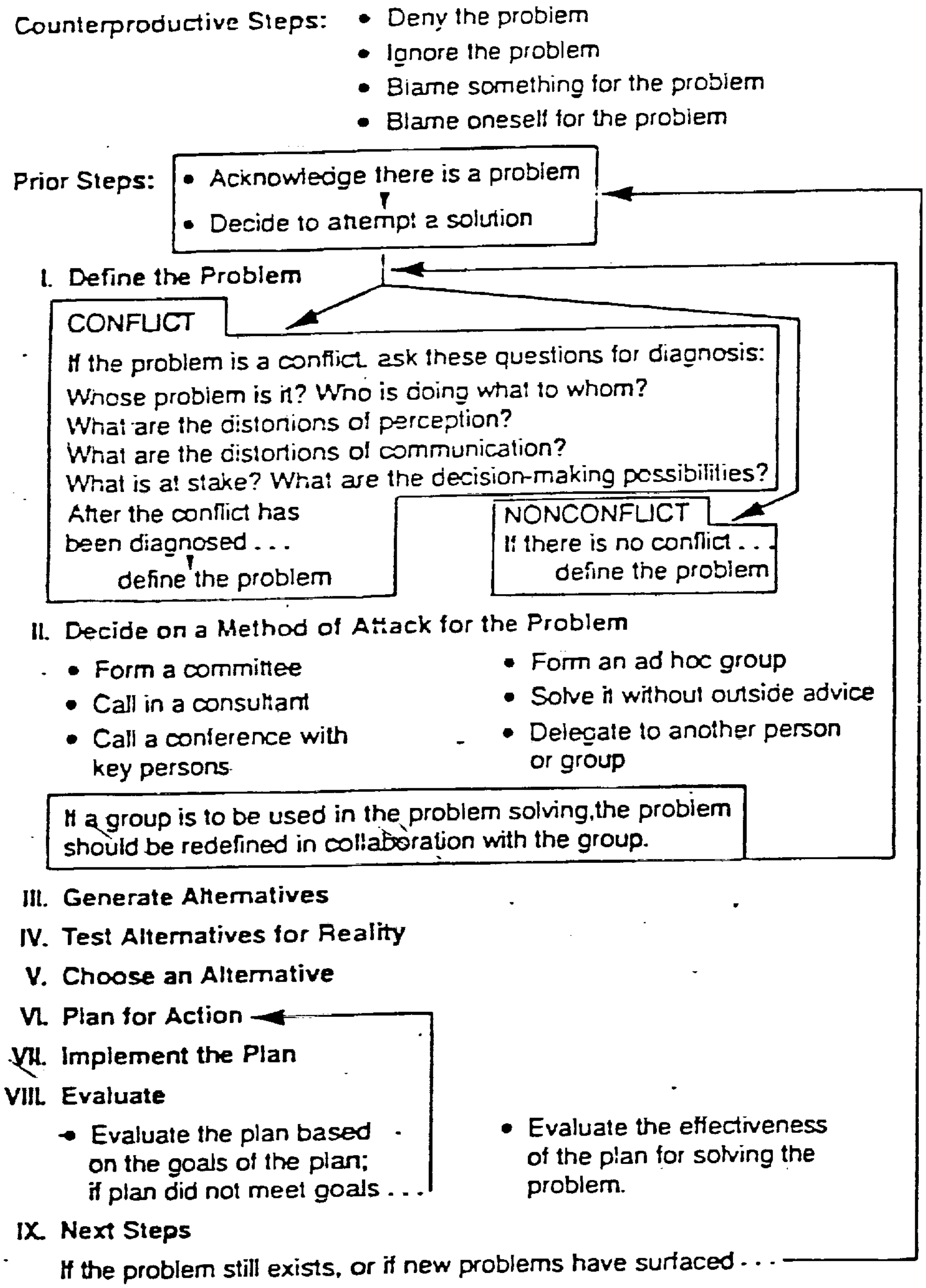
The stakes involved (e.g., the presence or lack of presence of a crisis, the consequences of resistance and lack of change).

Table 2.8 [37]

Comparison of the Techniques of Organizational Change

	Types of techniques					
Characteristic	Organizational Behavior Modification	Management by Objectives	Management Development	Organization Development	Management Auditing	Control Cycle
Focal point	Individuals	Individuals	Individuals	Entire organization or part	Entire organization or part	Entire organization or part
Symptoms of problems requiring attention	Undesirable behaviors of workers resulting in substandard performance	Different expectations and interpretations by superiors and subordinates of subordinates' performance	Deficiencies in performance of tasks requiring mental or social skills to do present job and/or lack of skills to do future job	Destructive conflict and lack of cooperation among individuals and groups	Existing or anticipated problems or opportunities: product demand and supply, structure, functions, processes	Inability to adapt organization to changing environment using feedback control on product demand and supply, structure, functions, processes
Kinds of Changes sought or achieved	Improved fit between individual and job at nonmanagerial levels primarily	Improved fit between individual and job at managerial and professional levels	Improvement in mental and social skills at managerial and professional levels	Improved interpersonal and intergroup behavior	Improvements in product demand and supply, structure, functions, processes	Improvements in product demand and supply, structure, functions, processes
Theoretical bases	Behavioral theory	Behavioral and management theories	Behavioral theory	Behavioral theory	Management theory	Management theory
Type of control	Feedback to resolve problems	Feedforward/feedback to forestall problems or exploit opportunities	Feedforward/feedback to forestall problems or exploit opportunities, or feedback to resolve problems	Feedback to resolve problems	Feedforward/feedback to forestall problems or exploit opportunities, or feedback to resolve problems	Feedforward/feedback to forestall problems and exploit opportunities
Continuity	Intermittent	Continuous	Intermittent or continuous	Intermittent	Intermittent	Continuous
Change agent	Superiors and/or inside and outside consultants	Superiors: inside and outside consultants can assist	Superiors, with Personnel or Training Department to coordinate	Outside and/or inside consultants with backing of higher management	Outside and/or inside consultants with backing of higher management	All managers, with assistance of staff group and/or outside consultants

Table 2.9 [55]



The Nine-Step Problem-Solving Model

Table 2.10 [60]

Mission/Purpose – What Business do We Want?		Policy/Aims – What do We Want to be Relative to Our Environment?			
		Take Initiative		Do Not Take Initiative	
		Same Direction(s)	New Direction(s)	Through Decision	By Default
Monitor/Have Knowledge of Environment	Existing	(1) Positive Consolidation (Company Strengthens its Hold)	(2) Explorative	(5a) Waiting Game* or (5b) Rejection **	(10) Frustrated
	New	(4) Reluctant	(3) Initiative	(6a) Waiting Game* or (6b) No Go**	(11) Incapable
Do Not Monitor/Have Knowledge of Environment	Through Decision	(9) Negative Consolidation (Company Digs a Hole for Itself)	(8) Overconfident	(7) Indifferent	(12) Defeated
	By Default	(15) Complacent	(14) Foolhardy	(13) Detached	(16) Lost

* 'Waiting Game' Implies That Strategic Management Retains the Capacity to Take an Initiative When it Chooses to do so
** 'Rejection' and 'No Go' Imply That Strategic Management Does Not Retain Any Capacity to Take an Initiative

Notes: 1. This Matrix Assumes That Knowledge is Correlated With Best Assessment of the Risks Involved
2. With Respect to Mission/Purpose it is Assumed That if the Organization Does Not Monitor, Then it Does Not Monitor New or Existing Environment and Capabilities
3. With Respect to Policy/Aims it is Assumed That if No Initiative is Taken the Organization Continues in the Same Direction(s) Through inertia
4. Each of the Business Strategies in This Matrix Represents a Continuum

A business strategy matrix for corporate strategy

Table 2.11 [65]

The percentage of OP's, AFT's, OD's and PCT's employing different diagnostic categories

Category name	*Organization development type, %*	*Outside pressure type, %*	*Analysis for the top type, %*	*People change technology type, %*	*Overall*
1. Formal structure	85%	59%	69%	71%	69%
2. Goals of the system	33%	50%	47%	55%	45%
3. Informal structure	42%	42%	49%	44%	44%
4. External relationships	45%	42%	30%	39%	39%
5. Performance	39%	44%	49%	39%	43%
6. Individual/psychological variables	42%	31%	31%	55%	38%
7. Change problem area/change problem relation	39%	25%	16%	50%	30%
8. Culture	63%	17%	21%	28%	33%
9. Resources	18%	47%	54%	22%	39%
10. Reward system	18%	14%	21%	11%	19%
11. Leadership	24%	47%	21%	8%	28%
12. Work process	44%	17%	57%	39%	40%
N	(33)	(36)	(37)	(18)	(124)

Table 2.12 [67]

Cl. .ation of Some Typical Variables in Sociotechnical Systems

Market demand variables

1 Product mix
2 Short-term fluctuations in order pattern
3 Trends in product design and specification
4 Long-term trends in forecast demand
5 Competitive nature of product market

Resource market variables

1 Fluctuations in materials market
2 Quality variations in materials
3 Alternative sources in resource market

Labour market variables

1 Labour availability (state of labour market)
2 Family and social backgrounds
3 Age structure of workforce
4 Skills typically available in area
5 Earnings levels elsewhere in locality

Attitudinal variables

1 Expectations of effort and reward
2 Attitudes to overtime
3 Worker's evaluation of fairness of rules and controls
4 Manager's perception of his role
5 Manager's perceptions and expectations of shopfloor behaviour
6 Manager's expectation of supervisor behaviour
7 Shopfloor expectations of supervisor behaviour
8 Supervisor's perception of his own role
9 Intragroup relationships of cooperation and conflict
10 Intergroup relationships
11 Perceptions about raw materials and components
12 Values and dissatisfactions found in job itself

Unofficial manipulatory devices for avoiding or reducing conflict

1 Supervisory role behaviour
2 Operator and supervisor work allocation devices
3 Training system in practice
4 Limitation in and variation in individual or group output
5 Overtime level in practice
6 Misbooking of production, rejects, work content etc.
7 Working of conflict resolution mechanisms in practice
8 Manipulation of designed production schedule and produc ix
9 Manipulation of job values or of designed payment proceo .s

Designed technical variables

1 Design and layout of plant
2 Flexibility of equipment and process, capacities and extent of balance in throughput
3 Working conditions
4 Designed work allocation procedures
5 Designed training procedures
6 Specification of skills required
7 Optimal stock levels

Designed mediating mechanisms

1 Formal control procedures
2 Supervisory structures and supervisory job definition
3 Payment systems
4 Bonus fluctuations built in the pay system
5 Job values
6 Redundancy policies
7 Selection procedures
8 Production scheduling
9 Stock policy
10 Maintenance policy
11 Purchasing policies
12 Marketing policies

Behavioural performance variables

1 Labour turnover stability
2 Rates of absence, sickness etc.
3 Skill variations (as far as significant for operation of process)
4 Output per shift
5 Level of earnings
6 Actual manning levels

Dependent cost and technical performance variables

1 Unit cost
2 Rate of mechanical breakdown
3 Level of rejects
4 Level of recirculation, runs etc.
5 Demand for labour inputs
6 Percentage of trainees in workforce
7 Actual stock levels
8 Plant utilisation level
9 Manpower utilisation level

Table 2.13 [71]

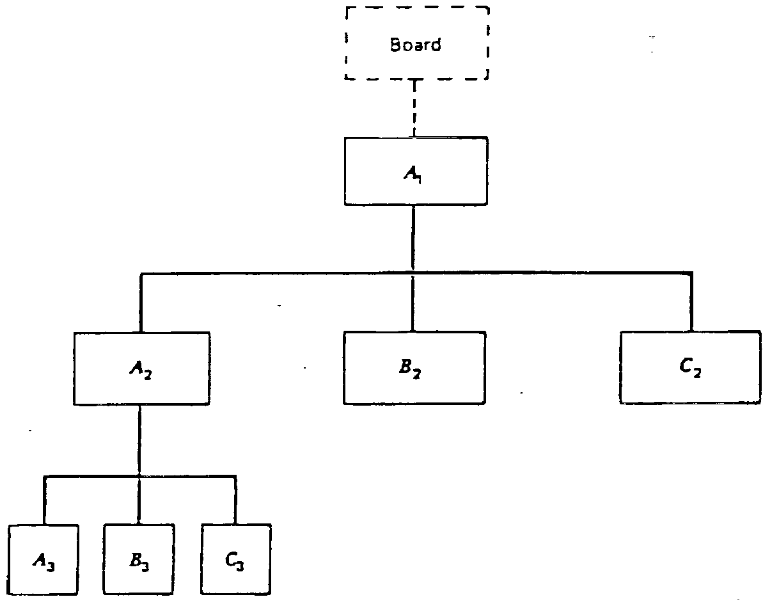


Figure 2.1 [1]

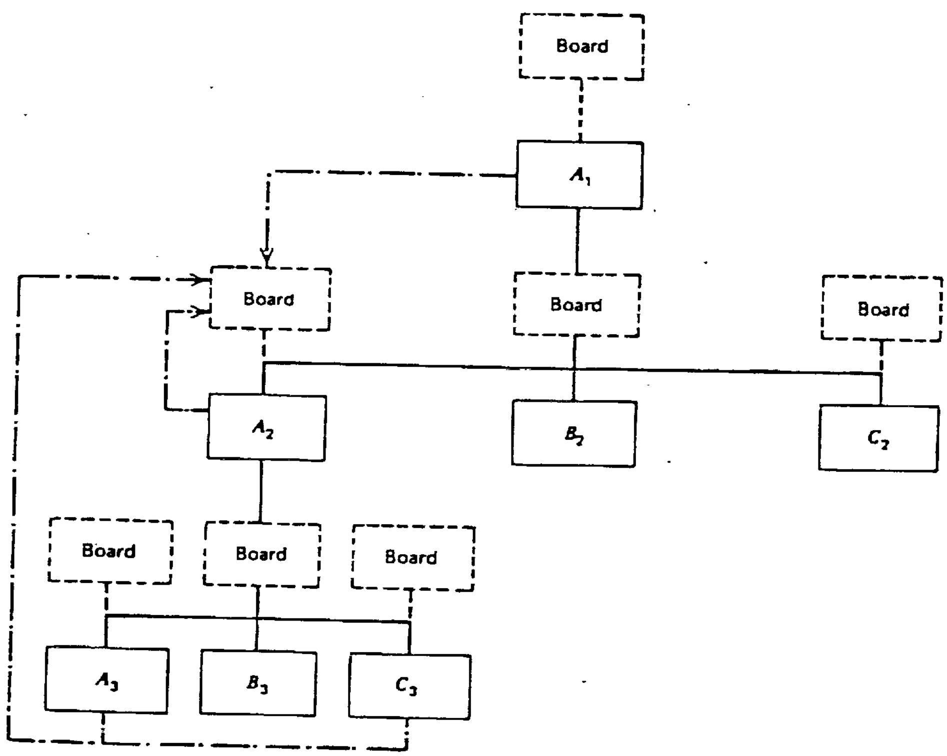


Figure 2.2 [1]

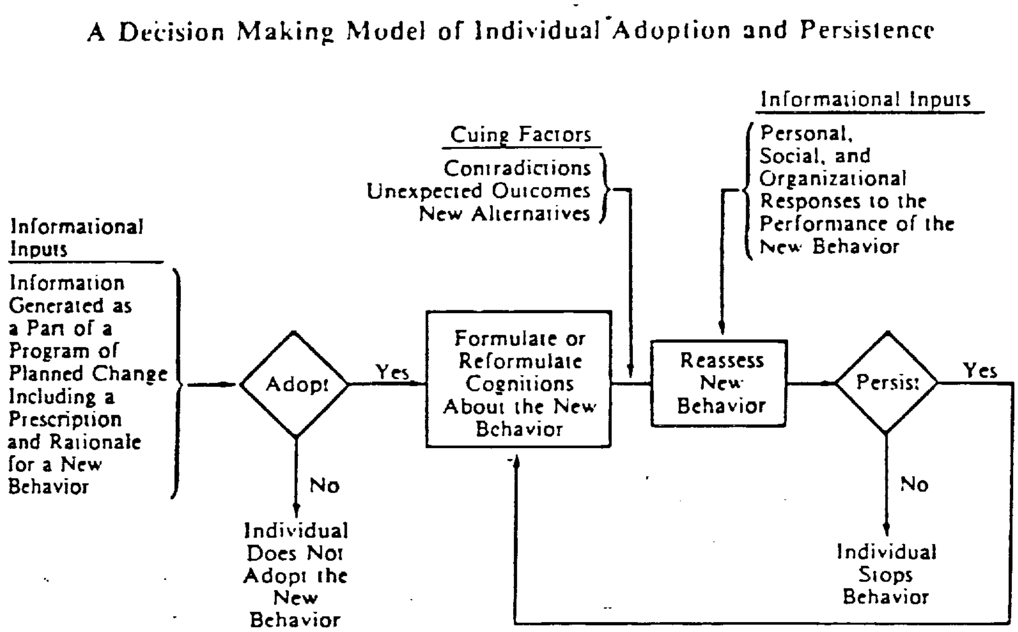


Figure 2.3 [12]

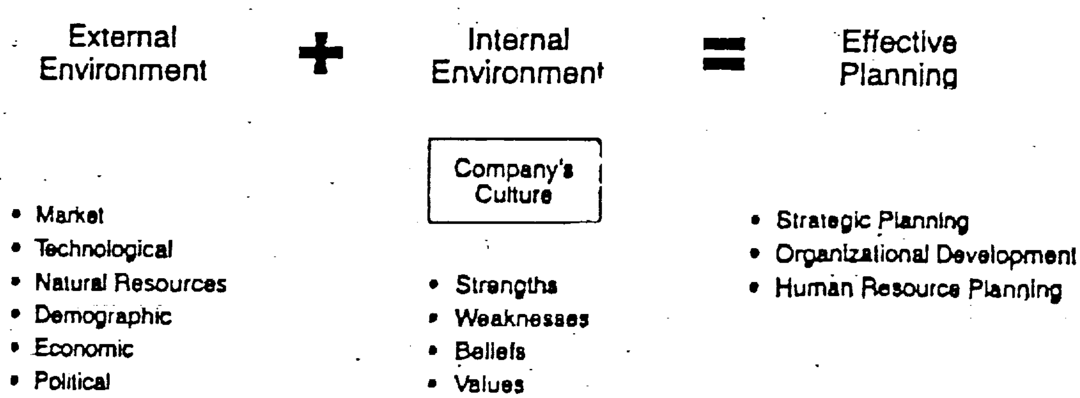


Figure 2.4 [18]

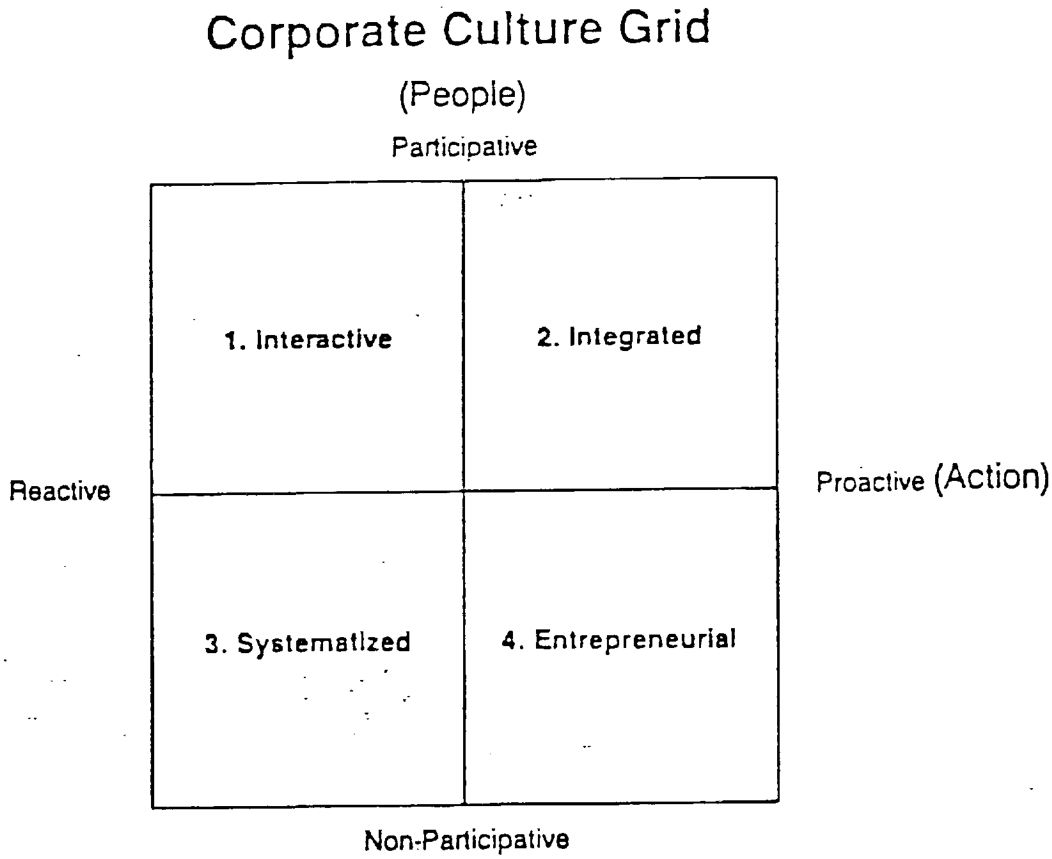

Corporate Culture Grid
(People)
Participative
1. Interactive
2. Integrated
Reactive
Proactive (Action)
3. Systematized
4. Entrepreneurial
Non-Participative

Figure 2.5 [18]

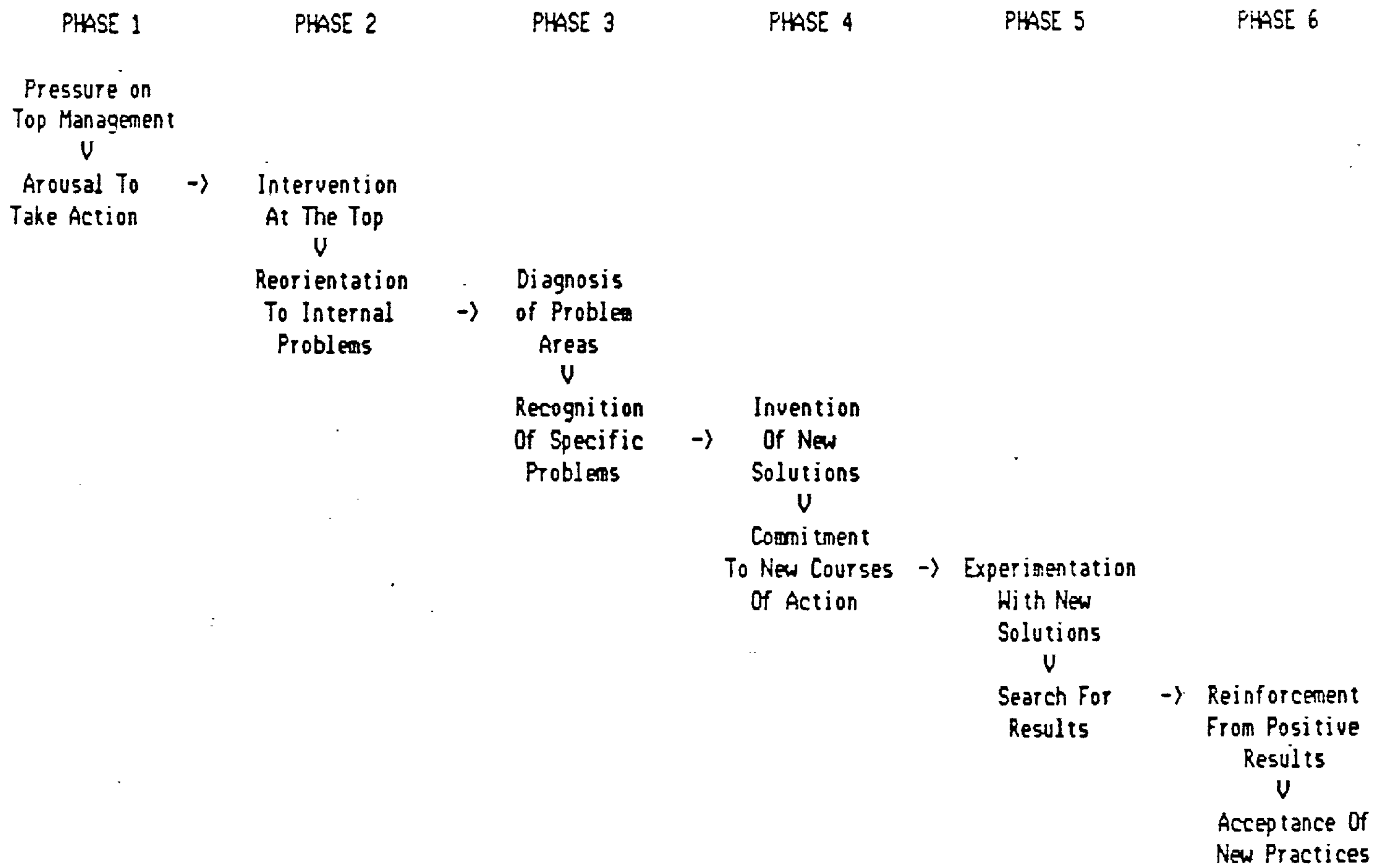
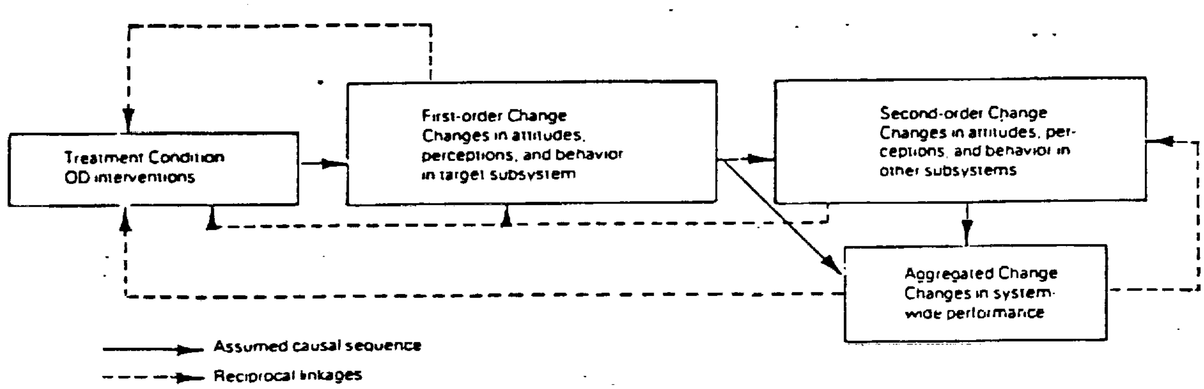
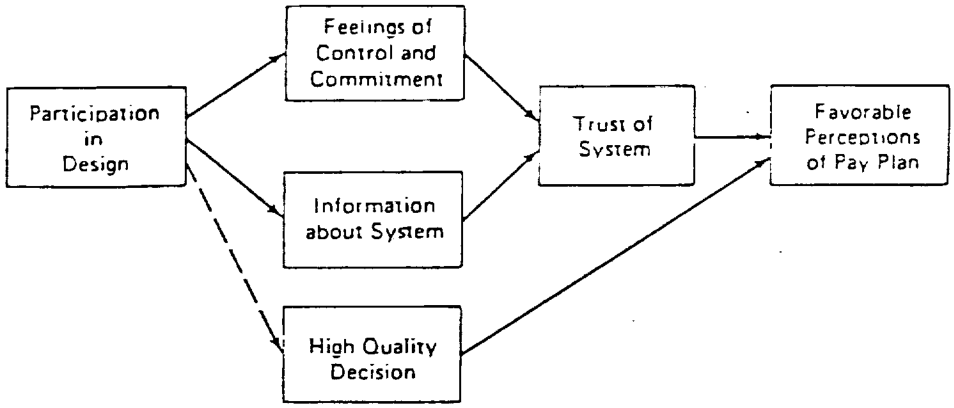


Figure 2.6 [27]



Causal linkages in planned change

Figure 2.7 [35]



The effects of participation on perceptions of pay.

Figure 2.8 [39]

5. *Strategies and Tactics*

5.1 *Coercive Strategies*

5.11 Strategy of Pressure
5.12 Strategy of Hierarchy
5.13 Strategy of Stress Induction

5.2 *Normative Strategies*

5.21 Strategy of Participation
5.22 Strategy of Involvement – Commitment
5.23 Strategy of Feedback Evaluation and Follow-up
5.24 Strategy of Displacement of Values
5.25 Strategy of External Relations
5.26 Strategy of Social Awareness
5.27 Strategy of Education and Training

5.3 *Utilitarian Strategies*

5.31 Strategy of Placement
5.32 Strategy of Empiricism
5.33 Strategy of Condition Assistance
5.34 Strategy of Goal Setting

5.4 *Tactics*

5.41 Tactic of Action Research
5.42 Tactic of Training – Counselling Syndrome
5.43 Tactic of Timing
5.44 Tactic of Technical Modification
5.45 Tactic of Manipulation of Charisma
5.46 Tactic of Communication
5.47 Tactic of Marginality
5.48 Tactic of Voluntary Association

* Garth Jones and Aslam Niaz. "Strategies and Tactics of Planned Organizational Change: A Scheme of Working Concepts," *Philippine Journal of Public Administration*, Vol. VII, No. 4 (October 1963), p. 276.

Figure 2.9 [47]

TYPOLOGY OF PRIMARY UNITS: INTERNALLY EMPLOYED STRATEGIES

		UNIT OF ANALYSIS	
ROLE OF UNIT MEMBERS		INDIVIDUAL	ORGANIZATION
	PARTICIPANT	I. 1. Training - Counseling Syndrome* 2. Involvement - Commitment 3. Marginality* 4. Voluntary Association* 5. Participation in Decisions	III. 1. Feedback, Evaluation and Follow-Up 2. Conditional Assistance
	NON PARTICIPANT	II. 1. Displacement of Values 2. Social Awareness 3. Education and Training 4. Empiricism 5. Manipulation of Charisma*	IV. 1. Stress Induction 2. Pressure 3. Hierarchy 4. Placement 5. Goal Setting 6. Action Research* 7. Technical Modification* 8. Timing*

Figure 2.10 [47]

Change Planning Checklist

Use this checklist to assess your organization's change planning readiness.

1. *Are your objectives clear?* Can you see the results you desire?
   - —What will you be doing differently?
   - —How will things look changed?
   - —How will your customers be responding after the change?
   - —How will your output change (percentage over a baseline)?
2. *Have you explored your own resistance* to the change?
   - —Who on the team feels uncomfortable with the change? What is the objection? How might this objection help you to rethink your approach?
   - —What new training or knowledge requirement(s) does the change put on you?
3. *Are you committed, as a management group,* to bringing about the change?
   - —Are team members enthusiastic about the change? How is this feeling expressed?
   - —Are team members informally getting together to look at ways to implement the change?
   - —Are you making decisions by consensus or by voting? Leadership decision?
   - —Does the organization's "rumor mill" support the change?
4. *Are you involving people at all levels* in planning the change?
   - —Who is being involved? Why involve these people?
   - —What do you want from them?
   - —How are you organizing their involvement?
5. *Are you field-testing the change on a small scale?*
   - —Have you selected a work unit that is supportive of the change?
   - —Have you made your objectives clear to this pilot organization? Do they have a clear picture of results desired?
   - —Have you let the pilot organization know that it's O.K. to make mistakes and that you are accessible to work through problems?
6. *How are you evaluating your change pilot project?*
   - —Have you made it a habit to regularly review your learnings from the pilot implementation?
   - —Are you seeking out negative as well as positive feedback?
   - —How are you gathering information and what is the information gathering telling you?
7. *When will conditions be right to implement the change organizationwide?*
   - —Do you have a firm understanding of how this change will impact other parts of the organization?
   - —Do you have supporters of the change throughout the organization with the clout to keep the change on track?
   - —Is the time right for change in terms of market conditions and/or other conditions in your environment?

Figure 2.11 [48]

Model for Understanding an Individual's Response to Change

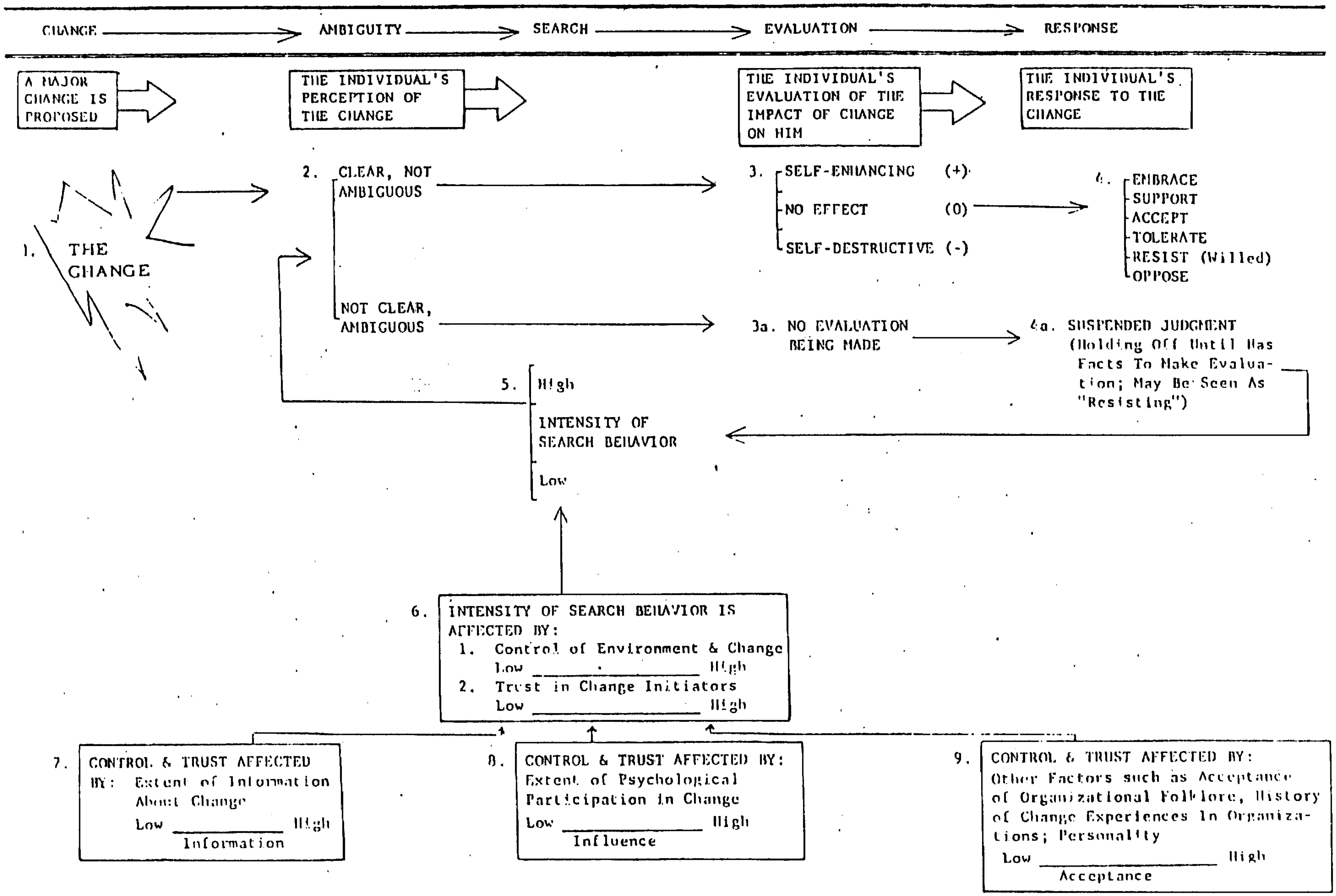


Figure 2.12 [51]

ORIGINAL PAGE IS OF POOR QUALITY

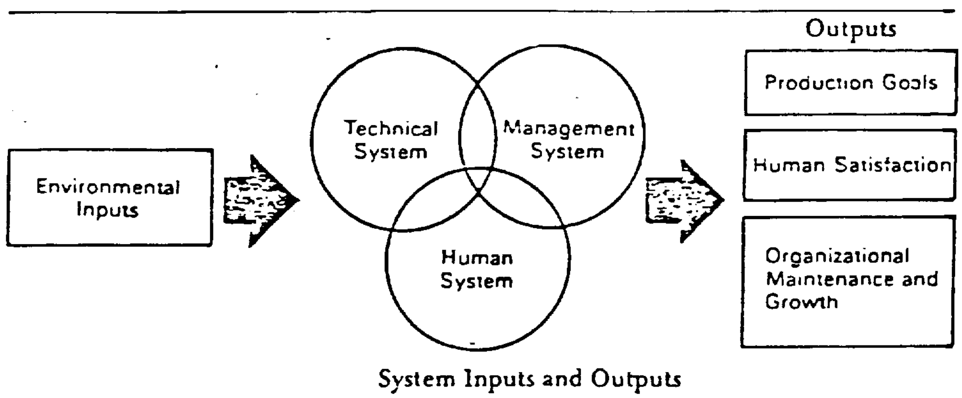


Figure 2.13 [53]

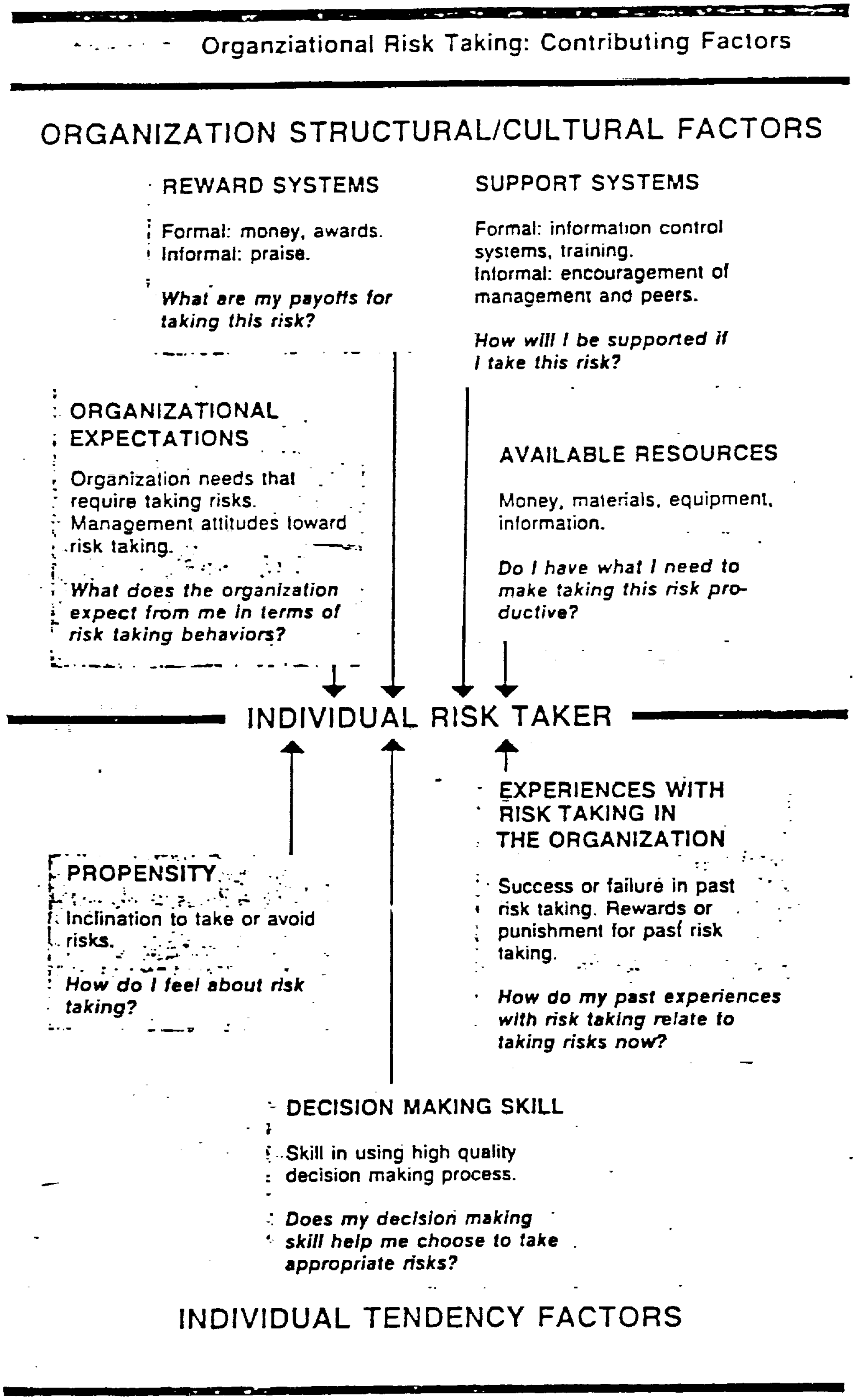
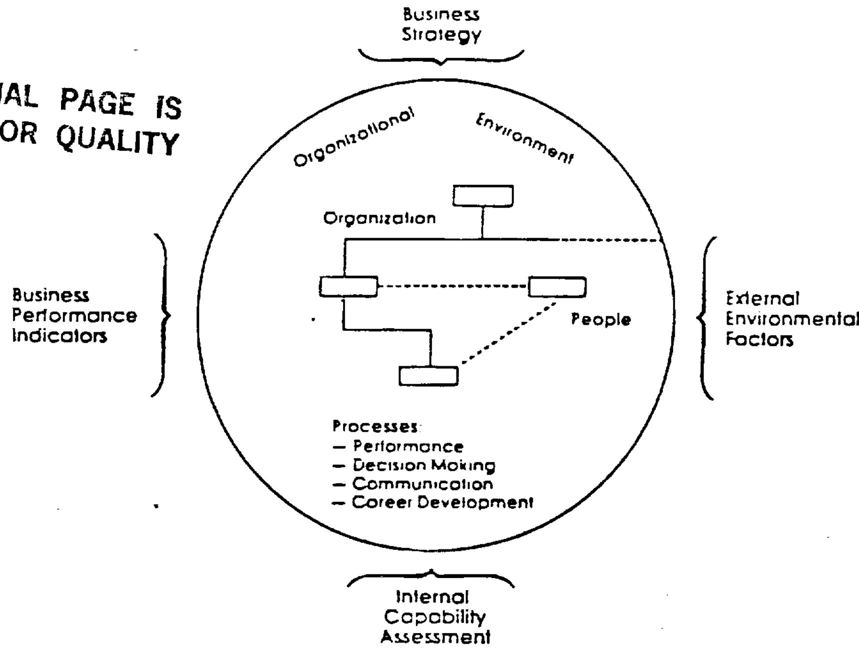
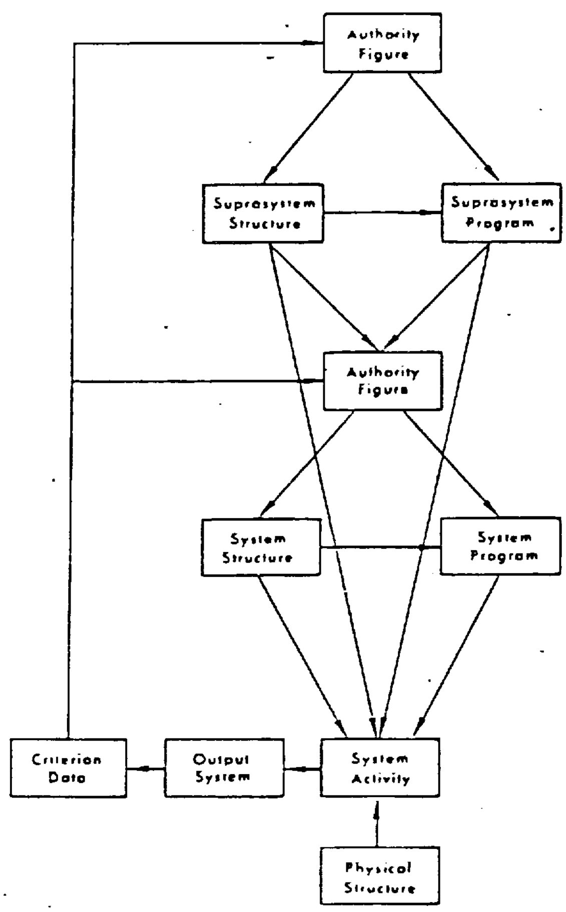


Figure 2.14 [57]



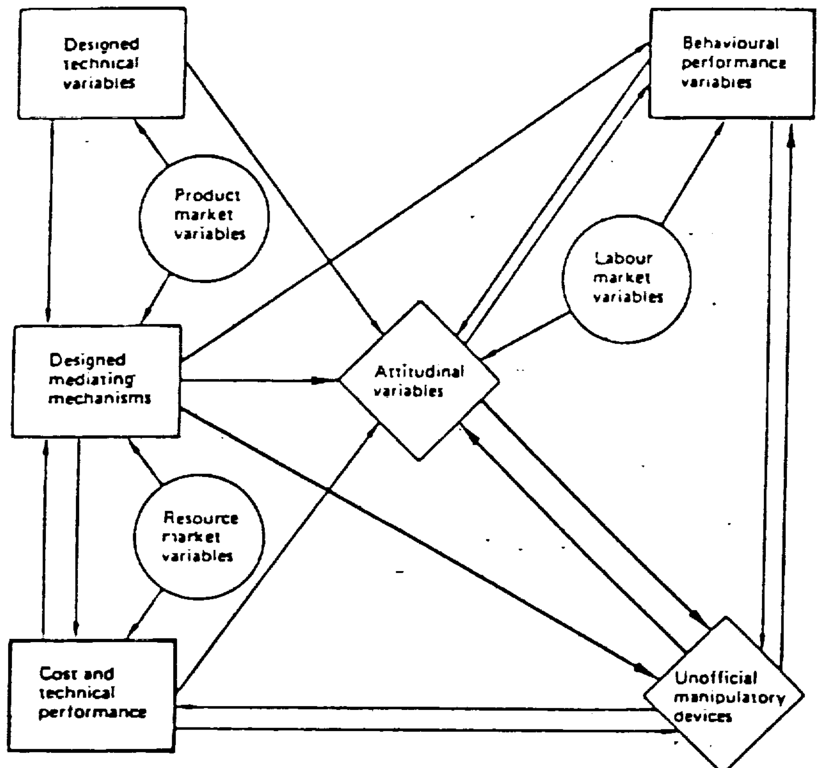
Systems approach to organization and human resources.

Figure 2.15 [62]



A general systems model of organizations.

Figure 2.16 [68]



Arrows indicate the direction and the complexity of influences between boxes

Interactions between classes in socio-technical systems.

Figure 2.17 [71]

3.0 LITERATURE SEARCH CONCEPT MATRIX

Proposed Transition Management Concept	Concurring Articles
Employee Participation Important In Transition Process	1, 2, 11, 13, 17, 37, 40, 44, 46, 52, 58, 64, 70, 72
"Circular" Organizational Structure Recommended To Allow Employee Participation	1
The Openness And Closedness Of Group Boundaries Is Self-Sustaining	2
The Optimal Structure For Changing Organizations Is To Establish Teams Composed Of Insiders and Outsiders	2
Teams Need To Have Optimally Open Boundaries And Have Relationships Of Mutuality Among Team Members And Between The Team And The System	2
Permanent Change In Systems Is Most Likely To Be Achieved And Sustained If Programmed Through A Series Of Cycles That Are Carried Out By Insiders And Outsiders	2
The Evaluation Phase In A Transition Program Is Very Important	2, 3, 12, 28, 37, 48, 50, 52
The Process Of Evaluation Can Be Hindered By Methodological, Administrative, And Miscellaneous Problems	3
The Detection And Measurement Of Beta Changes Was Demonstrated	4
People In The Organization Must Feel Pressure In Order To Change (Catalyst)	5, 15, 17, 54
New Ideas From Outside The Organization Are Needed For Successful Transition	5
Commitment Is Necessary For Transition	5, 20, 25, 27, 37, 46, 49, 59

Proposed Transition Management Concept	Concurring Articles
A Change Agent Is Required To Propose Ideas And Foster Momentum	5, 6, 15, 16, 20, 30, 31, 32, 34, 40, 45, 61, 67, 73
The Amount Of Power Shared Between Management And Subordinates Is An Important Transition Management Consideration	5, 42
The Appropriate Definition Of A Change-Target Boundary Is An Important Transition Management Consideration	5
The Amount Of Centralization In Transition Planning And Strategy Is An Important Transition Management Consideration	5
The Rate Of Organizational Change Is An Important Transition Management Consideration	5
Information Relating To The Need For Change, Plans For Change, And Consequences Of Change Must Be Shared By All Relevant People In The Group	6, 8, 11, 13, 37, 40, 44, 49, 52, 72, 74
Elite-Corps Was Discussed As A Transition Management Strategy	6
The Use Of Scholarly Consultations Was Discussed As A Transition Management Strategy	6
The Circulation Of Ideas To The Elite Was Discussed As A Transition Management Strategy	6
Developmental Research Was Discussed As A Transition Management Strategy	6
Action Research Was Discussed As A Transition Management Strategy	6, 9
Planned Change Involves Deliberate Mutual Goal Setting By One Or Both Parties (Compromise) With Equal Power	7, 37, 40, 41, 48

Proposed Transition Management Concept	Concurring Articles
Indoctrination Incorporates Mutual Goal Setting, With An Imbalanced Power Ratio	7
Coercive Change Has One-Sided Deliberate Goal-Setting, With An Imbalanced Power Ratio	7
Interactional Change Is A Non-Deliberate Change Characterized By Mutual Goal-Setting And Equal Power Distribution	7
Socialized Change Is Non-deliberate Change Characterized By Mutual Goal Setting And An Imbalance In Power	7
Emulative Change Is Non-deliberate Change Brought About Through Subordinate Emulation Of "Power Figures"	7
Natural Change Is Organizational Change With No Deliberate Or Planned Occurance	7
Group Forces Influence Change Programs	8, 25, 74
Recommended The Use Of Group Dynamics To Overcome Resistance To Change	8, 11, 30, 34
Actual Change Is More Likely When Groups Internally Decide To Change Instead Of Externally Being Told To Change	8, 15, 72, 74
Group Members Who Are To Be Changed And Those Who Are To Exert Influence For Change Must Have A Strong Sense Of Belonging To The Same Group	8, 11
The More Attractive The Group Is To Its Members, The Greater Is The Influence That The Group Can Exert On Its Members	8
In Attempts To Change Attitudes, Values, Or Behavior, The More Relevant They Are To The Group, The Greater Will Be The Influence That The Group Can Exert Upon Its Members	8

Proposed Transition Management Concept	Concurring Articles
The Greater The Prestige Of A Group Member In The Eyes Of The Other Members, The Greater The Influence He Can Exert	8
Efforts To Change Groups Or Group Members, Which If Successful Would Make Them Deviate From The Norms Of The Group, Will Encounter Strong Resistance	8
Strong Pressure For Changes In The Group Can Be Established By Creating A Shared Perception By Members Of The Need For Change, Thus Making The Source Of Pressure For Change Lie Within The Group	8, 11
Change In One Part Of A Group Produces Strain In Other Related Parts Which Can Be Reduced Only By Eliminating The Change Or By Bringing About Readjustments In The Related Parts	8
Raised The Issue of Questionable Methodological And Theoretical Standings Of Current Research In Planned Organizational Change	10
Recommended A Tandem Relationship Between The Researcher And the Consultants Assigned To The Planned Organizational Change Team	10
The Use Of Group Techniques Improved Communication For The Need To Change And Increased Participation In Planning The Change	11
Feedback Such As Contradictions, Unexpected Outcomes, And New Alternatives May Occur That Cause Individual To Re-evaluate Newly Adopted Behaviors	12
Confirming And Disconfirming Feedback About The Expected Outcomes Of A Behavior Affects The Decision To Persist Only When Outcomes Are Valued	12

Proposed Transition Management Concept	Concurring Articles
The Content And Not The Presence Of Feedback Affects The Behavior And Beliefs Of Employees	12
Feedback Has An Impact On The Strength Of Beliefs To Which It Is Targeted And, When No Other Feedback Is Available, May Transfer Beliefs About Outcomes That Are Indirectly Related To The Instrumental Feedback	12
Cultural Change Is One Of The Most Difficult Tasks That Management Can Undertake	13
If Cultural Change Is Required, The Company Needs To Examine Its Existing Culture In Depth and Acknowldege The Reasons For Revolutionary Change	13
Cultural Change Should Be Marked By A Changed Structure, New Role Models, New Incentive Systems, And New Rewards And Punishments	13
Change Scores Formed From Subtracting Pretest Scores From Posttest Scores Lead To Fallacious Conclusions Concerning The Amount Of Change Made	14
OD Change Agents Will Act More As An Advisor And Facilitator Than As A Change Initiator	15
Support For The Lewin Unfreeze, Change, Refreeze Model (Phases)	15, 45, 50, 51
The Organization Must Move Away From Generalized Goals Toward Specific Objectives	15, 44
Social Ties Built Around Previous Behavior Patterns Must Be Abandoned For New Relationships Which Support The Intended Changes	15
Self-doubt And Low Self-Esteem Must Be Removed	15

Proposed Transition Management Concept	Concurring Articles
In Considering Consultant Help, An Organization Should Allow That Some Changes May Be Necessary And Should Reflect This By Its Identification And Engagement Of A Consultant	16
An Organization Should Regard A Consultant As An Expert Resource And A Collaborating Equal, And Ensure His Participation In The Consideration Of Any Changes Which Should Be Made In The Assignment During Its Progress	16
An Organization Should Not Closely Direct A Consultant's Work, Nor Unreasonably Constrain Him By Restricting Personal Contacts Or Access To Organizational Information	16
A Consultant Should Work Closely And Directly With Members Of The Client Organization And Provide For Their Participation In The Consulting Assignment Either By Assignment To Specific Working Roles, Discussion Of Findings, Or An Opportunity To Initiate Proposals	16
An Organization Should Establish A Specific Point Of Contact And Liaison For A Consultant	16
Involve Enough Units In The Organization With Credible Managers In A Fairly Short Period Of Time	17
Agrees With "Four Question" Transition Management Format	17
Inertia Provides Resistance To Change	17
An Understanding Of Corporate Culture Is Important	17, 18, 19, 26, 44, 54, 59, 72, 73, 74
An Organization's External Environment Influences The Persistence Of Change	18, 25, 63

Proposed Transition Management Concept	Concurring Articles
Marketing Orientation, Employee Orientation, Problem-Solving Orientation, Innovation Orientation, & Service / Quality Orientation Influence Corporate Culture	18
Due To The Influence Of Corporate Culture, Corporate Strategy Alone Cannot Produce Winning Results	19
Cultural Change Is Slow And Expensive	19
Hiring, Promoting, And Terminating Systems Can Build Culture And Weed Out Incompatibles	6, 19
Use Of Organizational Development (OD) As A Transition Method	20, 21, 22, 30, 35, 36, 52, 53, 55, 60, 61, 67
The Organization's Environment, Characteristics, Commitment, And Internal Change Agent Were Significant Factors In Relation To The Success Of The OD Effort	20
Successful Change Efforts Were Related To Organizations That Are Open And Involved In Adjusting To The Change, With Specific And Great Commitment To The OD Efforts	20
Use Of Action Research As A Transition Management Technique	21, 30, 32, 52
There Are Problems With The Use Of Various Numerical Change Indicator Variables	22, 43
Confrontation May Be Used As A Method Of Organizational Change	23, 30
Laboratory-Induced Changes In Interpersonal And Intergroup Styles Have A Sustaining Effect Over A Period Of Time	24
Reward Systems Influence Change Programs	25, 39, 54, 57

Proposed Transition Management Concept	Concurring Articles
Managerial Support Is Necessary For Change Program Success	25, 37, 48, 52, 72
Organizational Structure, Culture, And Employee Responsibility For Idea Implementation Influence Innovation	26
Transition May Be Initiated By Unilateral Action, Power Sharing, Or Delegated Authority	27
Planning, Use Of Power, Type Of Interpersonal Relationships, And Rate Of Change Are Four Elements In Common With All Change Programs	28
A Structural Control Model Can Be Developed That Relates An Organization's Size And Levels Of Differentiation	29
MBO, Team Building, Behavior Modification, Transactional Analysis, And Human Resource Accounting May Be Used For Transition Programs	30
Different Types Of Change Agents Exist	31
Coercive, Normative, And Utilitarian Types Of Strategy Exist	32
American Management Has Been Reluctant To Abandon The Managerial Methods That Were Successful In The 1950's And 1960's	33
Companies That Have Progressive Human Resource Practices Have Significantly Higher Long-Term Profitability And Financial Growth	33
Transition Programs May Be Focused Either At Individuals, Groups Of Individuals, Or Organizational Structural Variables	34, 41
Direct Manipulation Of Organizational Structural Variables Is A Powerful Approach To Produce Enduring Change	34

Proposed Transition Management Concept	Concurring Articles
Job Enlargement And Job Rotation Were Used To Improve Productivity	36
Managerial Expectations On Performance Often Serve As Self-Fulfilling Prophecies	36
Increasing Size, Bureaucratization, And Differentiation Decreased Job Satisfaction And Increased Job Tension	38
When Employees Perceive Pay And Performance Are Related, Employees Are Motivated To Perform Well	39
Pay Incentive Systems Do Not Always Produce Higher Motivation	39
Feelings Of Satisfaction Are Important Determinants Of Absenteeism And Turnover	39
Change Agents Often Are Too Concerned With Technical Aspects Of Change To Be Aware Of Related Social Aspects	40
Change Agents Should Utilize Employees That Have First Hand Knowledge And Experience Of The Organizational Area Under Transition	40
Supervisory Actions, Rather Than The Change Program, May Cause Transition Resistance	44
Strategies Should Be Classified By the Unit Of Analysis, Role Of The Unit Member, And The Position Of The Unit Under Analysis	47
Change Implementation Should Be First Tested On A Small Scale	48
Successful Change Is Not Likely To Occur Following The Single Application Of Any Technique	52
No Single Technique Is Optimal For All Organizations, Contexts, And Objectives	52

Proposed Transition Management Concept	Concurring Articles
There Can Be No Major Organizational Change Without A Change In Management Style	54
Transition Goes Faster With New Management Groups Instead Of Old Ones	54
Major Change Cannot Be Done Quickly	54
MBO Proposed As A Change Strategy	55, 69
Changes In Structural Variables Lead To Effective Change Programs	56
Incremental Structural Change Programs Were Less Likely To Be Undertaken By High-Performing Firms	56
Risk-Taking Is Influenced By Organizational Expectations, Reward Systems, Support Systems, And Available Resources	57
Change Agents Must Be Able To Contend With Political Forces Within The Client Organization	61
Change Agents Must Have Good Credentials, Have Powerful Allies, And Maintain A Neutral Appearance To Be Effective	61
OD Has Had Trouble Finding A Strategic Position In Most Organizations	62
OD Professionals Often Are Not Well Versed In The Business Issues Facing Their Client	62
OD Skills And Concepts Are Generally Not Possessed By The Senior Human Resource Managers Who Are Formally Closer To Top Management; Thus, OD Is Not Used Or Strongly Advocated	62
Job Security Influences The Effectiveness Of Change Programs	64, 72

Proposed Transition Management Concept	Concurring Articles
The Strategic Management Process Involves Analysis, Planning, Implementation, And Control	65
Organizational Policy And Aims Should Be Considered When Planning	65
Technological Sophistication Enhances Change Forces In The Direction Of Participative Management	66
Technological Sophistication Acts To Increase Permanence Of Change Efforts	66
Changes In The Suprasystem Induce Changes In The System, But Not Vice-Versa	68
Changes In Structure Induce Changes In Program, But Not Vice-Versa	68
Permanent Changes In System Activity Data Requires A Change In And The Subsequent Equilibration Of Both The System And Its Suprasystem	68
There Are Numerous Sources Of Stress Which Are Inherent In Organizational Change Programs	70
Organizational Variables Such As Product Market, Resource Market, Labor Market, Technical Expertise, Mediating Mechanisms, Attitudes, Manipulatory Mechanisms, Employee Behavior, And Costs Can Be Used As Change Levers	71
Change Must Be Perceived As A Way Of Reducing Burden	72

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CHAPTER III

VERIFICATION AND EXPANSION OF KNOWLEDGE

1.0 INTRODUCTION

2.0 ANALYSIS OF THE EXPANSION OF KNOWLEDGE THROUGH INDUSTRIAL VISITATION

3.0 VERIFICATION

APPENDICES

III A : PUBLICATION/PRESENTATION OF RESEARCH

III. VERIFICATION AND EXPANSION OF KNOWLEDGE

1.0 INTRODUCTION

The objectives stated in the title of this chapter were accomplished by two separate methods. Our knowledge was expanded by moving our industrial visitation process to an industry with a relatively new culture and one which has undergone a large amount of change in a short period of time. The interview process is discussed in section 2 of this chapter. The verification part of this process was accomplished by numerous presentations and publications of our work to both the professional and the academic forum. The specifics are covered in section 3 of this chapter.

2.0 ANALYSIS OF THE EXPANSION OF KNOWLEDGE THROUGH INDUSTRIAL VISITATION

During this year, eight companies were visited, all in Juarez Mexico and all part of the Maquiladoras or twin plant industry. The plants visited included two Packard Electric plants, BRK, Westinghouse, Electro Circuits, Honeywell, RCA, and GE. In addition, several of the industrial park associations and Maquila associations were visited. This industry is unique and has a large amount of government intervention. In addition the industry has gone through a considerable growth stage in the last several years with the work force being around 75 thousand currently. This work force had a major cultural change imposed on it when it went from an agrarian basis to a manufacturing one. All of these points along with the fact that a large amount of companies were located in close proximity were factors in choosing this industry for visitation.

2.1 IMPRESSIONS DRAWN FROM THE INTERVIEWS

One of the first impressions drawn from working with this industry is that it is very low on the Maslow Hierarchy of Needs list. A significant portion of the cultural change is no doubt due to the need for the basic substance of life supported by the minimum wage. The work force remains transient with employees working for a while and then moving on, either back to their original homes or to another plant. This seems to show that the satisfaction of lower level needs does not guarantee retention.

Another problem that surfaces in almost all of this industry is that of obtaining the proper balance between production and design. To deal with this issue, many of the plants are requiring cross-training between the two areas.

This industry seems to produce a very high quality product. One of the reasons is no doubt that the low labor cost allows a large number of quality inspectors to be hired. Perhaps a more important reason is that the work force has been trained in quality from its inception into the industrial world.

As a final impression it was difficult to identify transition strategies in this work force. Things are changing very quickly. In addition, many of the strategic decisions are made at the home plants, located in other countries.

2.2 CONCLUSIONS

A great deal of useful information was gained from the visitation process. Much of this information is valuable in its application to the transition of NSTS to an operational environment. The following concepts re-enforce the list of conclusions drawn from last year's industrial interview process.

- For smooth operations, a product must be designed for production.
- Cross-training is essential to smooth the design operations interface.
- Quality must be built into a new program or product from its beginning.
- In order to impact retention, higher order needs than just the basics of life or salary must be addressed. Ego and self-fulfillment seem to be important here.

3.0 VERIFICATION

In the highly technical world of today, any work, no matter how elaborate, cannot be taken for granted to be unquestionably complete. There are numerous highly qualified researchers in the wide world of academia and industry, who are sometimes working in closely similar areas. The intellectual input of such colleagues and professionals is very important for the growth and development of the research activity. Therefore, it is very important that the researchers exchange their work in order to simplify and substantiate their research efforts.

Conferences are one of the principal meeting places for the exchange of ideas and thoughts by researchers. This year, three papers were presented at the National and International levels in order to publicize the research work and gain valuable response from different areas of the academic and professional comunities. As a consequence, it was noted that the research activity is for the most part, in the right direction. It was also noted that in most situations, our research work in the area of transition management is substantially ahead of others. However, there were some valuable comments about the validation of some of our theoretical research work. Those comments and suggestions are well taken. Furthermore, they have solidified our aspiration and commitment to survey more individuals and companies in order to give us a more reliable basis for theoretical investigation.

Another channel of verification of theoretical and practical ideas and thoughts is by means of publication in reputable journals. This mode of presentation usually covers a wider segment of researchers and professionals involved in similar activities. Moreover, most prestigious journals have elaborate refereeing process. When the paper goes through the refereeing process in such journals, it is scrutinized by several people at the edge of technology in that research area, before it is cleared for publication. Such extensive exploration by the referees improves the quality of the paper, and usually provides good direction for the future research. Two of our papers have already been through that rigorous refereeing process. One of them has already appeared in a journal and the other is due for publication. Besides, two other papers have appeared in the proceedings of the conferences in which they were presented. Moreover, four other papers are, at present, passing through the time consuming process of scrutiny and hopefully will be published soon. Three other papers are in the final stages of the preparation for our submission.

A summary of the presentations and publications of the research is contained in Appendix III A of this chapter.

APPENDIX III A

PUBLICATION/PRESENTATION OF RESEARCH

1. TRANSITION LIFE CYCLE - AN R&D TO OPERATIONS PERSPECTIVE

   - Submitted for publication to the IEEE Transactions on Engineering Management.

2. R&D TO OPERATIONS TRANSITION MANAGEMENT

   - Presented At The National Decision Science Institute Annual Meeting In Honolulu, Hawaii, Nov. 23-25, 1986.

   - Submitted for publication to The Academy of Management Review.

3. TRANSITION MANAGEMENT - A STRUCTURED PERSPECTIVE

   - Published In The Proceedings of The International Conference on Engineering Management: Theory and Application, Swansea, England, (September 15-19, 1986).

   - Submitted for publication to the IEEE Transactions on Engineering Management.

4. TRANSITION MANAGEMENT - A PERSPECTIVE

   - Published In The Proceedings Of The 24th Annual Southern Management Association Meeting at Atlanta, Georgia, November 12-15, 1986.

5. TRANSITION MANAGEMENT OF AN ORGANIZATION

   - Working Paper, UH-UP, Houston, Texas, 1987.

6. AN INDUSTRIAL INSIGHT INTO THE MANAGEMENT OF CHANGE

   - Working Paper, UH-UP, Houston, Texas, 1987.

7. DISASTER ON FLIGHT 51-L: AN IE PERSPECTIVE ON THE CHALLENGER ACCIDENT

   - Published in Industrial Management, Vol. 28, No. 5, 1986. (See Appendix VI C)

8. OPERATIONAL ARM FOR THE SPACE SHUTTLE PROGRAM : A PERSPECTIVE DIRECTION

   - Working Paper, UH-UP, Houston, Texas, 1987. (See Appendix VII G)

9. **AN ANALYSIS OF THE FLIGHT RATE CAPABILITY OF NASA's NSTS PROGRAM**

- To Appear in the Logistics Spectrum.(See Appendix IV E)

10. **OPTIMAL SCHEDULING IN AN M-STAGE FLOW SHOP WITH MULTIPLE PROCESSORS**

- Submitted to TIMS/ORSA for Presentation in May, 1987.
- Submitted for Publication in the International Journal of Production Research. (See Appendix IV A)

CHAPTER IV

SPACE SHUTTLE SCHEDULING AND FLIGHT RATE CAPABILITY

APPENDICES

IV. SPACE SHUTTLE SCHEDULING AND FLIGHT RATE CAPABILITY

1.0 INTRODUCTION

The primary focus of this chapter is on methods and tools necessary for effective operations and managerial planning. To this end, several areas of production management have been studied in extensive detail in this chapter. The scheduling of the Space Shuttle and the flight rate capability analysis, for better planning and predictability, are the examples of such operational instruments studied here for effective planning. The use of mathematical models to solve scheduling problems, and simulation models to estimate the flight rate capability will enhance the potential of the management to predict and control the system. Furthermore, such tools are expected to be very effective in reducing the operational cost of the system.

In the following sections, brief descriptions of the scheduling and flight rate simulation analysis are presented. A rather detailed description of the research work has been included in the appendices of this chapter.

2.0 SCHEDULING OF THE SPACE SHUTTLE

The Space Shuttle goes through three specific facilities namely the OPF, VAB, and PAD, in the same order before being launched into space from the PAD at Kennedy Space Center (KSC). The Orbiter Processing Facility, OPF, is where basic processing is done on the Orbiter. The Vertical Assembly Building, VAB, is where the Orbiter is mounted with its Solid Rockets and External Tank. The Launch PAD, is where most payloads are mounted, and it is the launch site. There are multiple processing resources of each facility and the problem under consideration is that of scheduling the space shuttle through them such that a specified regular measure of performance such as mean flow time or makespan is optimized. Although a similar sequence is followed for processing by the space shuttle for all types of missions, making it a flow shop scheduling problem, the presence of multiple facilities and limited number of space shuttles complicates the situation.

In order to address the subject matter of space shuttle scheduling, the problem of a flow shop with multiple processors is formulated as a mixed integer programming (MIP) problem in Appendix IV A. The special case of flow shop problem formulation developed there can be applied in the use of the Space Shuttle processing. The direct utilization of the method developed is in solving the sub-problem of finding the sequence for a small group of jobs equalling the number of space shuttles available. The missions available in the scheduling bracket, or window are the candidates for the sequencing positions. In case the number of available missions in the scheduling window under consideration is greater than the number of space shuttles, then sensitivity analysis can be performed to find the best sequence. Furthermore, the restrictions on the availability of the space shuttle can be easily modeled as well for the subsequent scheduling windows. The objective function in this formulation could be the optimization of any one, or more regular measures of performance as established by the NASA administration.

3.0 FLIGHT RATE CAPABILITY

There are several factors which may be instrumental in causing any management to present somewhat higher or lower production, and/or flight rates. However, using unrealistic figures as production targets can be extremely dangerous for the smooth flow of the work in a production or operations environment. Furthermore, the selection of target production figures may also have a detrimental effect on the long range planning and objectives of the organization. Therefore, it is imperative that management studies and uses the right production (or flight) rates before making any organizational commitment. An analysis of the flight rate capability of NASA's Space Shuttle program through the use of simulation is presented in appendix IV E of this chapter. The study of the simulation model will provide an example of the managerial investigation process. However, before presenting the analyses of the simulation modeling, some thoughts about flight rates, uses of flight rates, and the flight decision process are necessary. They are presented in appendices IV B, IV C, and IV D respectively. In addition, a brief outline of the three topics is presented in the following sections.

3.1 FLIGHT RATES

Two broadsides in the appendix, "Flight Rate Capability" and "Uses of Flight Rates" address the general issue of determining and using flight rates. One of the major messages is that in order to determine the flight rate at which the system can perform the first step is to determine the amount of control in the system presently. It is very difficult to determine a realistic flight rate based on only 24 flights, particularly with the amount of variability that seems to be in the system. Once the amount of control is determined then confidence or reliability factors can be assigned to flight rates. The main message here is that different usages may generate different flight rates.

3.2 FLIGHT DECISION PROCESS

The underlying issue here is the method to be used to both control and insure safety while gaining experience with a developmental product. One method is to define the experience envelope of a product as the collection of data, both analytical and historic, under which it is felt that the performance of the product is predictable. When performing within this envelope, the burden of proof to an objector to performance is to show that the product is unsafe in this environment. When performing outside this envelope the burden of proof is to prove that it is safe to move outside. As experience is gained and analysis is done then the envelope changes in a corresponding manner. A level of confidence is also associated with this envelope. When costs are small then a large level of confidence is not necessary. However when costs are large then the opposite is true.

APPENDIX IV A

SCHEDULING IN A FLOW SHOP WITH MULTIPLE PROCESSORS

1.0 INTRODUCTION

A flow shop sequencing problem is characterized as processing of n jobs on m machines. The machines are laid out in unidirectional flow pattern and each job is processed identically in the fixed ordering of the machines. The objective of job scheduling can be that of minimizing the maximum completion time to complete processing all jobs on all of the machines average time to complete all jobs, or any other regular measure of performance. More detailed work could involve the optimization of multiple objectives, or goals. The sequencing of a flow shop with multiple facilities at each stage is a special case of the flow shop problem. It involves sequencing of n jobs in a flow shop, where for at least one stage, the processor has one or more identical machine(s). Stated another way, the problem is a special case of the job shop problem in which all jobs to be scheduled follow the same machine sequence. The problem was first identified by Salvador (1973). He suggested a branch and bound approach to solve the problem for the permutation flow shop with multiple processors. However, no work has been reported to formulate it mathematically and possibly solve it for real life applications.

The purpose of this paper is to formulate the flow shop with multiple processors scheduling problem as mixed integer programming (MIP) problem and give some real life examples to demonstrate the usefulness of the model. A special case of this formulation, when the number of machines at each stage of processing is one, represents a pure flow shop; a MIP representation of which is also presented. Many real life examples are also introduced which demonstrates the presence of numerous such problems in production scheduling.

An important aspect when dealing with the scheduling problems is that even the simplistic case of static flow shop minimizing the makespan belongs to the family of combinatorial problems. The complexity of the problem is further increased by the fact that unlike the single machine case, the inserted idle time may be advantageous. The number of possible schedules for such problems are to the extent of $(n!)^m$ (Baker, 1974). The excessive number of possible combinations make the scheduling of flow shop even more complex, and the solutions have only been obtained for some elementary problems. One of the simplified class of the flow shop problems is which considers only permutation schedules, and even in this case the number of possible alternatives are n! (Gupta, 1972). Furthermore, it has been shown that the three and more machine permutation flow shop problems are NP-complete problems (Lenstra et al., 1977). Therefore the complexity of the problem strongly suggest that polynomial-bounded method for solution is highly unlikely.

The number of possible schedules for total enumeration even for permutation schedule is excessively large and perhaps the only course available is a partial enumeration, commonly referred as branch and bound technique. The work done on flow shop has primarily focused around development of various branch and bound algorithms. Ignall and Schrage (1965), Lamnicki (1965), McMohan and Burton (1967), Ashour (1970), Gupta (1970), Szwarc (1977), Lageweg et al. (1978), and Bansal (1979) have applied branch and bound techniques to solve such problems. A comparison of some of them is contained in Baker (1975). Most of the other work has been developed through heuristic procedures. Palmer (1965), Campbell et al. (1970), Gupta (1971; 1972), Gupta and Maykut (1973), Dannenbring (1977), Gelders et al. (1978), King and Spachis (1980), Stinson and Smith (1982), Nawaz et al. (1983), Park et al. (1984), and others have developed some heuristics to solve flow shop problems. As far as flow shop with multiple processors scheduling is concerned, although Salvador (1973) suggested a branch and bound approach, and gave an equation for the lower bound, but no work has been reported to the knowledge of the authors on the development of such an algorithm.

2.0 PROBLEM DESCRIPTION

The problem of flow shop with multiple processors scheduling can be presented graphically as in Figure 1.

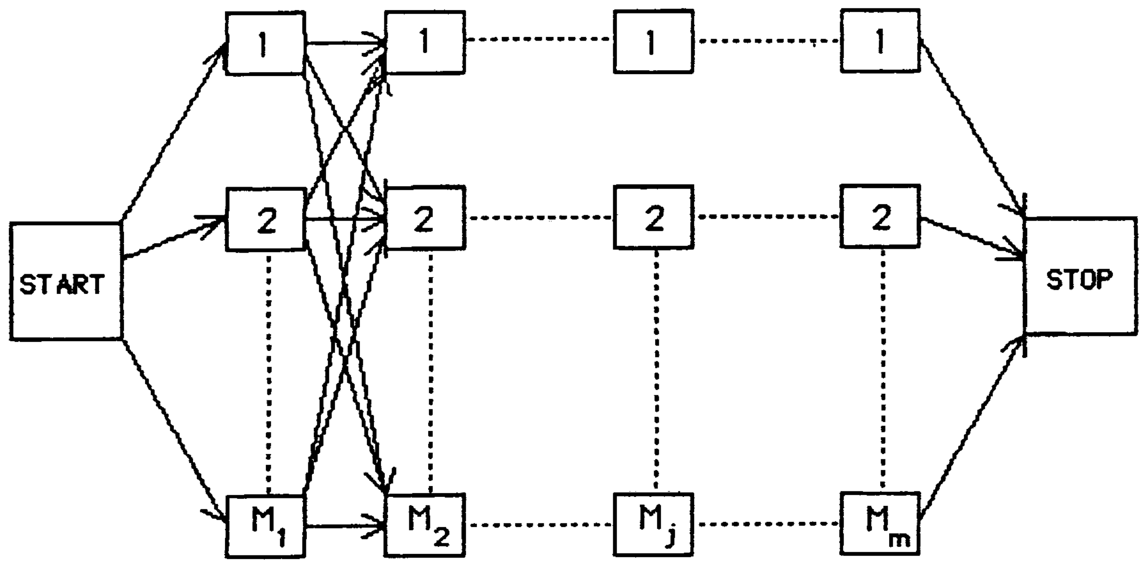

FIG. 1. FLOW SHOP WITH PARALLEL PROCESSORS

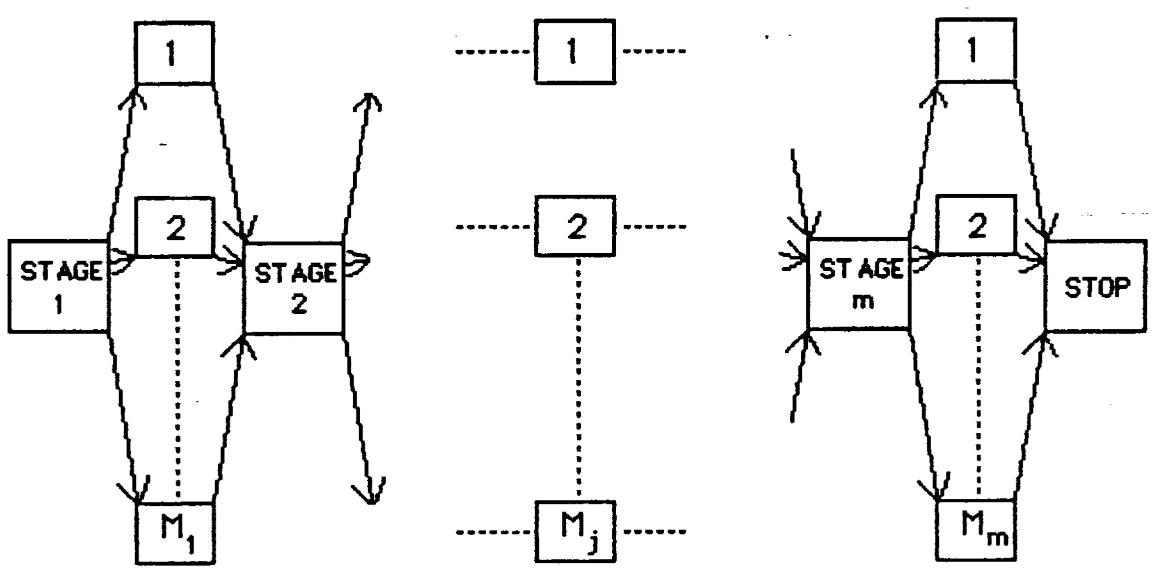

FIG. 2. QUEUING REPRESENTATION OF FLOW SHOP WITH PARALLEL PROCESSORS

There is a main queue of incoming jobs, and each job can go to any one of the M_1 machines at stage 1. As can be seen in Figure 2, there is a queue at each stage of the flow shop processing, and theoretically all of the jobs can be routed to any one of the M_j machines $(1 \leq j \leq m)$ at stage j. When the job has been processed through the last stage m, using one of the M_m machines, it is complete and at that point can leave the system. In theory, the jobs can take $\prod_{j=1}^{m} \binom{n-1}{M_j-1} \left(\frac{n!}{M_j!} \right)$ possible sequence combinations, some of which may not have to be explored.

There are two decision activities which occur at each stage of the problem. The first decision is the assignment of the job to a specific machine k from M_j parallel machines, at stage j, and the second is the scheduling of jobs on each one of the machines at that stage. The two decisions are closely linked and both of them effects the quality of the scheduling results.

There are numerous solution techniques that can be applied to the stated problem. The choice can range from an integer programming, mixed integer programming, linear programming, branch and bound algorithm, simulation experimentation to heuristic procedures for single or multiple objectives. The optimal seeking techniques obviously have the advantage of coming up with optimal solution, but the major drawback is in the computation time and being intractable for large problems.

3.0 APPLICATIONS OF THE PROBLEM

The application of this type of problem occurs more often than one would imagine. Many high volume production facilities have several independent flow shops. The process in such facilities is such that they are interchangeable at each stage and are therefore practically similar. Salvador (1973) first recognized the problem in the polymer, chemical, process and petro-chemical industries where there are several parallel plants which can be considered as flow shops, and the jobs can practically be processed at any one of the plants at each stage of the processing. Assembly lines in which more than one products are manufactured, and each work station has multiple machines is also an obvious application of this problem. Similarly, the situation where parallel machine(s) is (are) added at one or more stages of the flow shop to ease the pressure on the bottle neck facilities, and/or to increase the production capacities can be viewed as an application of the suggested problem.

The flow shop problems have a close relationship with the group technology applications. It is rarely the case when manufacturing group in such situations have pure flow shop formulation. In most of the situations, the requirement is that of multiple processors for some stages of processing. Such situations present themselves for the application of flow shop with multiple processors scheduling problem. Likewise, another utilization of the problem could be in a

Flexible Manufacturing Systems (FMS). In a special case of FMS where there are parallel machine installations which are capable of processing any one of the jobs, on one or more of the parallel facilities, is a likely example. The restriction, or simplification on this problem is that once a job enters an FMS, it can no longer use any of the other parallel facilities. In other words, the sequencing choice is made only at the first stage.

Yet another modification to the capacitated flow shop problem can be skillfully applied in the use of the Space Shuttle processing at Kennedy Space Center (KSC). In this example, the space shuttle goes through a similar processing sequence each time it is getting ready to fly a mission in space. There are multiple processing facilities at each stage and the orbiter can practically use any one of them for the processing. The restriction in this case is on the number of machine operators (or space shuttles) in the system. The objective function in all of these cases could be the optimization of any one or more regular measures of performance.

4.0 MATHEMATICAL FORMULATION

The purpose of production scheduling in any situation is to determine an optimal schedule which will optimize a pre-determined criteria. Parallel to the need of seeking an optimal solution is the requirement of being practical and efficient for the real life applications. Quite often, both of these requirements are at odds with each other and a compromise solution in the form of a heuristic is often reached. But, in order to evaluate heuristic for their practical value, many times it may be necessary to compare their performance with respect to the optimal seeking mathematical or analytical formulation. Moreover, such formulation most often provides insight into the intricacies of the problem and eventually help in the development of the heuristics. Wagner (1959) first introduced the integer programming formulation for the machine scheduling problems and also developed one for the the permutation flow shop. The MIP formulation for the optimal scheduling of M-Stage flow shop with multiple processors is generalization of the formulation to include non-permutation schedules, as well as, the multiple processors at each stage of the flow shop. As a special case, non-permutation representation of a pure flow shop is also presented.

Makespan, or the maximum completion time is the most commonly used criteria to evaluate the flow shop algorithms / heuristics in the literature. It is therefore natural to first develop such a model which optimizes the makespan for the flow shop with multiple processors scheduling problem. A mixed integer programming formulation is developed to minimize the makespan of the stated problem. As will be seen latter, a slight variation will make it possible to formulate the problem for other criteria such as minimize the mean flow time, or the minimize lateness or mean lateness.

Before starting the mathematical formulation, it may be logical to make some assumptions in order to make the problem somewhat tractable. The following are some of the basic assumptions:

i) All jobs are available for processing at time zero.

ii) The processing time of jobs is known and constant.

iii) All jobs follow the same machine sequence.

iv) The flow shop consists of $m \geq 2$ stages or levels.

v) Each level or stage has $M_j \geq 1$ machines; $j = 1, \ldots, m$; with inequality holding for at least one M_j.

vi) Set-up time is considered a part of processing time.

vii) Set-up time is independent of the job sequence.

viii) No machine failure or downtime is allowed.

ix) No job may be split or pre-empted.

The objective function in this formulation is the minimization of makespan, or the time to complete the last operation. Mathematically,

Minimize Z

Subject to $Z \geq F_{im}$ for all i (1a)

Where F_{im} is the flow time of job i on the last set of machine(s) M_m.

For the mean flow time criteria, the constraint can be modelled as $Z \geq \sum_i F_{im} / n$ (1b)

Similarly for minimizing the lateness, the restriction can be modelled as $Z \geq F_{im} - d_i$ for all i (1c)

Where d_i is the due date for job i.

Finally, for minimizing the mean lateness, the restriction will be $Z \geq \sum_i (F_{im} - d_i) / n$ (1d)

If the restriction of the simultaneous availability of the jobs has to be relaxed, then the system can be modelled with additional set of restrictions such that the processing does not start before the release time. This modification to 1a and 1b will provide optimal solution to two other criteria (i.e. minimize the maximum, and mean completion time).

The Mixed Integer Programming (MIP) formulation presented in Table 1 assigns the jobs to the individual machines at each stage of the flow shop. Two binary, or 0,1, variables are used in the formulation. First, X_{irjk} is used to take account of the precedence relationship among the jobs for each machine k ($1 \leq k \leq M_j$) at each stage j ($1 \leq j \leq m$). Second, Y_{ijk} to assign jobs to only one machine k at each stage, or in other words to provide safeguard against the multiple machine assignment at each stage of the processing. Equation 2 of the Table 1 guarantee that the job is assigned to only one of the machine k at each stage j. Equation 3

OBJECTIVE FUNCTION:

MINIMIZE Z

SUBJECT TO:

	$Z \geq F_{im}$	for all i	(1a)
or	$Z \geq \sum_i F_{im} / n$		(1b)
or	$Z \geq F_{im} - d_i$	for all i	(1c)
or	$Z \geq \sum_i (F_{im} - d_i) / n$		(1d)
	$\sum_{k=1}^{M_j} Y_{ijk} = 1$	for all i and j	(2)
	$F_{i,j+1} - F_{ij} \geq \sum_{k=1}^{M_{j+1}} Y_{i,j+1,k} P_{i,j+1,k} + t_{ij}$	for all i and j	(3)

$$Q(2 - Y_{ijk} - Y_{rjk} + X_{irjk}) + F_{ij} - F_{rj} \geq P_{ijk}$$

$$Q(3 - Y_{ijk} - Y_{rjk} - X_{irjk}) + F_{rj} - F_{ij} \geq P_{rjk} \quad \text{for all i,r,j and k} \quad (4)$$

$Y_{ijk} = 0,1$		for all i,j and k
$X_{irjk} = 0,1$		for all i,r,j and k
$F_{ij} \geq 0$		for all i and j

WHERE:

- n = Total number of jobs.
- m = Total number of machine stages in the flow shop.
- i = Number of job; $i = 1, \ldots\ldots\ldots, n$.
- j = Number of machine stage; $j = 1, \ldots\ldots\ldots\ldots, m$.
- M_j = Total number of parallel machines at stage j.
- k = Number of machine at stage j; $k = 1, \ldots\ldots\ldots, M_j$.
- P_{ijk} = Processing time for job i, at stage j, on machine k.
- t_{ij} = Travel time of job i, from stage j to j+1.
- F_{ij} = Flow time of job i at stage j.
- Q = A large number $\geq \sum_i \sum_j \sum_k^{M_j} P_{ijk}$.
- X_{irjk} = 1 If job i preceeds job r, on stage j, at machine k. 0 Otherwise.
- Y_{ijk} = 1 If job i, on stage j, is assigned to machine k. 0 Otherwise.

TABLE 1. MATHEMATICAL FORMULATION OF THE FLOW SHOP WITH MULTIPLE PROCESSORS.

makes sure that the processing of the job at stage j+1 does not start before it is completed at stage j, and it has reached stage j+1 for the processing. The fourth set of constraint in Table 1 are non-interference constraint. If job i and job r are not assigned to the same machine k at stage j, then both constraints will be inactive by construction. In case they are assigned to the same machine k at stage j, then one of them will guarantee non-interference, meaning both of the jobs can not be worked on simultaneously, and the other will become inactive by design. For example, if either job i or job r, or both are not assigned to the machine k, then a large number, Q or 2Q, is added to the first of the set of equation 4, and 2Q or 3Q is added to the second equation of the set, thereby making both of them inactive. On the other hand, if both jobs are assigned to the same machine k, then $Y_{ijk} = Y_{rjk} = 1$, and if job i precedes job r and Q will be added to the first equation, making it inactive. The second equation in the set will now guarantee non-interference. These equations of the set will switch roles if the job r precedes job i.

Table 2 presents an example of the formulation of the three stage flow shop problem with two parallel machines at each stage of processing. The problem has 172 constraints and 156 variables for a four jobs case which shows the size and complexity of the problem. Table 3 presents the number of variables and constraints for a general MIP formulation of the flow shop with multiple processor(s) scheduling problem.

AN EXAMPLE:

$n = 4;\ m = 3;\ M_1 = M_2 = M_3 = 2.$

STAGE j \ JOB i		1	2	3	4
1	k=1	P_{111}	P_{211}	P_{311}	P_{411}
	k=2	P_{112}	P_{212}	P_{312}	P_{412}
2	k=1	P_{121}	P_{221}	P_{321}	P_{421}
	k=2	P_{122}	P_{222}	P_{322}	P_{422}
3	k=1	P_{131}	P_{231}	P_{331}	P_{431}
	k=2	P_{132}	P_{232}	P_{332}	P_{432}

SOLUTION:

MINIMIZE Z

SUBJECT TO:

$$Z \geq F_{13}$$

$$Y_{111} + Y_{112} = 1$$
$$Y_{121} + Y_{122} = 1$$
$$Y_{131} + Y_{132} = 1$$

$$F_{11} \geq Y_{111}P_{111} + Y_{112}P_{112} + t_{11}$$
$$F_{12} - F_{11} \geq Y_{121}P_{121} + Y_{122}P_{122} + t_{12}$$
$$F_{13} - F_{12} \geq Y_{131}P_{131} + Y_{132}P_{132} + t_{13}$$

$$Q(2 - Y_{111} - Y_{211} + X_{1211}) + F_{11} - F_{21} \geq P_{111}$$
$$Q(2 - Y_{111} - Y_{311} + X_{1311}) + F_{11} - F_{31} \geq P_{111}$$
$$Q(2 - Y_{111} - Y_{411} + X_{1411}) + F_{11} - F_{41} \geq P_{111}$$

$$Q(3 - Y_{111} - Y_{211} - X_{1211}) + F_{21} - F_{11} \geq P_{211}$$
$$Q(3 - Y_{111} - Y_{311} - X_{1311}) + F_{31} - F_{11} \geq P_{311}$$
$$Q(3 - Y_{111} - Y_{411} - X_{1411}) + F_{41} - F_{11} \geq P_{411}$$

$$Q(2 - Y_{112} - Y_{212} + X_{1212}) + F_{11} - F_{21} \geq P_{112}$$
$$Q(2 - Y_{112} - Y_{312} + X_{1312}) + F_{11} - F_{31} \geq P_{112}$$
$$Q(2 - Y_{112} - Y_{412} + X_{1412}) + F_{11} - F_{41} \geq P_{112}$$

$$Q(3 - Y_{112} - Y_{212} - X_{1212}) + F_{21} - F_{11} \geq P_{212}$$
$$Q(3 - Y_{112} - Y_{312} - X_{1312}) + F_{31} - F_{11} \geq P_{312}$$
$$Q(3 - Y_{112} - Y_{412} - X_{1412}) + F_{41} - F_{11} \geq P_{412}$$

TABLE 2. AN EXAMPLE OF THE FLOW SHOP WITH MULTIPLE PROCESSORS SCHEDULING.

$$Q(2 - Y_{121} - Y_{221} + X_{1221}) + F_{12} - F_{22} \geq P_{121}$$
$$Q(2 - Y_{121} - Y_{321} + X_{1321}) + F_{12} - F_{32} \geq P_{121}$$
$$Q(2 - Y_{121} - Y_{421} + X_{1421}) + F_{12} - F_{42} \geq P_{121}$$

$$Q(3 - Y_{121} - Y_{221} - X_{1221}) + F_{22} - F_{12} \geq P_{221}$$
$$Q(3 - Y_{121} - Y_{321} - X_{1321}) + F_{32} - F_{12} \geq P_{321}$$
$$Q(3 - Y_{121} - Y_{421} - X_{1421}) + F_{42} - F_{12} \geq P_{421}$$

$$Q(2 - Y_{122} - Y_{222} + X_{1222}) + F_{12} - F_{22} \geq P_{122}$$
$$Q(2 - Y_{122} - Y_{322} + X_{1322}) + F_{12} - F_{32} \geq P_{122}$$
$$Q(2 - Y_{122} - Y_{422} + X_{1422}) + F_{12} - F_{42} \geq P_{122}$$

$$Q(3 - Y_{122} - Y_{222} - X_{1222}) + F_{22} - F_{12} \geq P_{222}$$
$$Q(3 - Y_{122} - Y_{322} - X_{1322}) + F_{32} - F_{12} \geq P_{322}$$
$$Q(3 - Y_{122} - Y_{422} - X_{1422}) + F_{42} - F_{12} \geq P_{422}$$

$$Q(2 - Y_{131} - Y_{231} + X_{1231}) + F_{13} - F_{23} \geq P_{131}$$
$$Q(2 - Y_{131} - Y_{331} + X_{1331}) + F_{13} - F_{33} \geq P_{131}$$
$$Q(2 - Y_{131} - Y_{431} + X_{1431}) + F_{13} - F_{43} \geq P_{131}$$

$$Q(3 - Y_{131} - Y_{231} - X_{1231}) + F_{23} - F_{13} \geq P_{231}$$
$$Q(3 - Y_{131} - Y_{331} - X_{1331}) + F_{33} - F_{13} \geq P_{331}$$
$$Q(3 - Y_{131} - Y_{431} - X_{1431}) + F_{43} - F_{13} \geq P_{431}$$

$$Q(2 - Y_{132} - Y_{232} + X_{1232}) + F_{13} - F_{23} \geq P_{132}$$
$$Q(2 - Y_{132} - Y_{332} + X_{1332}) + F_{13} - F_{33} \geq P_{132}$$
$$Q(2 - Y_{132} - Y_{432} + X_{1432}) + F_{13} - F_{43} \geq P_{132}$$

$$Q(3 - Y_{132} - Y_{232} - X_{1232}) + F_{23} - F_{13} \geq P_{232}$$
$$Q(3 - Y_{132} - Y_{332} - X_{1332}) + F_{33} - F_{13} \geq P_{332}$$
$$Q(3 - Y_{132} - Y_{432} - X_{1432}) + F_{43} - F_{13} \geq P_{432}$$

Above are forty three constraints for job 1. Similarly, there are forty three constraints each for job 2, 3, and 4.

Please note that P_{ijk}, t_{ij}, and Q are known constants.

TABLE 2 (Continued).

NUMBER OF VARIABLES:

$F_{ij} = n * m$

$Y_{ijk} = n * m \left(\sum_{j=1}^{m} M_j\right)$

$X_{irjk} = n\,(n - 1) \left(\sum_{j=1}^{m} M_j\right)$

NUMBER OF CONSTRAINTS:

1) $= n$

2) $= n * m$

3) $= n * m$

4) $= 2 * n\,(n - 1) \left(\sum_{j=1}^{m} M_j\right)$

TABLE 3. NUMBER OF VARIABLES & CONSTRAINTS.

As may be obvious from the table that the number of variables and constraints increase rapidly, thereby making it difficult to solve the larger problems.

The non-permutation pure flow shop is special case of the above formulation of the problem, as has been discussed before. It is the situation in which there is a single processor at each stage of the flow shop processing, or simply stated $M_1 = \dots = M_m = 1$, the representation becomes that of the pure flow shop. Table 4 presents the mathematical formulation of such problem. As is obvious from Table 1 and 4, the model can be easily modified for optimizing multiple criteria.

5.0 SUMMARY AND CONCLUSION

The flow shop with multiple processors scheduling problem is in an area of direct application for some of the real life problems of production scheduling. There are many manufacturing and other situations where this problem formulation can be usefully employed. A slight modification of this formulation is of direct interest to NASA's Space Shuttle scheduling problem. Although the stated problem has been identified before, no work has been reported on the mathematical formulation or for solving any real life problem. This paper presents a Mixed Integer Programming formulation of the stated problem which provides insight into the intricacies of the problem. The problem formulation is

OBJECTIVE FUNCTION:

MINIMIZE Z

SUBJECT TO:

$$Z \geq F_{im} \quad \text{for all } i \quad (1a)$$

$$\text{or} \quad Z \geq \sum_i F_{im} / n \quad (1b)$$

$$\text{or} \quad Z \geq F_{im} - d_i \quad \text{for all } i \quad (1c)$$

$$\text{or} \quad Z \geq \sum_i (F_{im} - d_i) / n \quad (1d)$$

$$F_{i,j+1} - F_{ij} \geq P_{i,j+1} + t_{ij} \quad \text{for all } i \text{ and } j \quad (2)$$

$$Q(X_{irj}) + F_{ij} - F_{rj} \geq P_{ij}$$

$$Q(1 - X_{irj}) + F_{rj} - F_{ij} \geq P_{rj} \quad \text{for all } i, r \text{ and } j \quad (3)$$

$$X_{irj} = 0,1 \quad \text{for all } i, r \text{ and } j$$

$$F_{ij} \geq 0 \quad \text{for all } i \text{ and } j$$

WHERE:

- n = Total number of jobs.
- m = Total number of machine stages in the flow shop.
- i = Number of job; $i = 1, \ldots, n$.
- j = Number of machine stage; $j = 1, \ldots, m$.
- P_{ij} = Processing time for job i, at stage j.
- t_{ij} = Travel time of job i, from stage j to j+1.
- F_{ij} = Flow time of job i at stage j.
- Q = A large number $\geq \sum_i \sum_j P_{ij}$.
- $X_{irj} = \begin{cases} 1 & \text{If job } i \text{ preceeds job } r\text{, on stage } j. \\ 0 & \text{Otherwise.} \end{cases}$

TABLE 4. MATHEMATICAL FORMULATION OF A PURE FLOW SHOP.

combinatorial in nature, and is useful when applied to the smaller problems. However, the formulation is useful in understanding the structure of the problem and can serve as a benchmark in the development of heuristics.

Further research is recommended in the development of useful heuristics which should substantially help in finding the solution methodologies for the large scale problems. The problem also lends itself for careful simulation studies of the dynamic formulation.

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APPENDIX IV B

FLIGHT RATE CAPABILITY : PRELIMINARY THOUGHTS

1.0 INTRODUCTION

The process of determining the flight rate is similar to determining the amount of production that an industrial system can deliver. This industrial similarity holds even though the Shuttle processing is more complex, difficult and expensive than most industrial applications. The management process of the Shuttle is complicated by the fact that the Shuttle is relatively new having been processed only 24-25 times and by the fact that NASA is new to the business of routine processing.

There are several methods used in industry to determine process rates. One is to look at a comparable process and develop rates based on similarities. Since there is nothing similar to the Shuttle, this approach does not seem to lead anywhere. Another method is to look at historic data within the organization. Unfortunately, 24 flights does not provide sufficient information to generate reliability.

The Shuttle program has evolved from an extremely optimistic view through stages from 60/year to 24/year to a pessimistic view of 9-12/year. In truth, a lot of the processing information appears to be random data. The as-run information from KSC reads, flight by flight, like different books. If much of the processing data is random, then predicting flight rates from the mean of a random process is going to lead to difficulty and certainly will not generate reliable numbers.

The first step in determining a realistic flight rate is to determine the amount of control or confidence that management has in the process and its related data. Can process steps be repeated on a new flight during the same time interval and with the same amount of resource? Once the amount of control in the process is determined then the reliability of generated predictions (read this as flight rate) falls out. Regardless of its usage in generated schedules, determining what is controlled and what is random is essential in order to accelerate the process rate. In short, in order to have routine processing you must have controlled processing. In order to have controlled processing you must know what is controlled and what is not. Then the uncontrolled issues can be addressed. But control is the key concept.

To address an issue of this sort, assumptions must be made. Typically one assigns enough constraints, through assumptions, to develop a model for which an answer can be determined. Then, where possible, the constraints are relaxed one at a time to make the model more useful. To that end the following initial assumptions are made.

There are at least two uses for determining flight rates. One is for satisfying the real pressure generated by having to respond to budget questions. Another is for usage in long range planning.

2.0 ASSUMPTIONS

1. JSC can support anything that KSC can fly.
2. Sufficient resource will be applied to find at least a partial answer to the flight rate problem.
3. The attempt to answer the flight rate problem is in relationship to long range planning as opposed to its usage in the near term.

3.0 SUGGESTIONS

- o The as run data from KSC needs to be broken up into the traditional industrial engineering categories of processing: operations, inspections, transportation, storage, and delay for each flight.
- o These categories then need to be further sub-divided into planned versus unplanned work.
- o This task, which is non trivial and will require a large amount of effort, needs to be done by a combined JSC-KSC team.
- o Coefficients of unplanned versus planned need to be generated to demonstrate what is and what is not controlled.

- Then a flight rate can be determined and a level of confidence in that flight rate can be assigned.
- Statistical studies seeking correlations between processing parameters need to be continued as a next step in the reduction and usage of the data.

APPENDIX IV C

USES OF FLIGHT RATES

1.0 INTRODUCTION

Before one begins to develop a large amount of information and analysis on flight rates the question of intended usage must be addressed. Depending on the intended usage, it may be necessary to develop different rates and to use different methods to develop them. The choice of method and the amount of time spent will also have some correlation to the amount of confidence that a particular schedule justifies.

A concept that would seem to be essential is that when flight rates are discussed that there be some agreement as to which flight rate is being discussed and what the intended usage of the information really is. Certainly, ambiguity among decision makers has the potential of creating serious problems.

2.0 USES OF FLIGHT RATE

2.1 To Determine Manifests and to Meet Customer Commitments

In this sense there is some pressure being placed on the system by the desired users of the Shuttle. One major usage of flight rate is to determine how well the system can respond to this pressure in the sense of determining what payload can be flown when.

2.2 To Respond to POP's and Budgets

There is always a need for money to support the program. A reasonable assumption is that the amount of money which will be obtained is related to the flight rate that is planned.

2.3 For Use in Long Range Planning

Future concerns of NASA can have a large impact both on the number of flights needed and on the capability of the system to produce flights. As an example, the space station both generates a need to support more flights and syphons off resources, both money and people, which will be needed to support a higher flight rate. ELV's enter into this picture somewhere also.

2.4 To Determine Ways and Means of Increasing Production

Any schedule developed to apply 5 years in the future based on 24 flights is going to have a large amount of error. However, the simple attempt to determine a realistic schedule should assist in the problem of increasing the flight rate.

3.0 CONCLUSION

Perhaps, all flight rates should be the same. Perhaps these differences are only perceived. However two underlying truths seem to apply. One is that it is difficult to imagine the same information being used in many different ways as being effective. The other is that if the policy is to use the same flight rate for all applications then this policy should result as the product of careful and logical thinking with a large amount of input from all concerned and should be well communicated and understood throughout the organization. The policy should not be the result of ommission but rather the result of commission.

APPENDIX IV D

THE FLIGHT DECISION PROCESS

1.0 INTRODUCTION

The Roger's report mentioned several times the question of determining when the burden of proof should lie on proving safe and when it should lie on proving unsafe. The intent of this short paper is to address this issue and perhaps to provide some codification of the question.

2.0 EXPERIENCE ENVELOPE

When a design is being developed and moved into an operational era an experience envelope is generated at successive steps in the process. This envelope is based not just on experience but also on analysis. The intent of this envelope is to provide a description of expected performance based on factors such as the environment, the conditions under which the design is expected to perform, loads, and in general, all known or analyzed factors which might affect the performance of the design. As the design is used, the envelope grows and performance can be predicted with greater certainty for a larger number of conditions due to history and the opportunity to do more analysis.

3.0 THE BURDEN OF PROOF

When a system is going to perform within its experience envelope, the burden of proof lies on showing that it is unsafe to use the design within its experience envelope. After all, this is the primary reason for developing an experience envelope: to indicate parameters under which performance can be predicted.

When a system is going to perform outside its experience envelope, the burden of proof lies on showing that it is safe to use this design in the new environment. This is new territory and must be explored cautiously. Moving outside the envelope requires, in the absence of history, a careful analysis to be done on expected performance.

4.0 LEVELS OF CONFIDENCE

When costs, in the sense of any of money, people, or equipment, are small, then the level of confidence in the envelope need not be so great. However, when costs are high, then a large level of confidence in the predictions of the envelope is necessary. The intent here is to reduce risk. With high costs and a cautious approach, the envelope can grow and produce expanded performance.

APPENDIX IV E

AN ANALYSIS OF THE FLIGHT RATE CAPABILITY OF NASA's SPACE SHUTTLE PROGRAM

1.0 INTRODUCTION

The Space Shuttle Program of NASA is an extensive research and development endeavor with aspirations of moving to an operational era. The program continues to grow, in size and complexity, and the need to find an operational structure is also increasing progressively in the same direction. The Space Shuttle Challenger's disaster has made this system even more complex and critical, and has, at least on the surface, made the move to operations more difficult. A potential complicating factor is that of removing undue pressure from the system and channeling resources in order to improve the entire system. The findings of the Presidential Commission on Space Shuttle Challenger's disaster suggests that, although the disaster occurred because of an engineering failure, it was rooted in a long strings of problems in management, communications, safety, quality control, etc. (1); most of these problems were of an operational nature. One of the findings of the commission indicates a contributing factor being rooted in the difference between R&D and Operational management. When the program was declared to be operational after the test flights, the report points out, NASA started flying more frequent missions with the same resources, which resulted in a diversion of attention to the more pressing immediate problem of meeting the schedule. The consequence was undue pressure on the entire system (2).

As this program moves to a steady operational status, it is important that appropriate planning/analysis models of the system be developed to support the program. An example of such a model is Flight Rate Capability Simulation Model, the use of which will help the management to analyze the effects of a planned flight rate before making a commitment. The determination of the flight rate is a difficult problem and one about which much controversy exists. The Rogers' Commission (2) and the National Research Council (3) have both studied flight rate as a result of Challenger incident, which further point out the difficulty of the problem.

The flight rate simulation analysis will help to ascertain the ways and means to achieve a target rate and impact subsequent allocation of resources. An aspirant example for the application of a flight rate capability model may be to find bottleneck facilities and to determine the necessary resources to rectify the situation in order to achieve the desired capability. Another use of such a simulation model may be to observe how much increase in flight rate can be achieved by adding one more Orbiter or by increasing any other resource of the production process.

This paper presents a Flight Rate Capability Model for the Space Shuttle. The simulation language, GPSS, has been used for the modeling. The purpose of presenting this model is to provide a direction for the planning of flight rate capability. The simulation model presented here is meant to provide an analysis tool for the resource allocation and capital investment planning.

2.0 FLIGHT RATE CAPABILITY MODEL

The Space Shuttle goes through three specific facilities, Orbiter Processing Facility (OPF), Vertical Assembly Building (VAB), and Launch Pad (LP), in the same order before being launched into space from the LP at Kennedy Space Center (KSC). The OPF is where basic processing is done on the Orbiter. The VAB is where the Orbiter is mounted with its Solid Rocket Boosters and External Tank. The LP is the launch site where most payloads are mounted, and the propellant is loaded. Before the Orbiter goes into the LP, it requires the Mobile Launch Platform (MLP). At the VAB, the Orbiter is mounted on the MLP, which stays with the Shuttle until it is launched into space. At that time the MLP is brought back and is processed before it can be made available for the next mission. In the future, the Orbiter will also be launched from Vandenberg Air Force Base. In that case, the Space Shuttle is processed in the OPF at KSC, and is then loaded on the Shuttle Carrier Aircraft (SCA) with the Tail Cone and sent over to Vandenberg where it is

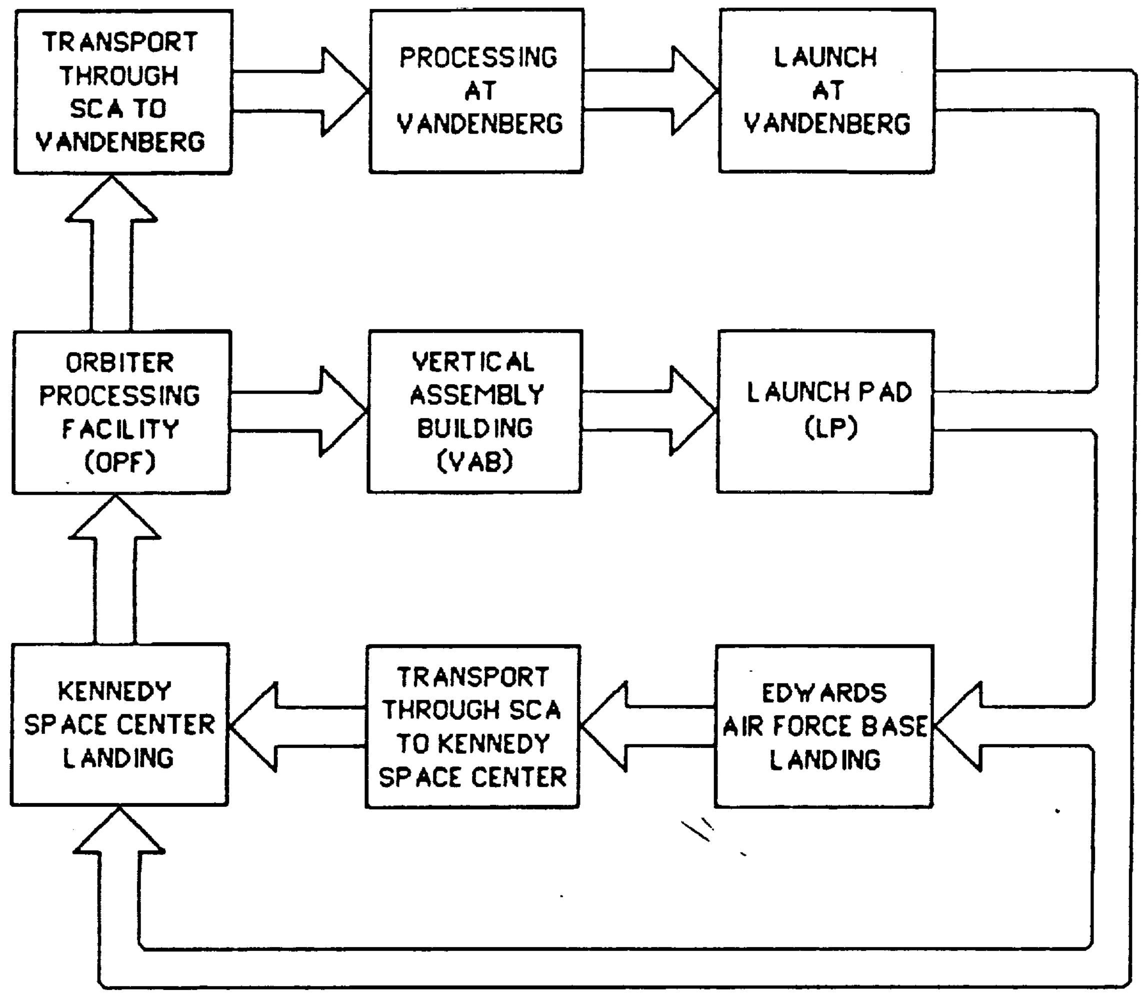

FIGURE 1. SCHEMATIC DIAGRAM OF SPACE SHUTTLE PROCESSING.

processed further and launched. In both cases, the Space Shuttle can either land at Edwards Air Force Base in California, or KSC in Florida. There are other alternate landing and abort sites in Europe and Africa, but they are not currently considered in the model. If the Space Shuttle lands at Edwards, then it is loaded onto the SCA with the Tail Cone and is brought back to KSC for the processing of the next mission. Beside the time the SCA/Tail Cone spends with the ferry operation of the Space Shuttle, additional time is required for processing before it is can be made available for the next trip. All of this has been considered in the model and is schematically presented in Figure 1.

Most of the elements of the Space Shuttle processing are stochastic in nature, consequently the system has been stochastically modeled. This means that the probability distributions have been used in calculating various times. As the simulation proceeds, samples are taken from the appropriate probability distributions so as to model the stochastic behavior. The model is designed to run for one thousand times the number of working days in a year, and various flight rate tables are tabulated after every ten cycles. This is done to reduce the variance for flight rate projection figures. Also, different queue tables are printed to study the queuing behavior. The flow diagram of the model is presented in Figure 2.

The flight Rate Capability Simulation Model is a discrete change model in which most of the changes are occur

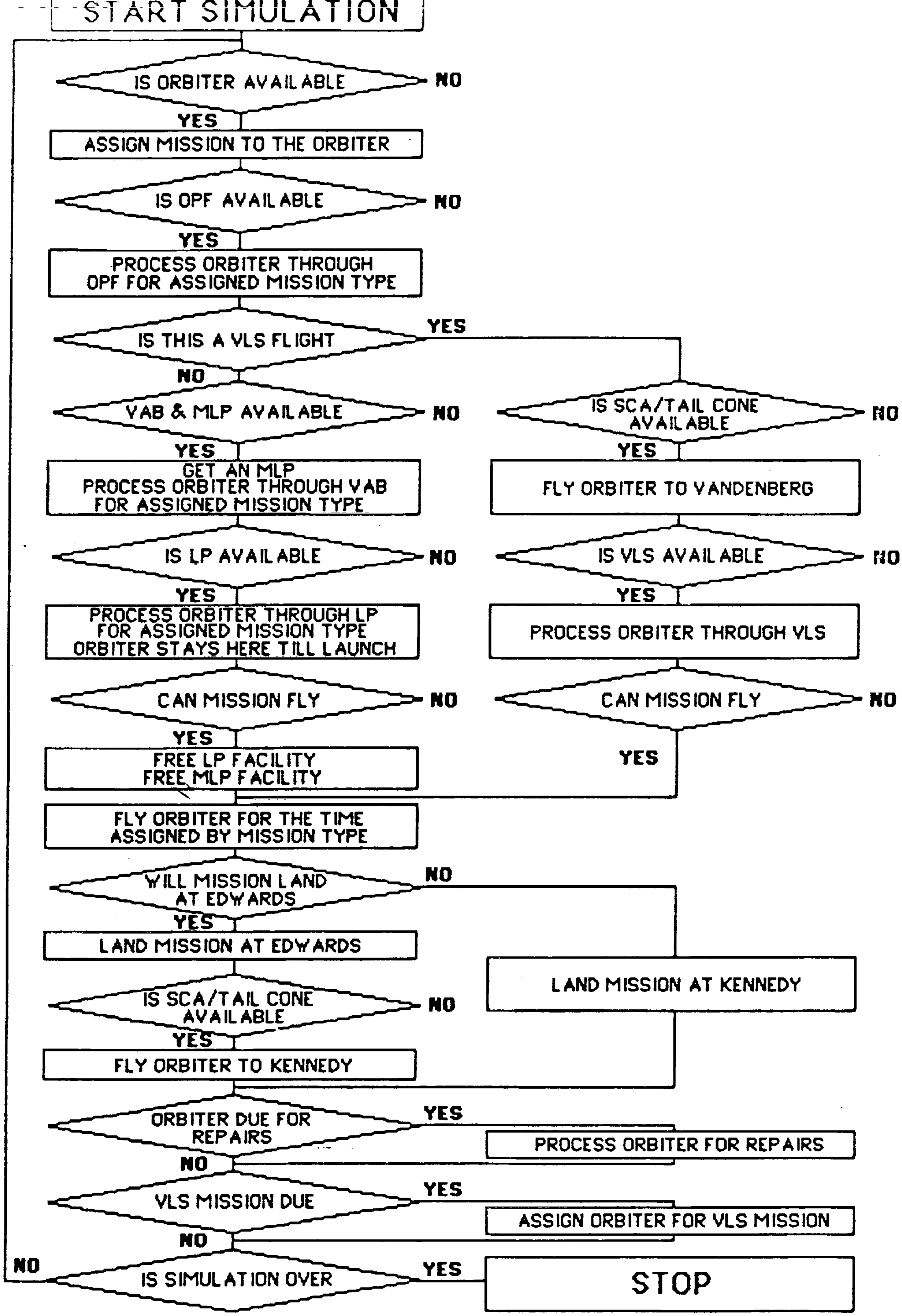

FIGURE 2. FLOW DIAGRAM OF SIMULATION STUDY.

NOTE: IN CASE OF A SINGLE EXIT DECISION BLOCK, THE TRANSACTION STAYS TILL IT CAN LEAVE.

due to some statistical distributions. The processing times in OPF, VAB and LP facilities have high variances. Even when the data points of the test flights flown early in the history of the Shuttle are removed, the variances are high enough to justify the use of the exponential distribution. One of the explanations for the high variances might be the fact that the data from all of the flights was considered together. Although some of the variance can be attributed to the difference in the flight types, we do not have enough data points to statistically reach a conclusion. The comparison of simulation runs with equal probability of past occurrence, and the ones using exponential distribution with a mean of historical data did not produce any statistically different results. Moreover, the plot of data also presents a similar situation and it was therefore decided to use exponential distribution in calculating the processing time of these facilities. The flight time was also modeled to follow the same distribution. Similarly, the processing time for the Orbiter at Vandenberg, and MLP processing time after it is brought back from the LP were also modeled to follow the exponential distribution, although data was not available to support or justify the assumption since the shuttle has not yet flown from Vandenberg. SCA/Tail Cone ferrying and thereafter processing time was considered to be quite standard and are therefore thought to be following a normal distribution with small variance. Again, no data is available to justify the claim. Some of the other times, mostly travel times, were considered known constants and were modeled that way. An Orbiter down time of 21 days per year is also included in the model and is treated as a constant. Another variable included in the analysis is the flight rate mixture. This variable is based upon a fixed number of Vandenberg (VLS) flights and a percentage mixture of other flight types launching out of KSC. Similarly, a ratio of Edwards and KSC landing is supplied in the model and can be changed for a different landing mix. Furthermore, a mixture of different payloads is supplied as a percentage. The choices of payload are Standard (STD), Department of Defense (DOD), Space Lab (S/L), and Mixed (MIX) type. The selection of choices is based on an analysis of both flown and projected payloads.

The system is modeled with a number of different types of facilities, the specifications of which can be changed by the user, if so desired. These include:

- Number of Orbiters;
- Number of OPF Facilities;
- Number of VAB Facilities;
- Number of LP Facilities;
- Number of MLPs' Available;
- Number of SCA/ Tail Cones;
- Number of Space Shuttles allowed in space at one time.

There are some restrictions on the model which are accordingly incorporated as:

- When there is a DOD job in the VAB or on the LP, then the next DOD job cannot enter the VAB unless the first has been launched in space;
- If the Space Shuttle flies from two different facilities on consecutive missions, then a fourteen day change over time is needed before the next mission can be flown.

Some of the processing times data which remained unchanged during the entire simulation study are as follows:

- Processing time at OPF for VLS missions : Exponentially distributed with a mean of 42 days;
- Mission processing time at VLS: Exponentially distributed with a mean of 63 days;
- MLP processing time: Exponentially distributed with a mean of 22 days;
- Time for SCA/Tail Cone flight: Normally distributed with a mean of 6 days and Standard Deviation of 1;
- Time to process reuse of Tail Cone: Normally distributed with a mean of 3 days and Standard Deviation of 1;
- Time between flying of two missions: One day;
- Time for MLP to go back for processing:7 days;
- In flight time of the Space Shuttle: 7 days.

CONSERVATIVE DATA

FACILITY / FLT. TYPE	OPF	VAB	LP
STANDARD	51	5	23
DOD	51	5	28
SPACE LAB.	61	5	22
MIX	55	5	23

REALISTIC DATA

FACILITY / FLT. TYPE	OPF	VAB	LP
STANDARD	40	5	17
DOD	40	5	22
SPACE LAB.	50	5	16
MIX	44	5	17

OPTIMISTIC DATA

FACILITY / FLT. TYPE	OPF	VAB	LP
STANDARD	30	4	16
DOD	30	4	21
SPACE LAB.	40	4	15
MIX	34	4	16

TABLE 1. MISSION PROCESSING TIMES DATA (IN DAYS) FOR THREE DATA TYPES.

3.0 RESULTS

The simulation runs based upon the three data types have been studied in reasonable details. Table 1 presents Conservative, Realistic and Optimistic estimates of the processing times, in the number of days, spent in each facility, for the STD, DOD, S/L, and MIX flight types. At this point, it may be noted that the three data sets are not based upon any statistical prediction equations, but are actually the result of management judgment at NASA. However, they have been used in this illustration to exhibit the working of the model and provide some useful guidelines for comparing the options.

The simulation runs for each set of the data, and landing and/or down time mix, as presented on the vertical axis of Table 2, are based upon the six categories of facilities grouping, as displayed on the horizontal axis of the same table. The flight mix in all of these runs is as follows:

STD.=26.7%; DOD=33.3%; S/L=20%; MIX=20%.

Table 2 presents the summary of the flight rates of the 84 simulation runs. Before any conclusions are drawn on the findings of the simulation, an obvious observation is in order. The simulation results presented here are very useful to perform what-if analysis for the planning of the flight

ALTERNATIVES OR FACILITIES MIX / DATA TYPES WITH FLIGHT MIX	NUMBER OF ORBITERS	1	2	3	4	5	6
		OPF=2 YAB=2 LP =2 MLP=3	OPF=3 YAB=2 LP =2 MLP=3	OPF=2 YAB=3 LP =2 MLP=3	OPF=2 YAB=2 LP =3 MLP=3	OPF=2 YAB=2 LP =2 MLP=4	OPF=3 YAB=2 LP =2 MLP=4
CONSERVATIVE DATA NUMBER OF VLS FLTS= 0. ORBITER DOWNTIME= 21 EDWARDS LANDING =100 %. KSC LANDING = 0 %.	3	9.239	9.977	9.203	9.355	9.287	10.047
	4	10.776	12.290	10.736	10.861	10.979	12.515
REALISTIC DATA NUMBER OF VLS FLTS= 0. ORBITER DOWNTIME= 21 EDWARDS LANDING =100 %. KSC LANDING = 0 %.	3	11.352	12.056	11.351	11.362	11.459	12.214
	4	13.146	14.621	13.103	13.254	13.392	15.280
REALISTIC DATA NUMBER OF VLS FLTS= 0. ORBITER DOWNTIME= 21 EDWARDS LANDING = 0 %. KSC LANDING =100 %.	3	11.852	12.820	11.871	11.903	12.168	13.071
	4	13.537	15.310	13.571	13.638	14.014	16.177
OPTIMISTIC DATA NUMBER OF VLS FLTS= 0. ORBITER DOWNTIME= 21 EDWARDS LANDING =100 %. KSC LANDING = 0 %.	3	13.269	13.838	13.252	13.358	13.491	14.169
	4	15.326	16.516	15.309	15.442	16.021	17.550
OPTIMISTIC DATA NUMBER OF VLS FLTS= 0. ORBITER DOWNTIME= 21 EDWARDS LANDING = 50 %. KSC LANDING = 50 %.	3	13.735	14.363	13.720	13.734	14.036	14.805
	4	15.705	16.924	15.560	15.775	16.562	18.146
OPTIMISTIC DATA NUMBER OF VLS FLTS= 0. ORBITER DOWNTIME= 0. EDWARDS LANDING = 0 %. KSC LANDING =100 %.	3	14.592	15.521	14.600	14.730	15.138	16.342
	4	16.319	17.655	16.307	16.353	17.369	19.468
OPTIMISTIC DATA NUMBER OF VLS FLTS= 2. ORBITER DOWNTIME= 0. EDWARDS LANDING = 0 %. KSC LANDING =100 %.	3	13.670	14.313	13.659	13.656	13.888	14.756
OPTIMISTIC DATA NUMBER OF VLS FLTS= 3. ORBITER DOWNTIME= 0. EDWARDS LANDING = 0 %. KSC LANDING =100 %.							
	4	15.153	16.792	15.111	15.124	15.421	17.455

TABLE 2. SUMMARY OF THE SIMULATION RUNS FOR THE FLIGHT RATE PER YEAR.

rate capability. Meaning, if the management can achieve the processing time capabilities which they furnished with this set of facilities mix, then these results are very likely to occur. However, they do not, by any means, provide an assurance of the flight rate capability unless it can be shown that the data represents the actual statistical projections. Even then there is an element of statistical uncertainty associated with the results and it may only be interpreted that way. The validity of the model, however, is established by the fact that when the actual processing time and flight mix is used, the results are very similar to the observed flight rates.

4.0 STATISTICAL PITFALLS OF SIMULATION MODELING

Simulation models are very meaningful in representing the present system and that is where they can be verified as well. Once the model passes the verification tests, it can be used to study the changes in the system by changing some input variables. Here, the choice of changes in input variables is something which needs some clarification. In the flight rate capability example, if the study is that of incrementing a major resource such as an orbiter by one unit, then the study will yield meaningful information as long as the processing time for the different facilities is not a function of time. Usually there is a learning curve pattern in the processing time, as well as the factor that as the facilities grow older, they require more maintenance and safety inspections. Both of these imply that processing time is a function of time and experience. Under such circumstances and realizing that the lead time of adding any facility in this example is several years, the need is that of statistically projecting the processing time data to the point when the facilities are planned to be made available. If the projection equation is either statistically unsound or projected beyond the experience base, then the output result of a simulation experimentation can at best be as good as the projections themselves. This leads us to a very serious pitfall in simulation and cautions us that the model results are only meaningful in the proper working range.

5.0 MODEL USEFULNESS FOR NASA

Computer simulation has found its use in almost all engineering and management situations. The computer simulation models often involves a "trial and error" way to demonstrate the likely effect of various policies. The results are usually interpreted in economic terms and a decision is usually reached in terms of the economic preference under the budgetary restrictions. The user has control over the source information, which means that if it is not properly supplied, then the results may not be meaningful for the desired application.

A simulation model usually represents some statistical experiment and it is important that the input data reflect that relationship. Another point of consequence is the time frame involved. For example, if NASA is considering the addition of a Space Shuttle or another OPF facility, then it is important to consider the lead time required in acquiring either one of them. Assuming it takes four years to build an Orbiter or an OPF facility, then the appropriate way to model will be to project the processing time of the facilities four years into the future and study the effect of each alternative on the model. If the processing time on the facilities are on a downward trend, then although an additional OPF facility may be economical today, it may not be the same in four years when having another Orbiter may become a more viable alternative. Similarly, if a target flight rate has to be achieved, the right combination of facilities and Orbiters can be found with the help of a Flight Rate Capability Simulation Model.

To answer such questions, it is important that NASA has a simulation model available. The model developed here represents the most significant aspects of Space Shuttle processing, and has helped NASA management to make judicious estimates of the flight rate capabilities. However, in order to gain realistic insight, NASA needs to incorporate other pertinent considerations into the model. Items like Flight Crew Simulator time, spare parts availability and others, if added, could present a more realistic view of the situation. With the aid of a complete simulation model, the NASA management will be in a position to compare alternatives. They will be able to see the effect of planned changes on the overall system before actually making a commitment. The scientific judgment, as the result of simulation experimentation, will be much more profound than with intuitive feelings or an isolated economic analysis.

6.0 CONCLUSION

The prime function of running a smooth operational organizations such as NASA's space shuttle program is that of planning the future requirements of the system. The performance evaluation of such an organization is generally based upon the quantity and quality of the work produced, and the economic considerations of how effectively the resources were utilized to gain the overall objectives of the organization. The economic considerations, in turn, includes timing and location of the production, along with the equipment, material, energy and labor utilization. All of these considerations must be converted to a common economic base when evaluating the contribution of the resources toward the overall objectives of the organization.

In capital intensive engagements, such as NASA's shuttle program, the managerial planning decisions are very crucial. They are deciding the monetary commitment and future direction of the organization over a long period of time. The decisions made in such conditions are generally irreversible and have serious implications. Therefore, it is imperative that such decisions must be made after complete deliberation and thorough scrutiny of the available choices. The Flight Rate Capability Simulation Model presented in this paper provides a planning tool and a probable direction for such a methodical investigation process.

7.0 REFERENCES

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[2] "Report to the President by the Presidential Commission on the Space Shuttle Challenger Accident," Government Printing Office, (1986).

[3] Waldrop, M. Mitchell, "Panel Questions Shuttle Flight Rate," Science, Issue No. 234, (October 24, 1986).

CHAPTER V

DEMOGRAPHIC SURVEY

APPENDICES

CHAPTER V. DEMOGRAPHIC SURVEY

1.0 INTRODUCTION

The purpose of this chapter is to characterize as far as possible the makeup of the AE, AM, C, D, E, F, G, S, T, and V offices regarding the age, grade, experience, starting age, and education of their professional employees. This process, which was conducted in the summers of 1984, 1985, and 1986, was done on the composition of the work force at JSC that had a strong probability of being involved in the management and technical support of the shuttle program. This base also has a high possibility of providing future needs in these areas. As the shuttle proceeds from an environment which is primarily R/D to one which is more operational in nature, human resource and manpower planning is an essential ingredient to smoothing the transition. Also, since changing demographics is a long lead time issue, a careful analysis of the demographic state and its trending seems to be necessary.

Appendix V A shows the demographic state of NSTS as of the summer of 1986. Appendix V B is a comparison of the 1984, 1985, and 1986 demographic studies. One difficulty encountered in the preparation of a comparison was that the means of collecting the data changed from 1984 to 1986 as familiarity was gained with the problem. This made some comparisons weak and made some others impossible. Specific instances of this problem will be mentioned as the data is discussed. In addition some of the data in the 1986 survey does not have a meaning when analyzed for change. Specifically there does not seem to be any value in looking at the way that degree migration has changed over the three year period.

2.0 CONCLUSIONS

The conclusions made from this study are, of course, very tentative since there are only three years of data, and the method of drawing the sample changed during the period. There are a few trends worthy of comment. One is the general overall loss in the total work force. The major question is whether this was planned or accidental. A related question is: If it was planned, was it planned by the right level in the organization and did the plan work? Another trend worth comment is the reduction of personnel in the GS 13 level. The same questions on planning are applicable here. Another trend that was found deals with the loss of technical talent. Why are these people leaving and is this good are bad for the organization?

3.0 RECOMMENDATIONS

1. The loss of technical talent has serious implications. This loss needs to be further examined and explained.

2. The GS 13 spike needs careful monitoring and control.
3. During both the stand down caused by 51L and the transition period to a more operational nature, great care and attention must be paid to the morale of the employees involved.
4. This study needs to be repeated in 1987.

APPENDIX V A

DEMOGRAPHIC SURVEY OF PROFESSIONAL EMPLOYEES

AE, ,AM, C, D, E, F, G, S, T, AND V ORGANIZATIONS

SUMMER 1986

1.0 INTRODUCTION AND OBJECTIVES

This report is the first half of a two part report. The purpose of this half is to characterize as far as possible the makeup of the above offices regarding the age, grade, experience, starting age, and education of their professional employees. These offices were chosen to reflect the base which composes the current management and technical support. This base also has a high probability of providing future needs in these areas. As the shuttle proceeds from an environment which is primarily R/D to one which is more operational in nature, human resource and manpower planning is an essential ingredient to smoothing the transition. The intent of this document then, in simple terms, is to show the demographic state of NSTS and its support elements as of the summer of 1986.

The size of the sample in the demographic survey was 1689 employees.

This survey was also done in the summers of 1984 and 1985. The second half of this report, which follows in

Appendix V B, is a comparison of these different surveys. Since changing demographics is a long lead time issue, a careful analysis of the demographic state and its trending seems to be necessary.

2.0 DEMOGRAPHICS

The rest of this report is devoted to a discussion of the charts presented.

2.1 AGE-CHART 1, CHART 2

Chart one shows a bimodal distribution of age. The cohort in the 46-50 year bracket is by far the largest with a sub-maximal point in the 26-30 year bracket. Normally, one would expect to see a chart which was loaded heavy on the front end with younger brackets having more members. This wave of older employees is indicative of down the road problems as these employees age and early retirement becomes more attractive.

Chart two shows the age by grade. An interesting point here is that grades 13 through SES are almost flat. This seems to indicate that promotion from 13 on is relatively slow. As an aside, as more people opt for early retirement, perhaps more slots will open up for early retirement.

2.2 GRADE-CHART 3

Chart three shows that the GS-13 slot is the largest with around 37% of the sample. The next largest cohort is the GS-14 grade with 21%. So the majority of the employees are graded 13 or above. This may be healthy for a developmental environment but may lead to down the road operational problems. This chart, along with the two previous seems to indicate that there is little if any feeder pipeline supplying new and younger talent to the program.

2.3 SERVICE-CHART 4

This chart is almost flat for 13 through SES at around 20 years. The average service for the sample was 16.4 years.

2.4 START AGE-CHART 5, CHART 6

Chart 5 shows the number of employees starting with NASA at a particular age. Most employees started with NASA between 23 to 24 years of age. The next largest cohort started at 21 to 22 years of age. What this chart shows is that for most of the sample, NASA was their first real job after school.

Chart 6 shows start age as function of grade. Since the chart is mostly flat, the start age does not vary much by grade. The average start age is 27 years.

2.5 COMBINED DEMOGRAPHICS-CHART 7

This chart shows age, service, and start age as a function of grade.

2.6 HIGHEST DEGREE-CHART 8, CHART 9, CHART 10

Chart 8 shows the level of the highest degree of the sample. Here, 27% of the sample has a masters degree or better. This again is healthy for R/D but spells trouble for operations.

Chart 9 shows that almost everyone is an engineer with science and math coming in second and third. Chart 10 is the same information by percentage.

2.7 BS DEGREE-CHART 11. CHART 12

The first degree that an individual holds goes a long way towards shaping their thought process. These charts show a majority of the bachelors degree sample holding an engineering degree with science and math coming in second and third as before.

2.8 MASTERS DEGREE-CHART 13, CHART 14

These charts show similar results for the masters degree as the previous 4.

2.9 DOCTORS DEGREE-CHART 15, CHART 16

These charts show a small surprise with the field of science having a strong majority of the doctors degrees. Engineering is second.

2.10 FIELD AND LEVEL OF DEGREES-CHART 17

This chart shows the field and level of the degrees of the sample. Two unusual points occur. One is that there are more doctors of science than masters. Another is that there are most masters of business than bachelors.

2.11 DEGREE MIGRATION-CHART 18

This chart shows the path from the second highest degree, provided there was at least a masters, to the highest degree. Most people followed a traditional path of second highest to highest in the same field. An exception to this is the business masters which attracted a large percentage from outside of business.

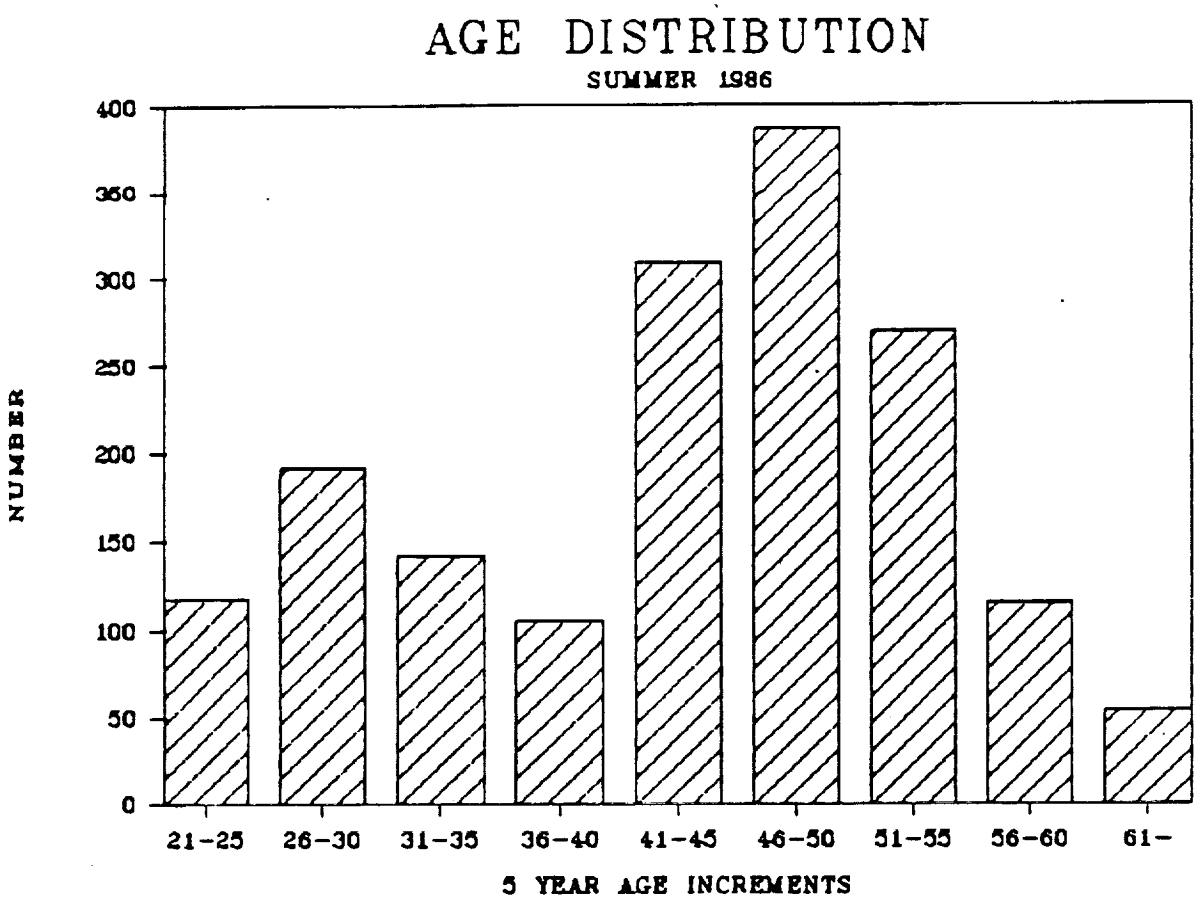

AGE DISTRIBUTION
SUMMER 1986
NUMBER
0
50
100
150
200
250
300
350
400
21-25
26-30
31-35
36-40
41-45
46-50
51-55
56-60
61-
5 YEAR AGE INCREMENTS

CHART 1

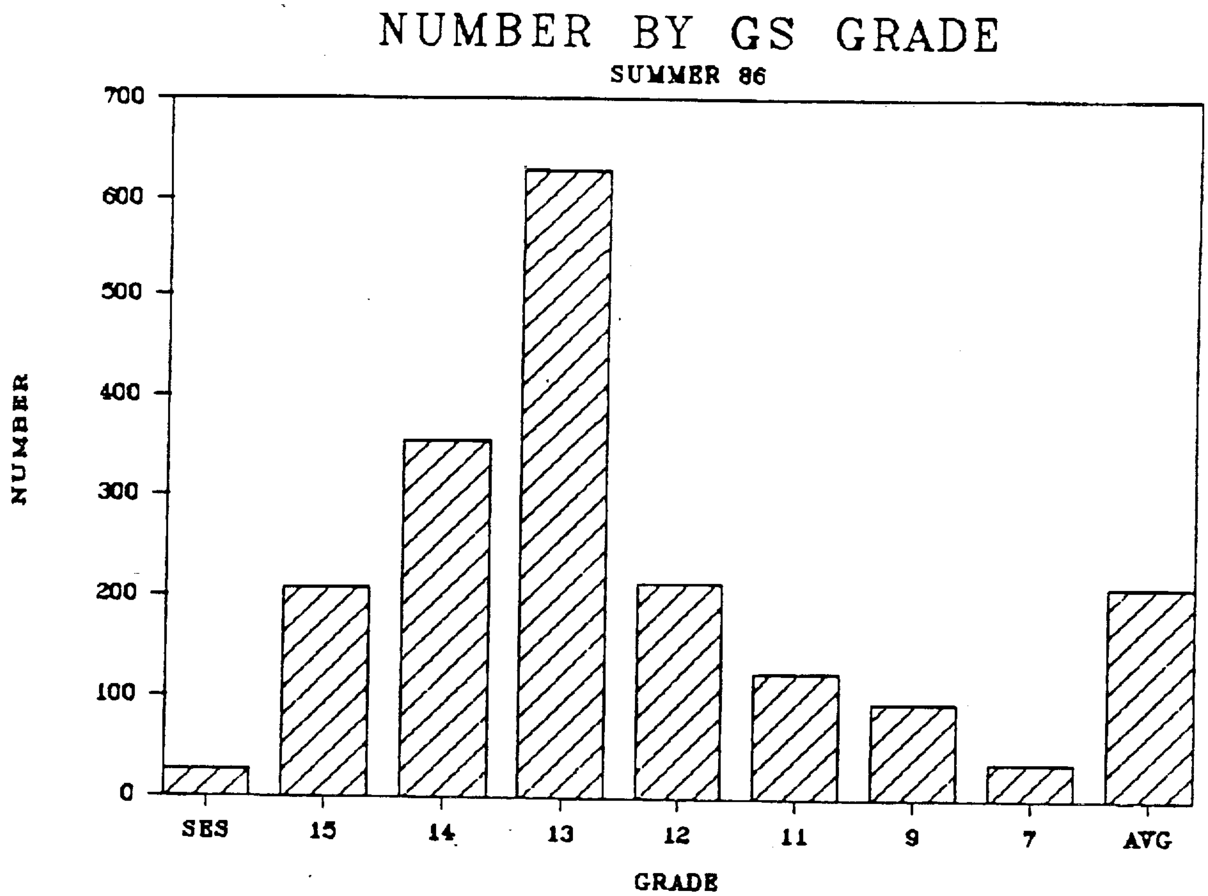


CHART 3

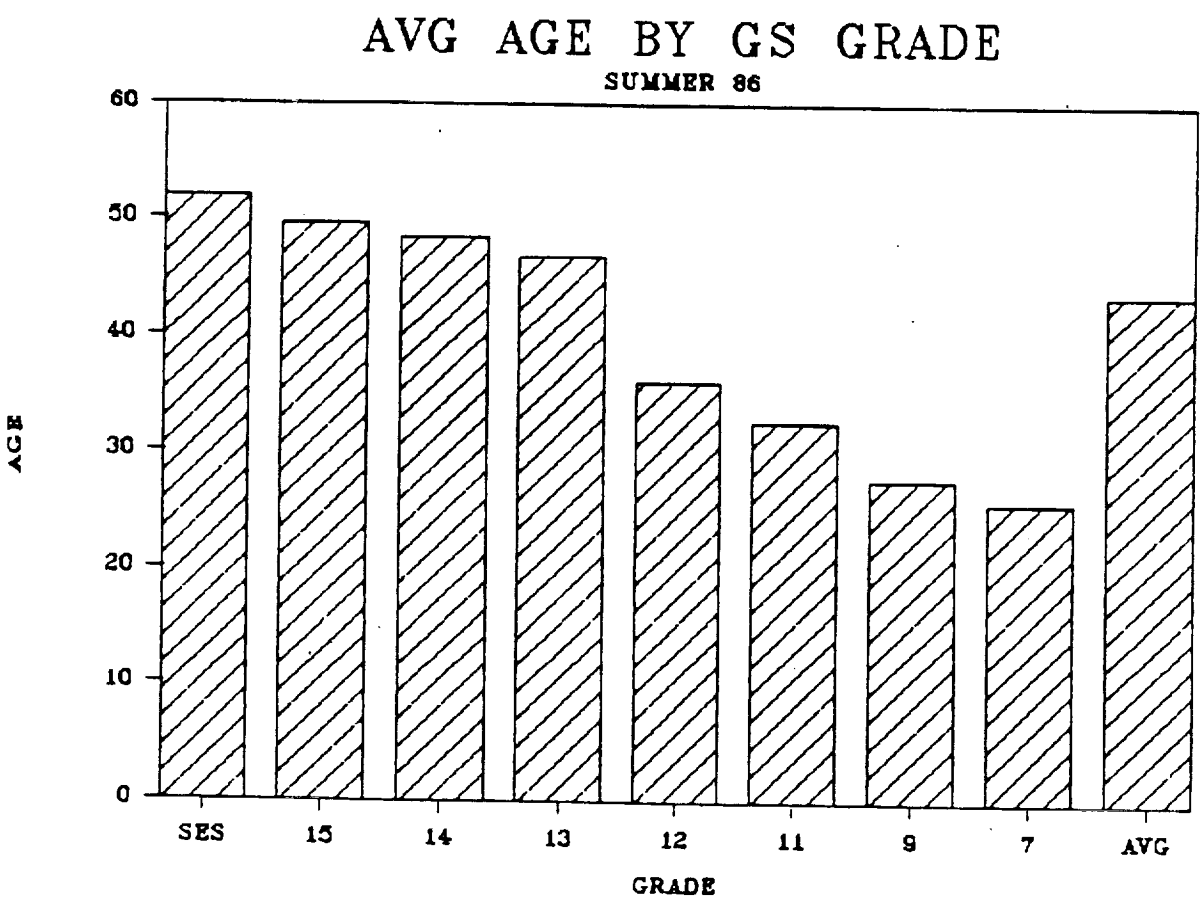


CHART 2

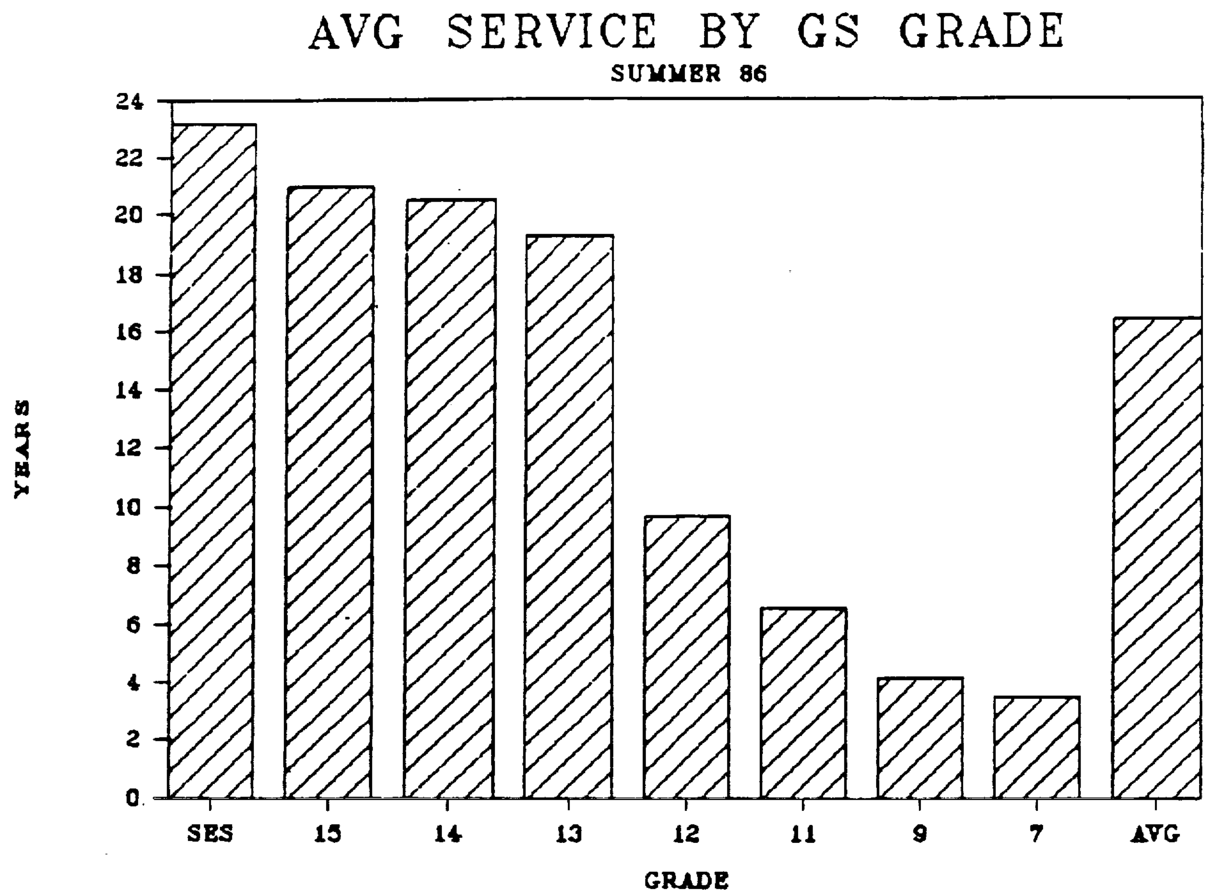

AVG SERVICE BY GS GRADE
SUMMER 86
YEARS
24
22
20
18
16
14
12
10
8
6
4
2
0
SES
15
14
13
12
11
9
7
AVG
GRADE

CHART 4

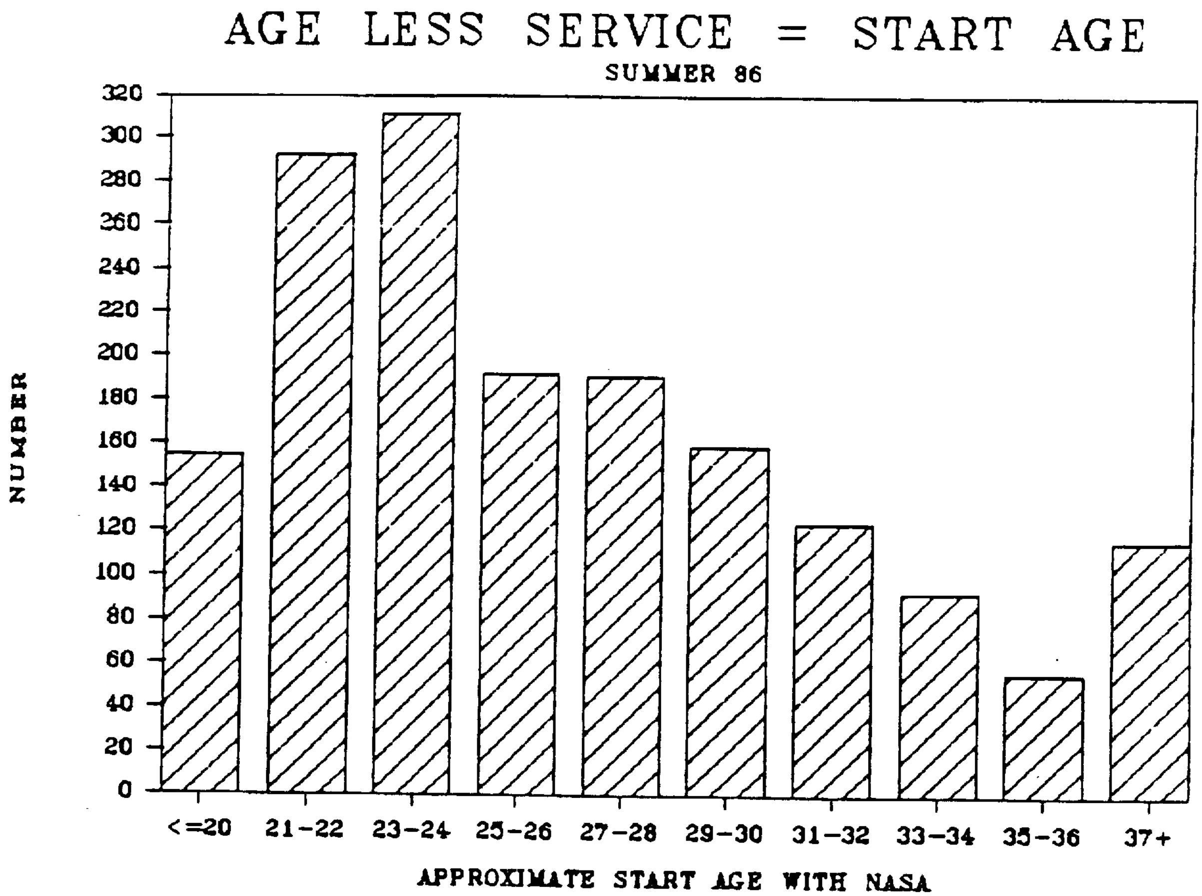

AGE LESS SERVICE = START AGE
SUMMER 86
NUMBER
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
<=20
21-22
23-24
25-26
27-28
29-30
31-32
33-34
35-36
37+
APPROXIMATE START AGE WITH NASA

CHART 5

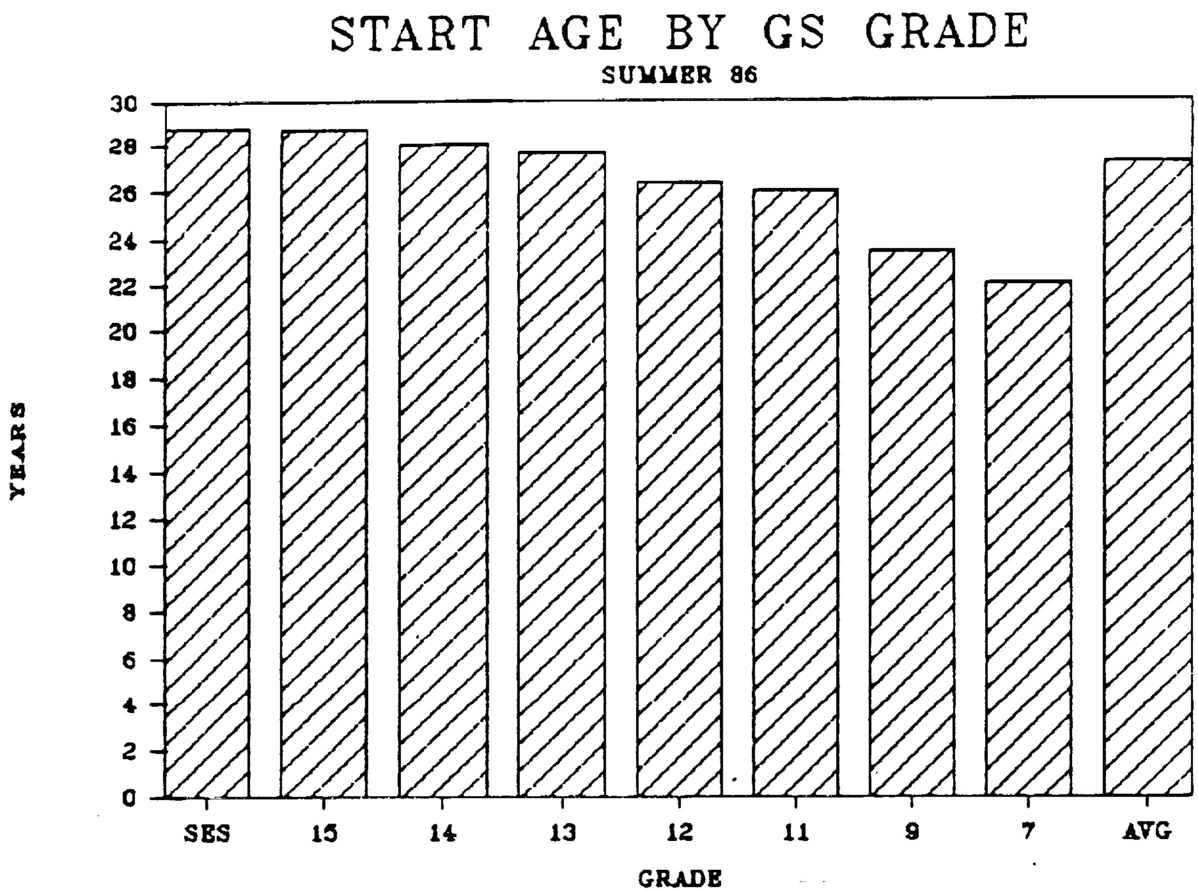

START AGE BY GS GRADE
SUMMER 86
YEARS
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
SES
15
14
13
12
11
9
7
AVG
GRADE

CHART 6

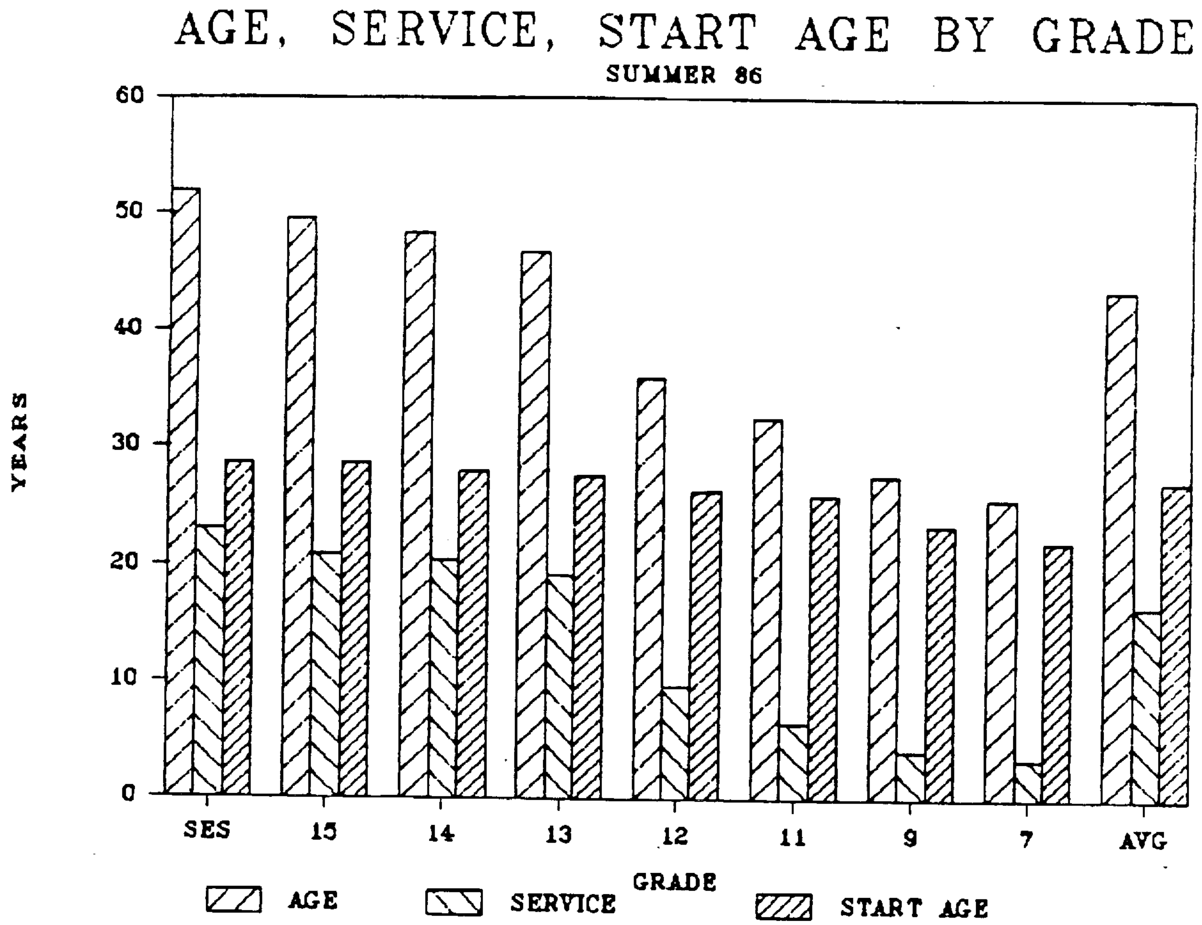

AGE, SERVICE, START AGE BY GRADE
SUMMER 86
YEARS
60
50
40
30
20
10
0
SES
15
14
13
12
11
9
7
AVG
GRADE
AGE
SERVICE
START AGE

CHART 7

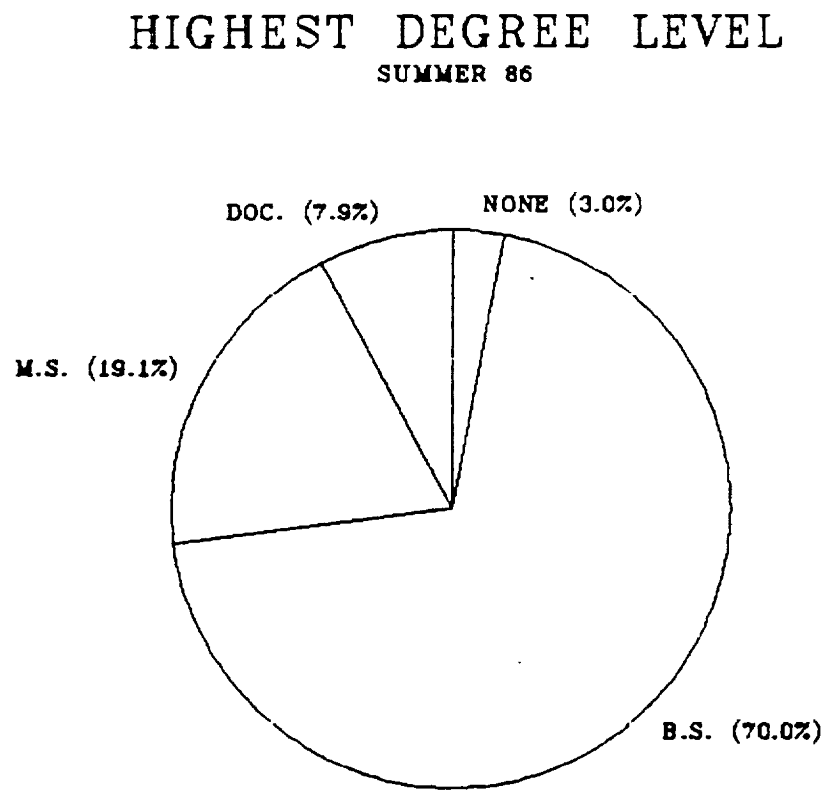


CHART 8

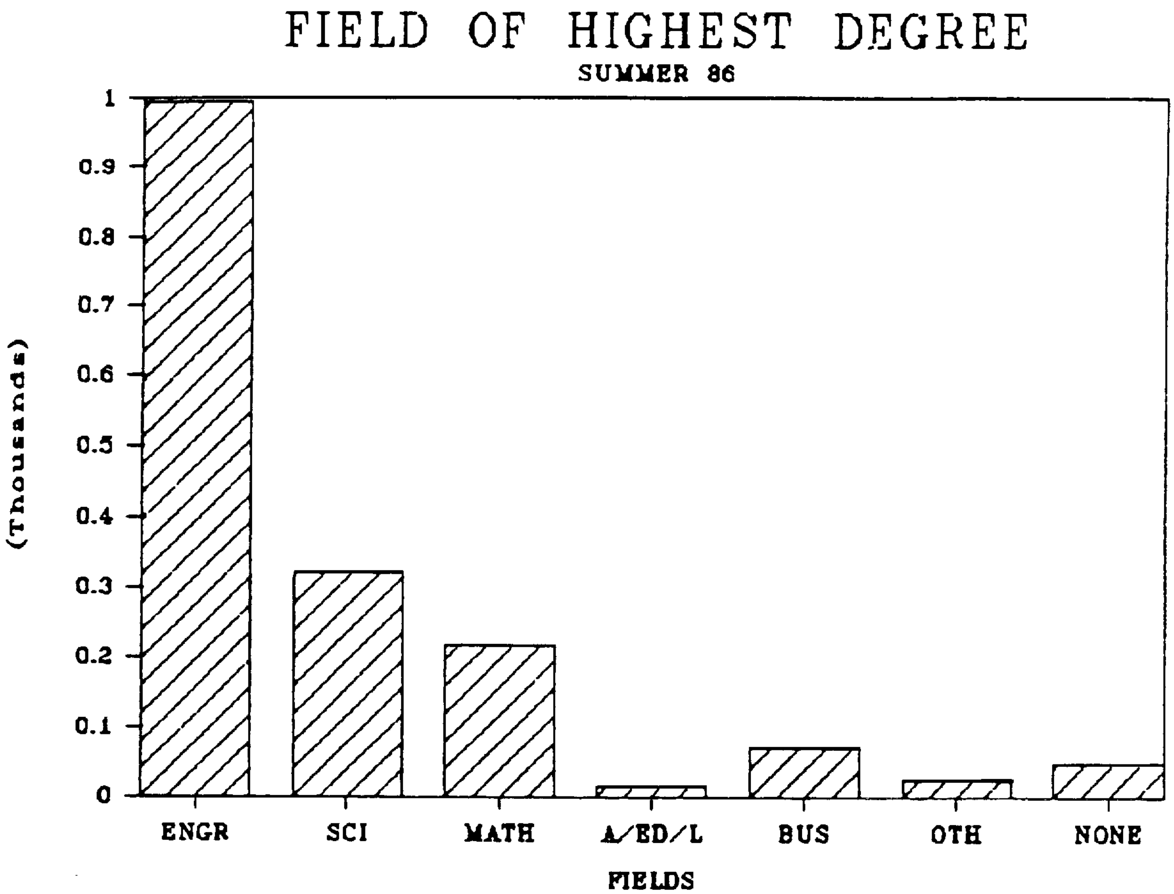


CHART 9

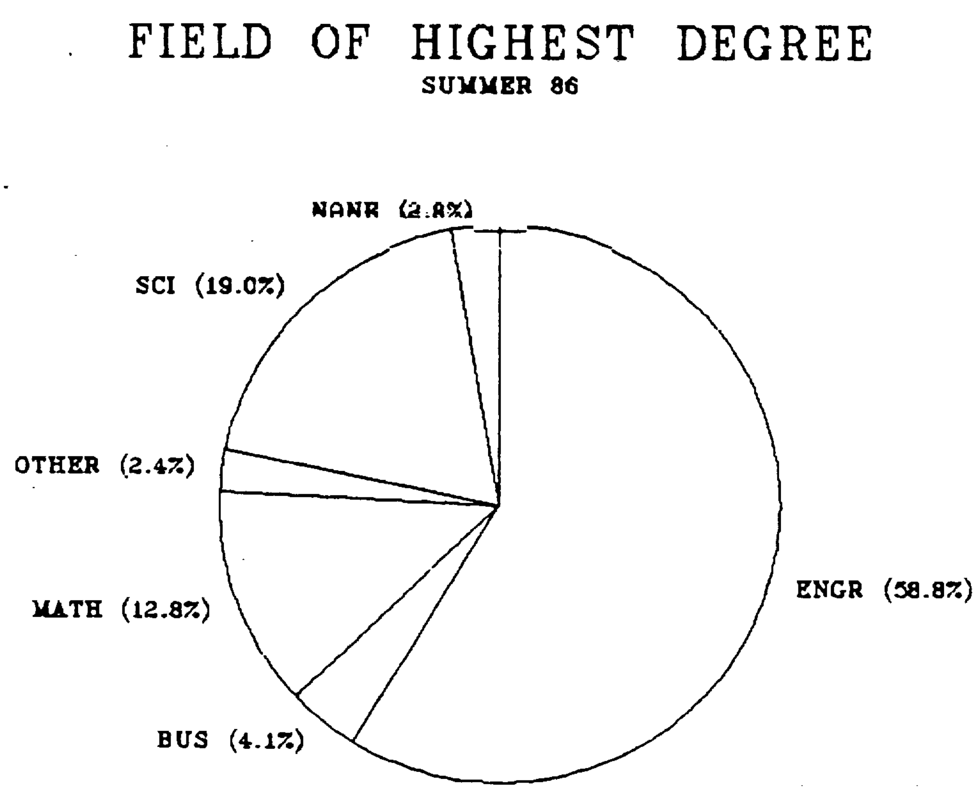


CHART 10

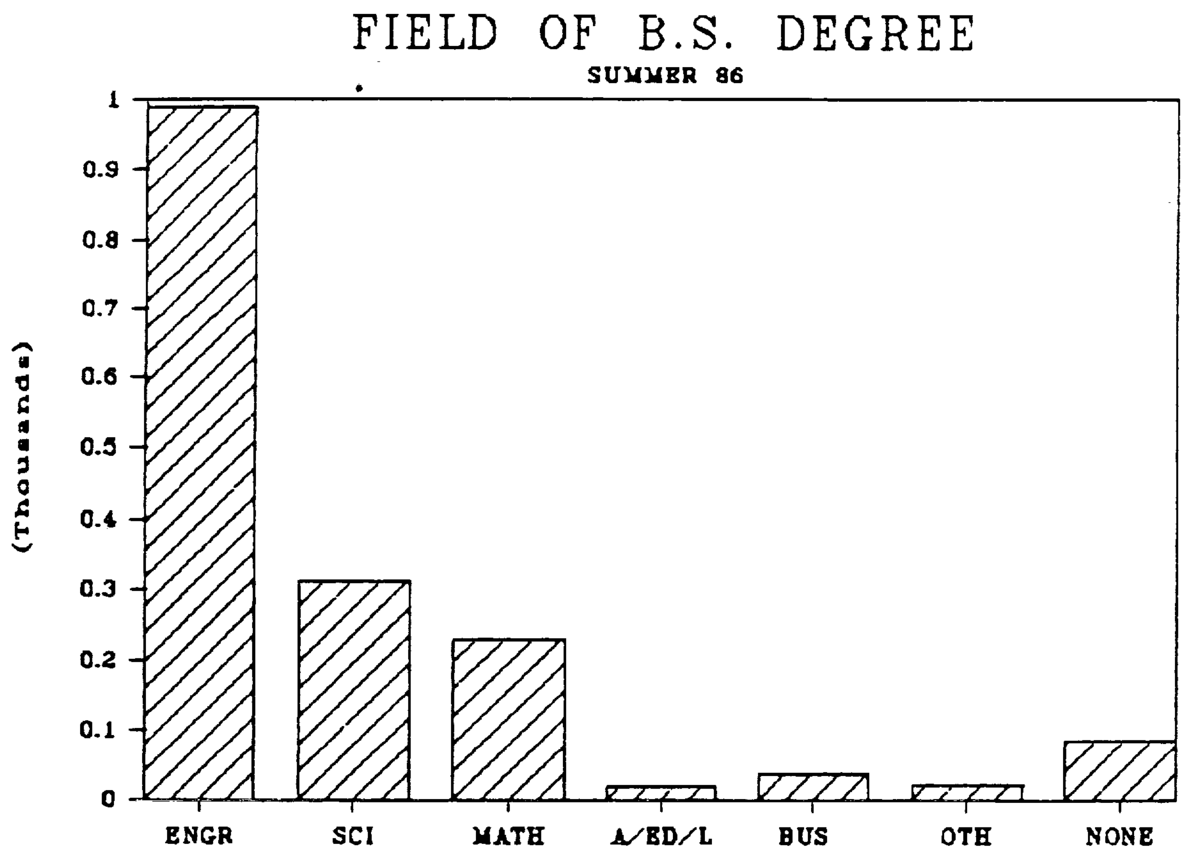


CHART 11

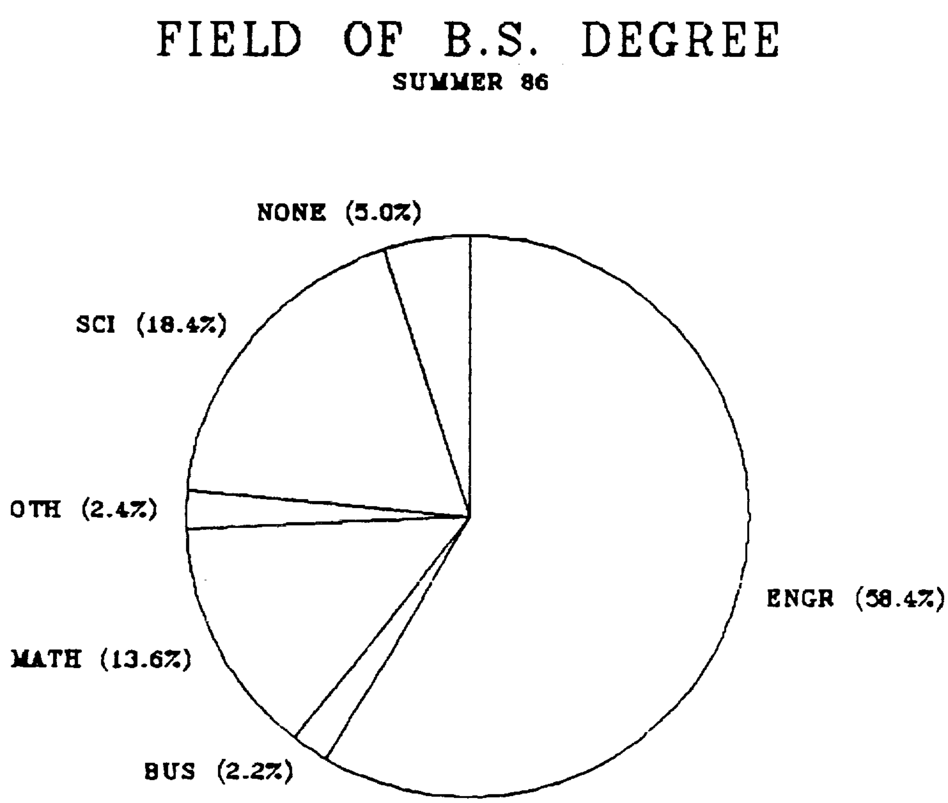


CHART 12

FIELD OF MASTER'S DEGREE

SUMMER 86

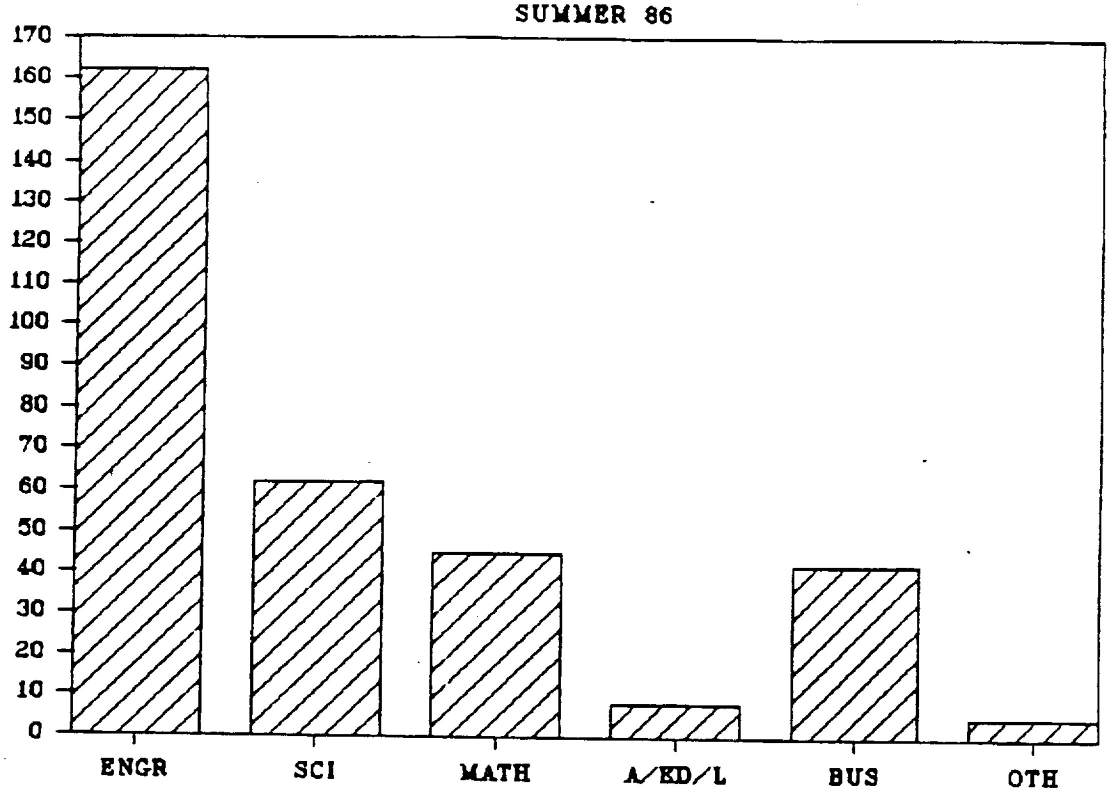


CHART 13

FIELD OF MASTER'S DEGREE

SUMMER 86

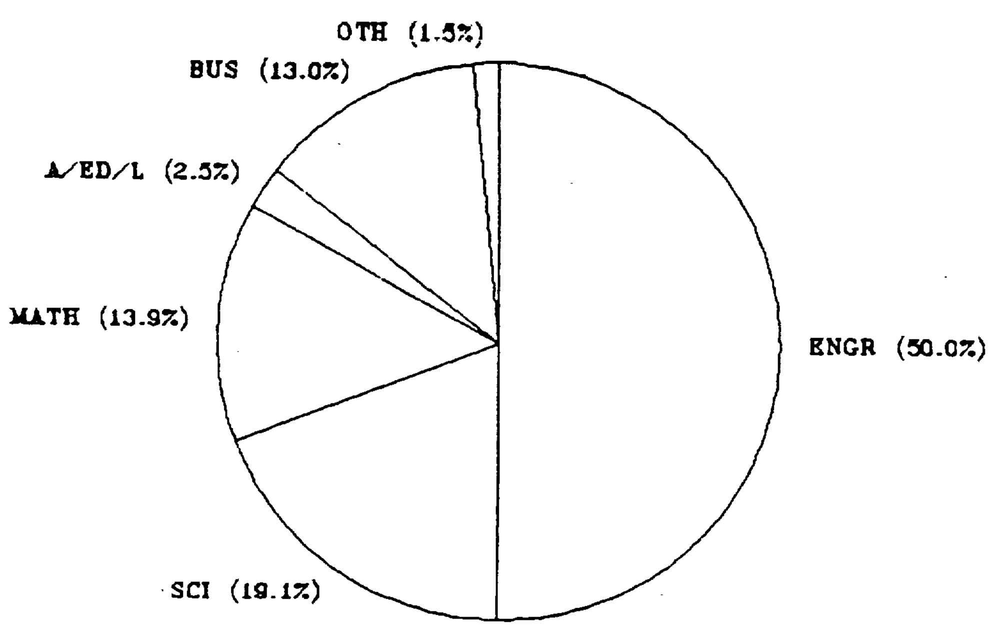


CHART 14

FIELD OF DOCTORS'S DEGREE

SUMMER 86

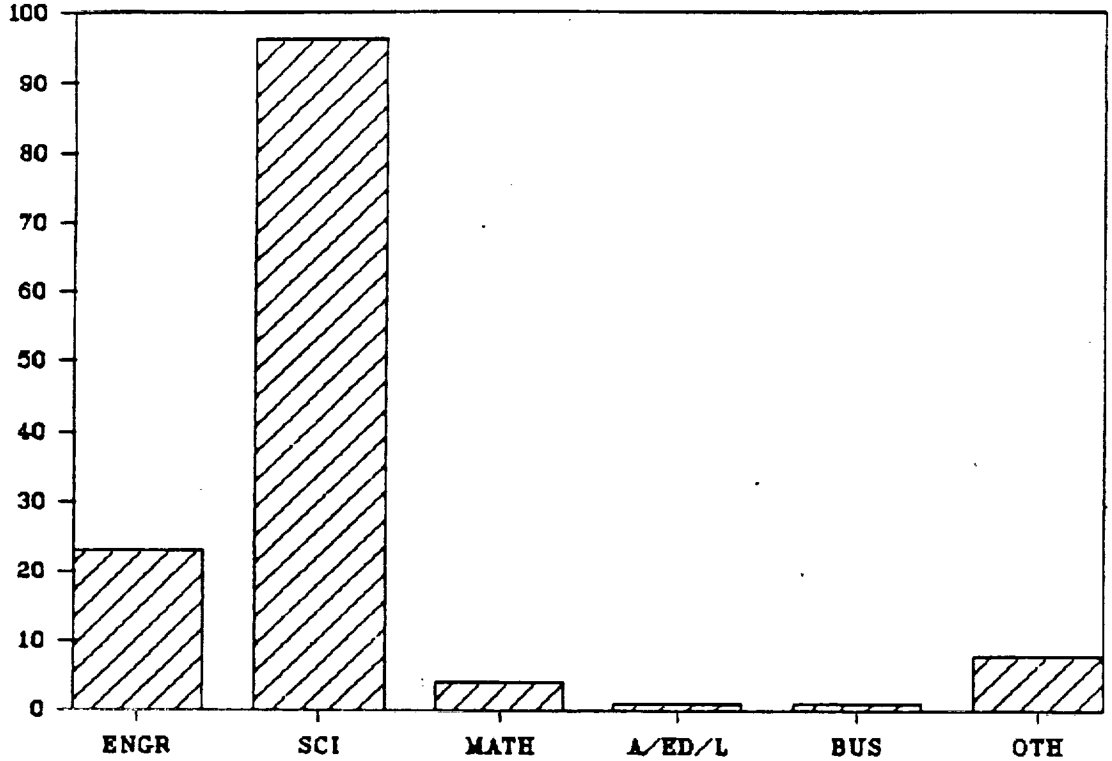


CHART 15

FIELD OF DOCTORS'S DEGREE

SUMMER 86

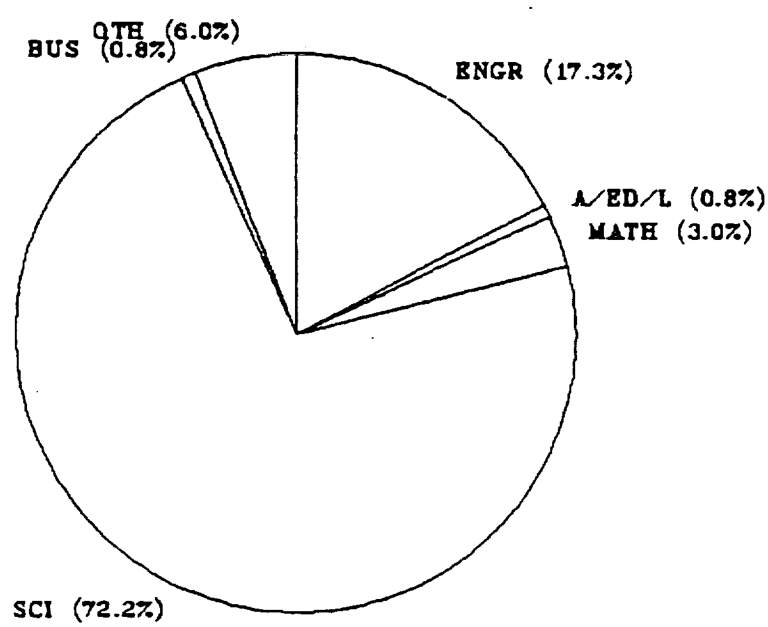


CHART 16

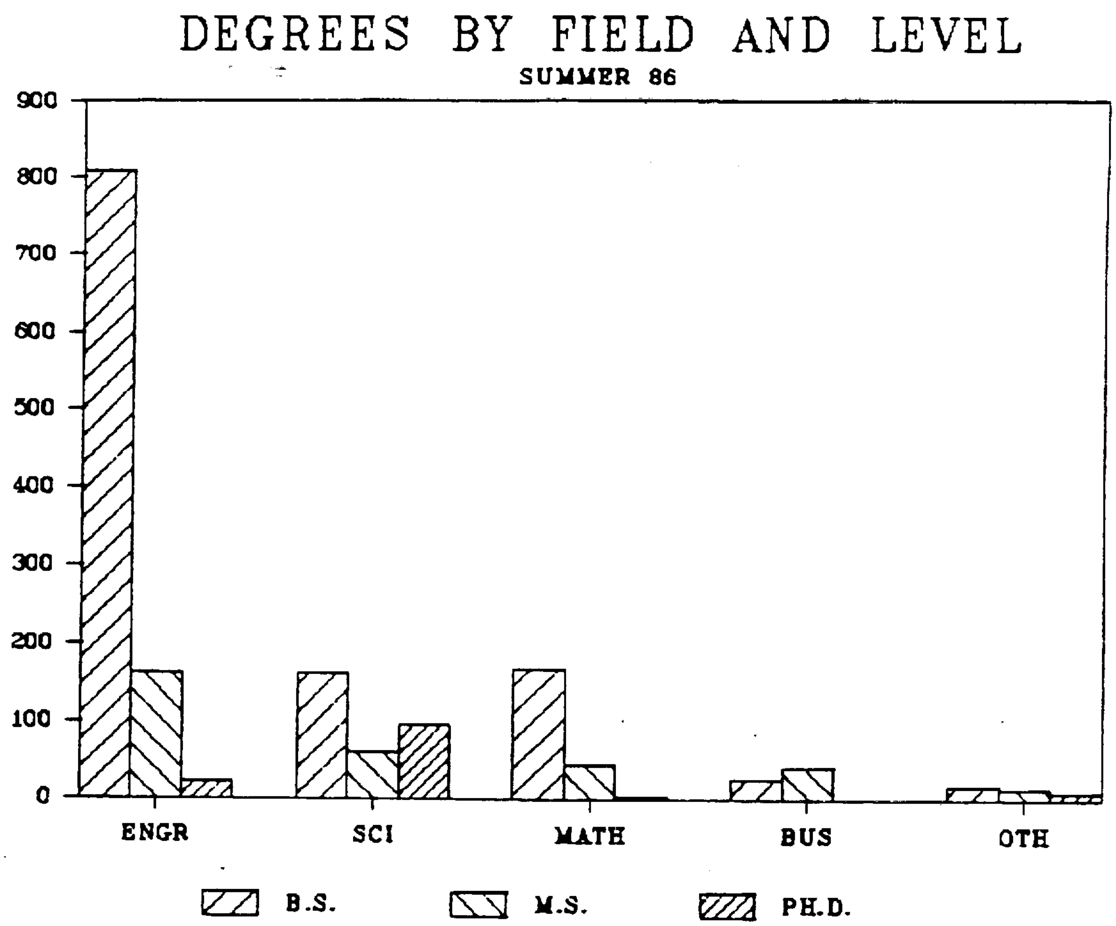

DEGREES BY FIELD AND LEVEL
SUMMER 86
900
800
700
600
500
400
300
200
100
0
ENGR
SCI
MATH
BUS
OTH
B.S.
M.S.
PH.D.

CHART 17

DEGREE MIGRATION
FOR
AE, AM, C, D, E, F, G, S, T, AND V
PROFESSIONAL EMPLOYEES
SUMMER 86

FROM \ TO		ENGR BS	ENGR MS	ENGR PHD	SCI BS	SCI MS	SCI PHD	MATH BS	MATH MS	MATH PHD	BUS BS	BUS MS	BUS PHD	A/E/L BS	A/E/L MS	A/E/L PHD	OTHER BS	OTHER MS	OTHER PHD	TOTAL
ENGR	BS	2	134	2	0	7	3	0	1	4	0	18	0	0	4	0	0	1	0	173
	MS	0	2	17	0	0	1	0	0	0	0	3	0	0	0	0	0	0	0	23
	PHD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SCI	BS	4	6	0	1	38	30	3	3	0	0	2	0	0	2	0	0	3	1	93
	MS	0	0	1	0	2	55	0	1	0	0	0	0	0	0	1	0	0	2	62
	PHD	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	3
MATH	BS	2	3	0	5	4	0	0	34	0	0	5	0	0	1	0	0	0	0	54
	MS	0	0	0	0	1	0	0	0	4	0	0	0	0	0	0	0	1	0	6
	PHD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BUS	BS	1	0	0	0	0	0	0	3	0	0	9	0	0	0	0	0	0	0	13
	MS	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
	PHD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A/E/L	BS	2	0	0	0	3	0	0	3	0	0	2	0	0	1	0	0	0	0	11
	MS	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	2
	PHD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
OTH	BS	0	17	0	0	6	1	0	0	0	0	0	0	0	2	0	0	0	2	28
	MS	0	0	2	0	0	2	0	0	0	0	0	0	0	0	0	0	0	3	7
	PHD	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOT		11	162	23	6	62	96	3	45	4	0	41	1	0	8	1	0	5	8	476

CHART 18

APPENDIX V B

DEMOGRAPHIC COMPARISON

1984-1986

1.0 INTRODUCTION

In the summers of 1984,85,and 86 studies were done on the composition of the work force at JSC that had a strong probability of being involved in the management of the shuttle program. The following tables shows the specific offices by year.

1984-85	1986
AM space operations	AM space operations
AE research and engineering	AE research and engr.
CA flight crew operations	CA flight crew operations
DA mission operations	DA mission operations
EA engineering	EA engineering
FA mission support	FA mission support
SA space and life sci.	SA space and life sci.
LA NSTS program office	GA NSTS system office
MA space shuttle projects off.	VA orbiter projects off.
	TA STS integrations and op

While the names changed somewhat in 1986 due to a reorganization of the NSTS program and project offices the people and the actual working positions surveyed stayed the same.

This report is the second half of a report finished earlier which showed an in-depth look at the 1986 offices and as such serves as a continuation of that report. One difficulty encountered in the preparation of a comparison was that the means of collecting the data changed from 1984 to 1986 as familiarity was gained with the problem. This made some comparisons weak and made some others impossible. Specific instances of this problem will be mentioned as the data is discussed. In addition some of the data in the 86 survey does not have a meaning when analyzed for change. Specifically there does not seem to be any value in looking at the way that degree migration has changed over the three year period.

2.0 RESULTS

2.1 NUMBER

Year:	1984	1985	1986
Sample size:	1732	1764	1689

The change in the sample from 84 to 85 may be due to the reorganizations that occurred during that time period. Table 3 shows the percent change as about a 2% gain from 84 to 85 and a 4% loss from 85 to 86. The key to the significance of this change is whether it was planned and controlled or whether it was uncontrolled and occurred against the best wishes of management. One would suppose that as the shuttle moves to an era which is more operational in nature and one in which jobs become more routine that some loss of the work force will occur.

2.2 AGE

Table one gives the ages by 5 year cohorts. Chart one shows the same information graphically. This information is not too reliable since the ages were drawn in 85 by GS grade within an office while in 86 age was drawn as a pure variable. The 85 method has the effect of smoothing out the extremes. Perhaps the most significant information in this section is that the average age stayed the same.

2.3 NUMBER BY GRADE

In Tables 2 and 3 and in Charts 2 through 7 the number of employees by grade is presented for 84, 85, and 86. Charts 5 and 6 perhaps present this information best. The spike at 13 has been reduced by what would appear to be upward movement to 14 with perhaps some attrition. The ones which increased are the grades of 15, 14, 11, and 9. The grades of 13, 12, and 7 reduced while the SES grade stayed the same.

If the GS 13 level is thought of as the Journeyman level with the earlier grades thought of as a lengthy apprenticeship or training program then the GS curves are no so disturbing. One point of consideration however is the reduction in new hires at the GS 7 level. This level in 86 was the lowest in the 3 year history with only 36 in 1986.

2.4 NUMBER BY FIELD OF HIGHEST DEGREE

Tables 4 and 5 along with Chart 8 show the number by field of highest degree. All fields lost people over the 3 years with the exception of business which showed a net gain of 28. This attrition is of course related to the general attrition of the work force over these 3 years.

2.5 NUMBER BY DEGREE LEVEL

Tables 6 and 7 along with Chart 9 show the number by degree level. All fields showed a loss over the 3 year history. There was a net loss of 75 from 85 to 86 with 5 of these being at the doctors level and 7 at the masters level.

2.6 NUMBER BY FIELD AND LEVEL

Tables 8 and 9 along with Chart 10 combine the information in D and E and show the number by field and degree for 85 and 86. Of the 5 doctors lost mentioned in E, 6 were lost from engineering and 1 was gained in arts/education/law. 10 masters were lost in technical areas while 3 were gained in business. This loss of engineering doctorates was slightly over 20% of the 85 level. This loss of top level talent is worth noting and tracking through the next year.

3.0 CONCLUSIONS

Only three years of data with the method of drawing the sample changing during the period of course makes the drawing of conclusions very tentative. There are a few trends worthy of comment. One is the general overall loss in the total work force. The major question is whether this was planned or accidental. A related question is if it was planned was it planned by the right level in the organization and did the plan work. Another trend worth comment is the reduction in the GS 13 level. The same questions on planning are applicable here. The last trend to be discussed deals with the loss of technical talent. This trend is brought out by the loss of higher level technical degrees. Why are these people leaving and is this good are bad for the organization?

4.0 RECOMMENDATIONS

1. The loss of technical talent has serious implications. This loss needs to be further examined and explained.
2. The GS 13 spike needs careful monitoring and control.
3. During both the stand down caused by 51L and the

transition period to a more operational nature, great care and attention must be paid to the morale of the employees involved.

4. This study needs to be repeated in 1987.

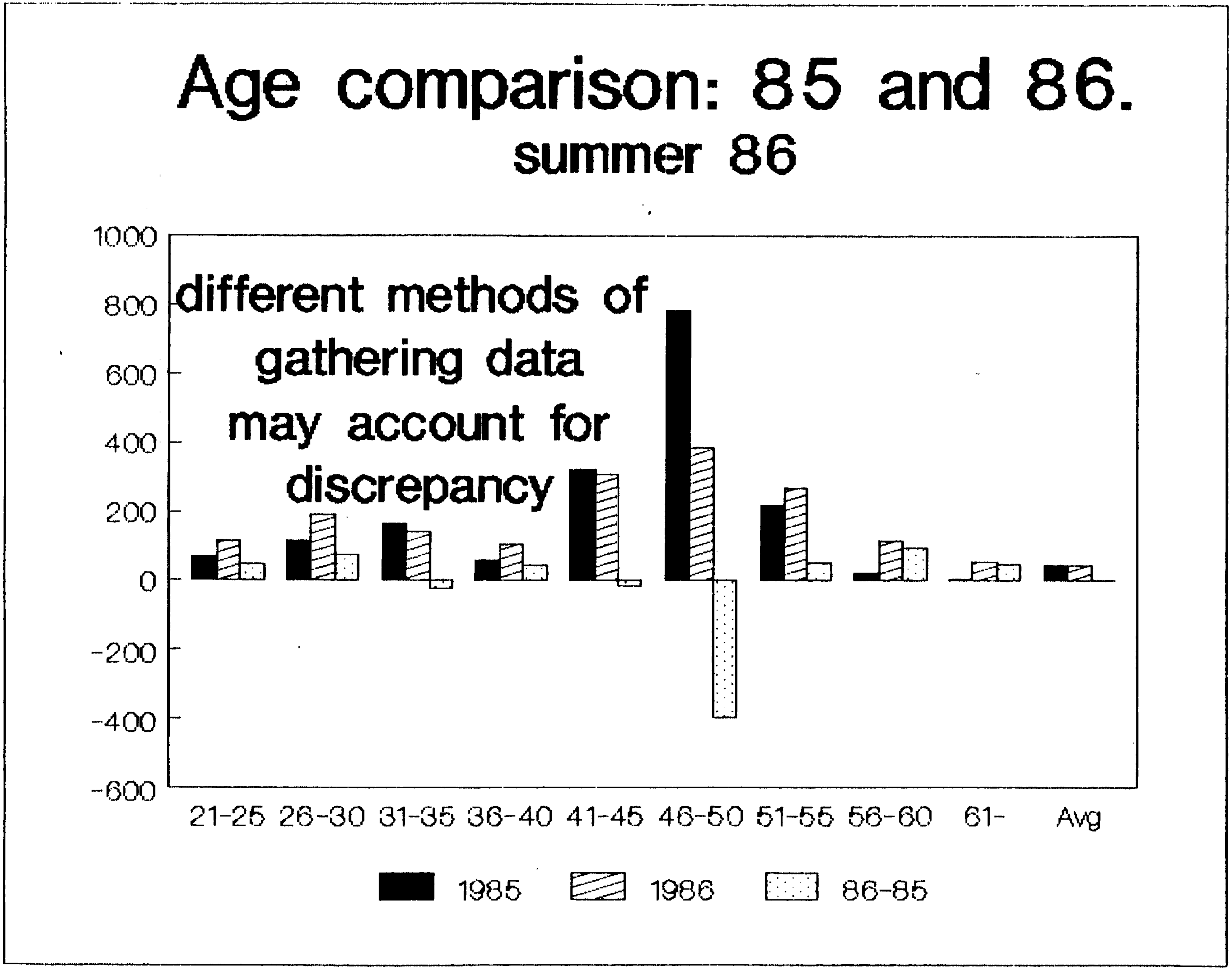
AGE COMPARISON: 85 AND 86
SUMMER 86

NOTE: During the summer of 85 the age data was gathered on an average age for GS grade within an office. For the summer of 86 the age was gathered as a pure variable. This accounts for the large delta difference within several of the age cohorts. The gathering method of 85 had the effect of smoothing out the extremes. For these reasons great care must be used in interpreting the age data presented here and in the histogram. The most significant fact contained in this chart is the fact that the average age stayed the same from one year to the next at 43.6 years.

AGE	85	86	86-85
21-25	70	117	47
26-30	116	192	76
31-35	164	142	-22
36-40	59	105	46
41-45	324	308	-16
46-50	783	386	-397
51-55	218	270	52
56-60	21	115	94
61-65	4	54	50
AVG	43.6	43.6	0

TABLE 1

CHART 1


Age comparison: 85 and 86.
summer 86
1000
800
600
400
200
0
-200
-400
-600
different methods of
gathering data
may account for
discrepancy
21-25
26-30
31-35
36-40
41-45
46-50
51-55
56-60
61-
Avg
1985
1986
86-85

GS GRADES COMPARISON: 84, 85, AND 86
SUMMER 86

GRADE	1984	1985	1986	85-84	86-85	86-84
SES	31	25	27	-6	2	-4
15	174	199	208	25	9	34
14	313	330	355	17	25	42
13	771	729	628	-42	-101	-143
12	256	233	214	-23	-19	-42
11	80	106	125	26	19	45
9	56	77	96	21	19	40
7	50	65	36	15	-29	-14
TOTAL	1731	1764	1689	33	-75	-42

TABLE 2.

PERCENT OF EMPLOYEES BY GS GRADE

GRADE	84	85	86	85-84	86-85	86-84
SES	1.8%	1.4%	1.6%	-0.3%	0.1%	-0.2%
15	10.1%	11.3%	12.3%	1.4%	0.5%	2.0%
14	18.1%	18.7%	21.0%	1.0%	1.4%	2.4%
13	44.5%	41.3%	37.2%	-2.4%	-5.7%	-8.3%
12	14.8%	13.2%	12.7%	-1.3%	-1.1%	-2.4%
11	4.6%	6.0%	7.4%	1.5%	1.1%	2.6%
9	3.2%	4.4%	5.7%	1.2%	1.1%	2.3%
7	2.9%	3.7%	2.1%	0.9%	-1.6%	-0.8%
TOTAL	100%	100%	100%	1.9%	-4.3%	-2.4%

TABLE 3

GRADE 1984

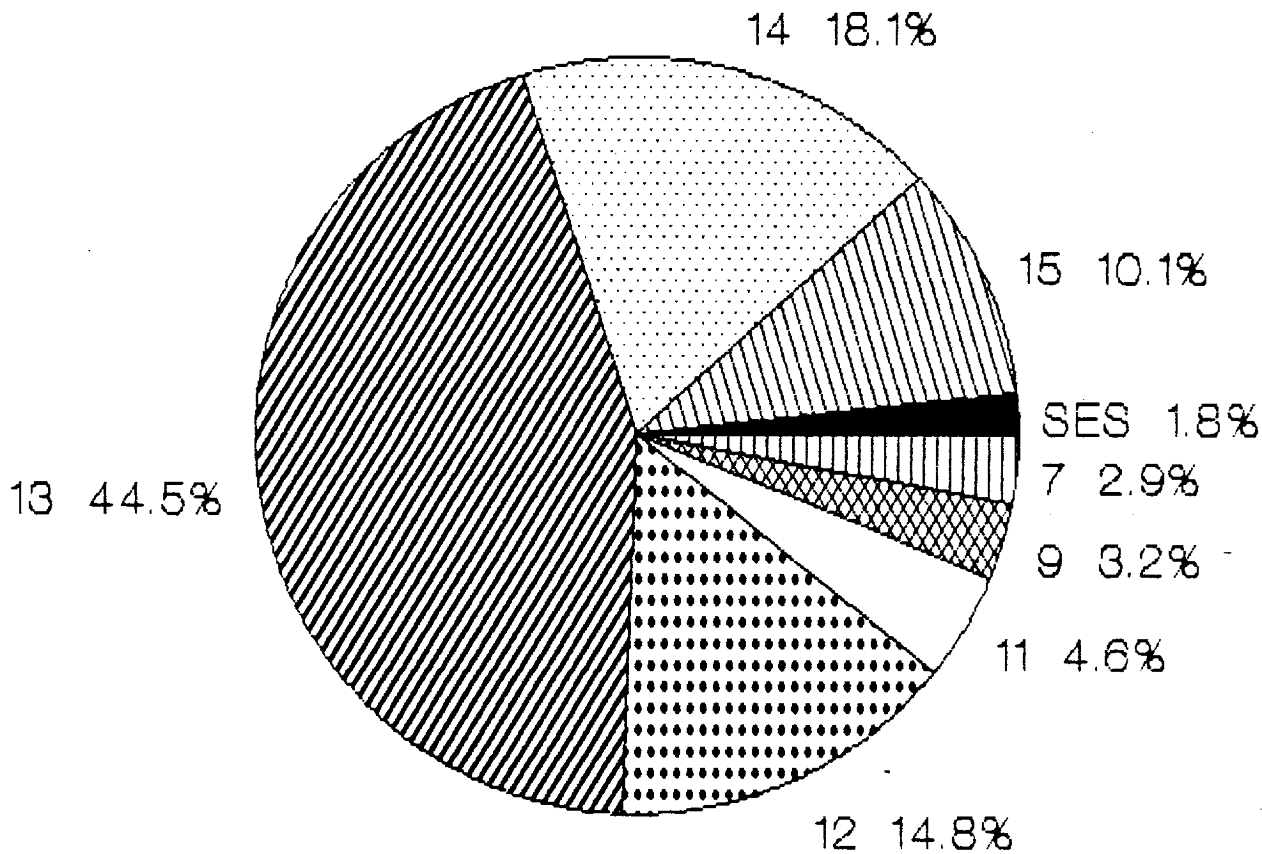


CHART 2

GRADE 1985

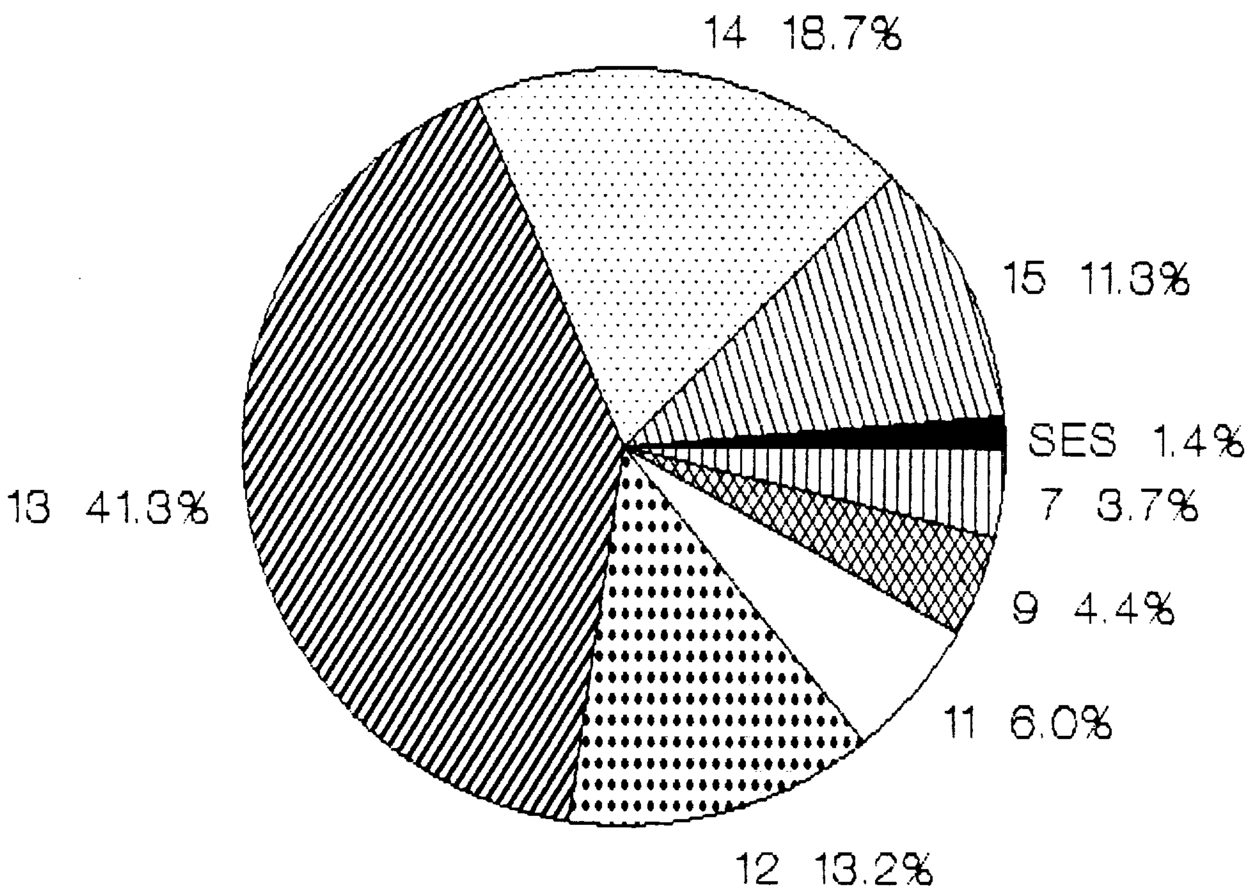


CHART 3

GRADE 1986

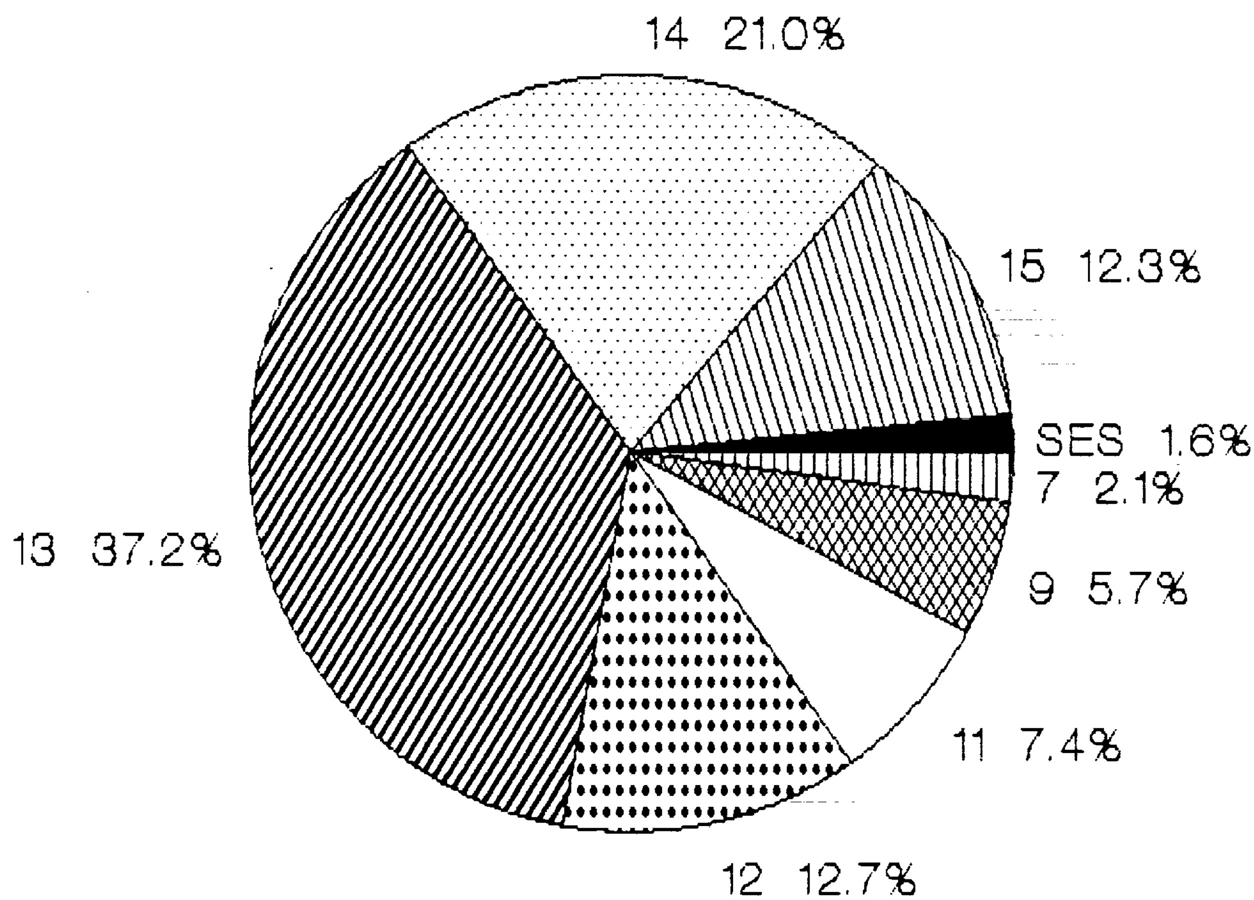


CHART 4

CHART 5

GS GRADE COMPARISON FOR 84, 85, 86

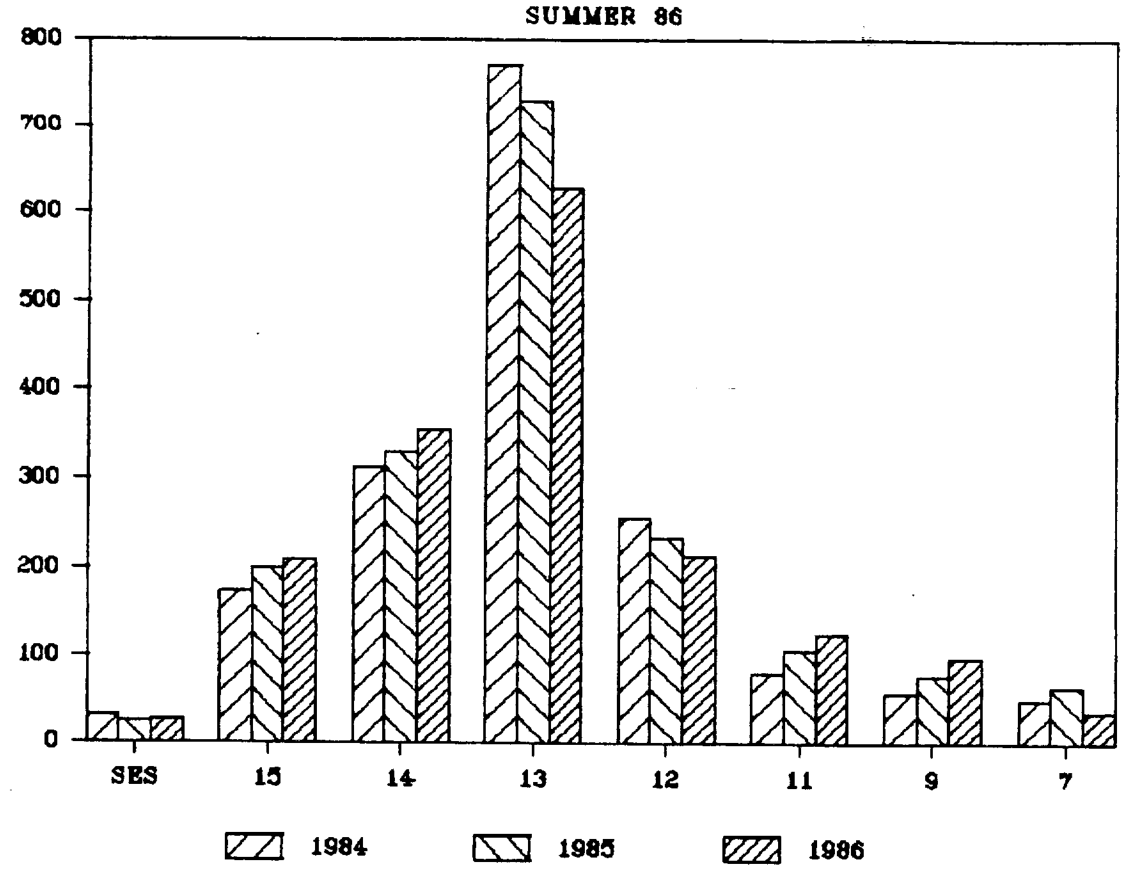
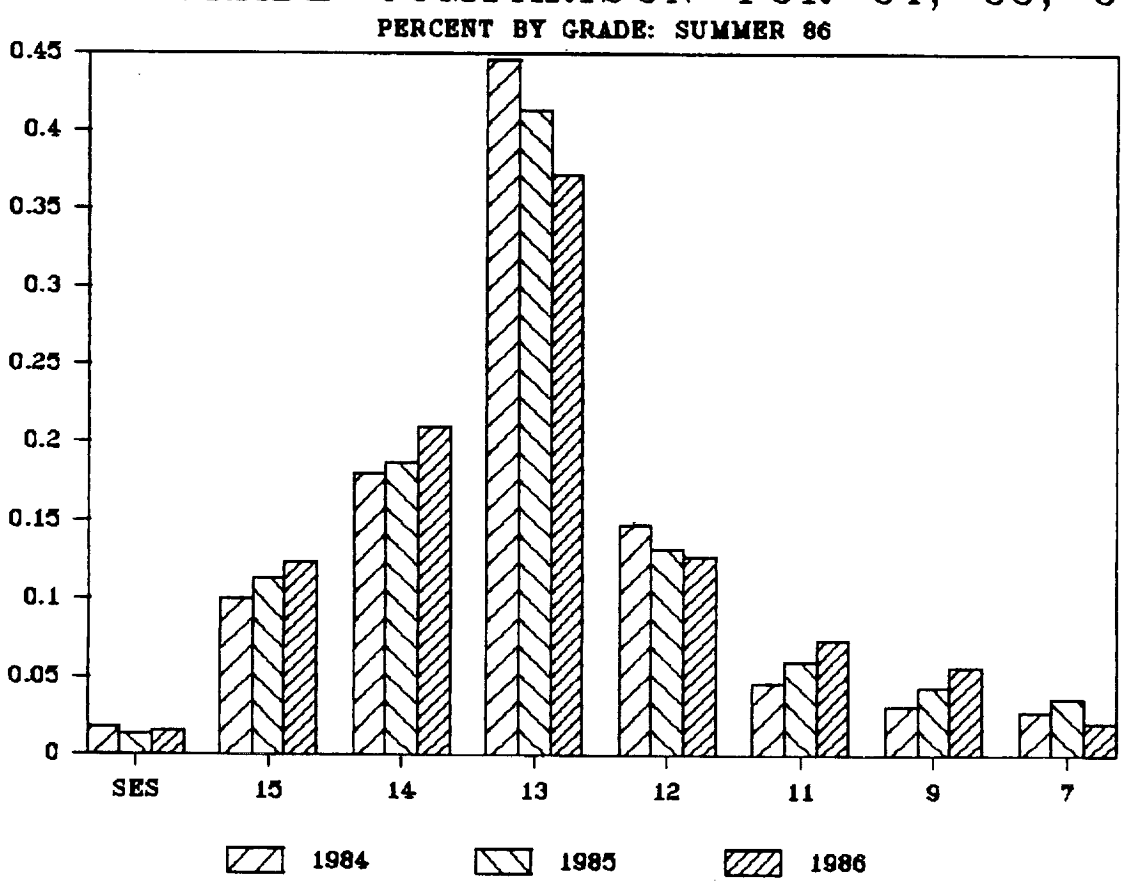


CHART 6

GS GRADE COMPARISON FOR 84, 85, 86



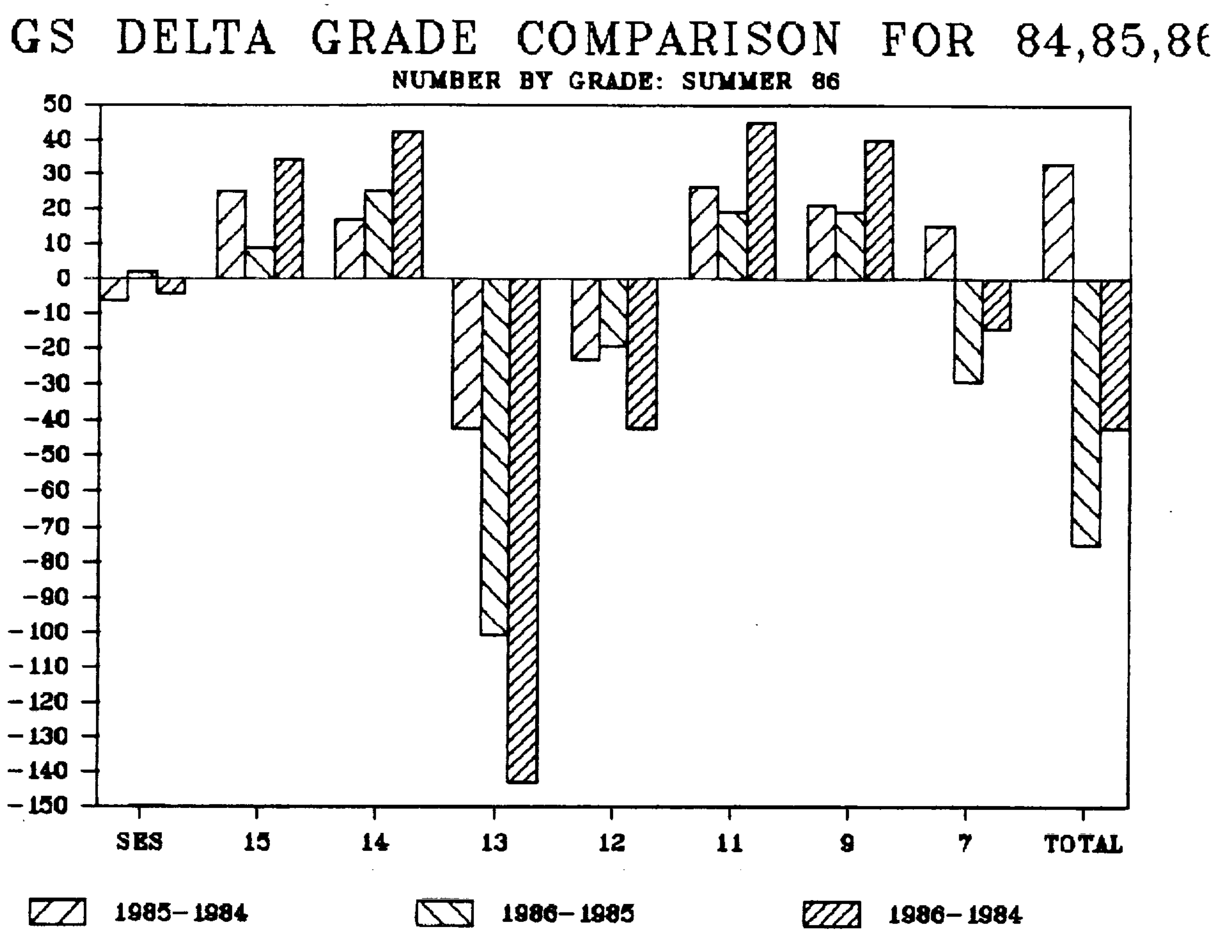

GS DELTA GRADE COMPARISON FOR 84,85,86
NUMBER BY GRADE: SUMMER 86
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
-130
-140
-150
SES
15
14
13
12
11
9
7
TOTAL
1985-1984
1986-1985
1986-1984

CHART 7

TABLE 4

HIGH FIELD

DEGREE	ENGR	SCI	MATH	A/ED/L	BUS	OTHER	NONE	
1984	1000	345	247	20	42	30	48	1732
1985	1038	333	240	16	63	24	50	1764
1986	993	321	217	15	70	26	47	1689
85-84	38	-12	-7	-4	21	-6	2	32
86-85	-45	-12	-23	-1	7	2	-3	-75
86-84	-7	-24	-30	-5	28	-4	-1	-43

NUMBER OF EMPLOYEES BY HIGHEST DEGREE

TABLE 5

DEGREE	ENGR	SCI	MATH	A/ED/L	BUS	OTHER	NONE	SUM
1984	57.7%	19.9%	14.3%	1.2%	2.4%	1.7%	2.8%	100.0%
1985	58.8%	18.9%	13.6%	0.9%	3.6%	1.4%	2.8%	100.0%
1986	58.8%	19.0%	12.8%	0.9%	4.1%	1.5%	2.8%	100.0%
85-84	1.1%	-1.0%	-0.7%	-0.2%	1.1%	-0.4%	0.1%	0.0%
86-85	-0.1%	0.1%	-0.8%	.0%	0.6%	0.2%	-0.1%	0.0%
86-84	1.1%	-0.9%	-1.4%	-0.3%	1.7%	-0.2%	.0%	0.0%

PERCENT BY HIGHEST DEGREE

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OF POOR QUALITY

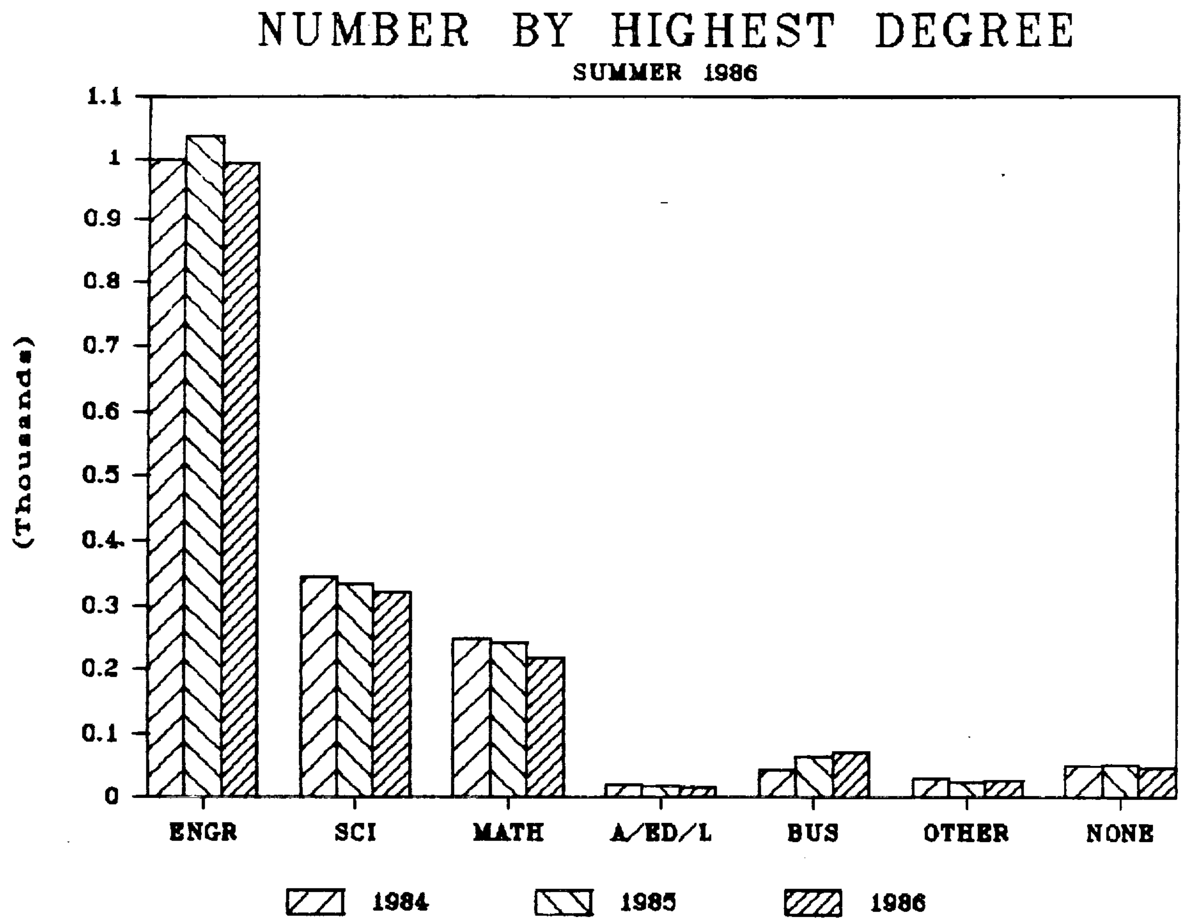
NUMBER BY HIGHEST DEGREE
SUMMER 1986
(Thousands)
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
ENGR
SCI
MATH
A/ED/L
BUS
OTHER
NONE
1984
1985
1986

CHART 8

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TABLE 6

NUMBER OF EMPLOYEES BY DEGREE LEVEL

YEAR	DOCTORS	MASTERS	BACHELOR	NONE	SUM
1984	138	334	1209	51	1732
1985	138	330	1248	48	1764
1986	133	323	1183	50	1689
85-84	0	-4	39	-3	32
86-85	-5	-7	-65	2	-75
86-84	-5	-11	-26	-1	-43

TABLE 7

PERCENT OF EMPLOYEES BY DEGREE LEVEL

YEAR	DOCTORS	MASTERS	BACHELOR	NONE	SUM
1984	8.0%	19.3%	69.8%	2.9%	100.0%
1985	7.8%	18.7%	70.7%	2.7%	100.0%
1986	7.9%	19.1%	70.0%	3.0%	100.0%
85-84	0.0%	-0.2%	2.3%	-0.2%	1.8%
86-85	-0.3%	-0.4%	-3.7%	0.1%	-4.3%
86-84	-0.3%	-0.6%	-1.5%	-0.1%	-2.5%

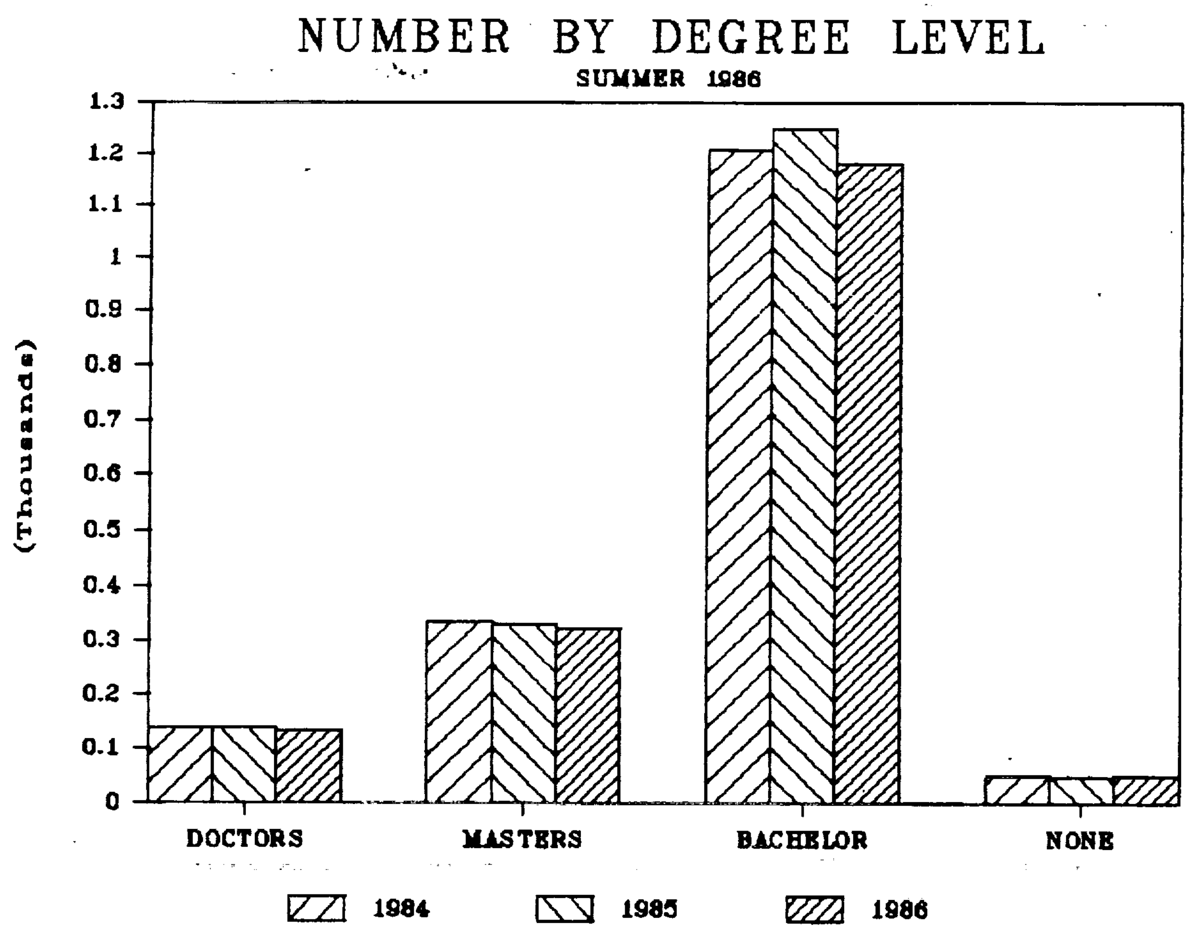

NUMBER BY DEGREE LEVEL
SUMMER 1986
(Thousands)
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
DOCTORS
MASTERS
BACHELOR
NONE
1984
1985
1986

CHART 9

ORIGINAL PAGE IS OF POOR QUALITY

DEGREES BY FIELD AND LEVEL
1985 TO 1986

	BACHELOR		MASTERS		DOCTORS		TOTALS	
	85	86	85	86	85	86	85	86
ENGR	839	808	170	162	29	23	1038	993
SCI	176	163	63	62	96	96	335	321
MATH	190	168	46	45	4	4	240	217
A/ED/L	8	6	8	8	0	1	16	15
BUS	24	26	38	41	1	1	63	68
OTHER	11	12	5	5	8	8	24	25
TOTAL	1248	1183	330	323	138	133	1716	1639
NONE	48	50	******	******	******	******	1764	1689

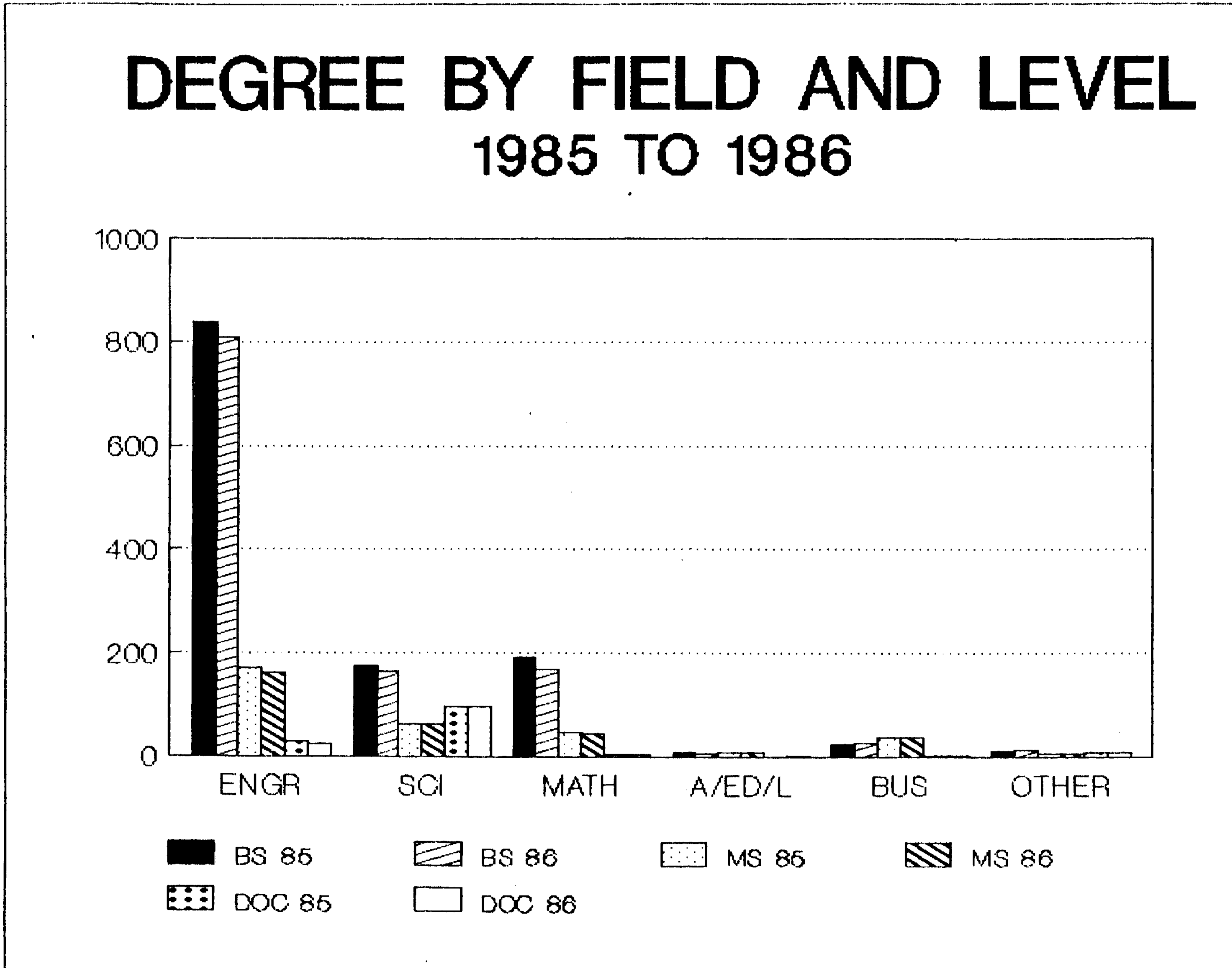
TABLE 8

DEGREES BY FIELD AND LEVEL
1985 TO 1986

	BACHELOR			MASTERS			DOCTORS			TOTALS		
	85	86	86-85	85	86	86-85	85	86	86-85	85	86	86-85
ENGR	839	808	-31	170	162	-8	29	23	-6	1038	993	-45
SCI	176	163	-13	63	62	-1	96	96	0	335	321	-14
MATH	190	168	-22	46	45	-1	4	4	0	240	217	-23
A/ED/L	8	6	-2	8	8	0	0	1	1	16	15	-1
BUS	24	26	2	38	41	3	1	1	0	63	68	5
OTHER	11	12	1	5	5	0	8	8	0	24	25	1
TOTAL	1248	1183	-65	330	323	-7	138	133	-5	1716	1639	-77
NONE	48	50	2							1764	1689	-75

TABLE 9

CHART 10


DEGREE BY FIELD AND LEVEL
1985 TO 1986
1000
800
600
400
200
0
ENGR
SCI
MATH
A/ED/L
BUS
OTHER
BS 85
BS 86
MS 85
MS 86
DOC 85
DOC 86

CHAPTER VI

ANALYSIS OF THE SPACE SHUTTLE ACCIDENT

APPENDICES

VI. ANALYSIS OF THE SPACE SHUTTLE ACCIDENT

1.0 INTRODUCTION

After the Challenger accident, a presidential commission, better known as the Rogers Commission, was established to investigate the events leading up to the disaster, to determine the cause of the accident itself, and to make recommendations to NASA to prevent a future reoccurence of this tragedy. In addition, the National Research Council (NRC) was charged with performing what might be described as a "watchdog" role and with doing its own investigation. Also, the Science and Technology Committee of the House of Representatives conducted its own investigations. This chapter deals primarily with the Rogers Commission Report [2], but also covers some aspects of the other organizations.

Upon issuance of the Commission's report (hereafter called the Report), the UH research team generated a detailed outline of the Report's findings and opinions. The findings indicated that all of the major problem areas, except that of the SRB joint design itself, were in areas traditionally associated with industrial engineering including management structure and communication, SR/QA, transition management, logistics, and documentation control.

This outline of the Report provided input for most of the work done in this chapter and provided further confirmation that the existing NSTS organizational structure was in need of change.. This chapter consists of five reports which are briefly described as follows.

2.0 ROGERS COMMISSION REPORT - OUTLINE AND MILESTONES

The detailed outline of the Rogers Commission Report can be found in Appendix VI A. This work was prepared in support of the Crippen Committee which was charged with the task of both investigating and responding to Recommendations II and V along with any questions relating to the flight decision process itself. Recommendation II deals with (1) the need for change in the STS management structure, (2) the importance of astronauts in the management positions at NASA, and (3) the establishment of an STS Safety Advisory Panel.

Recommendation V involves problems in (1) communication, especially involving the Marshall Space Flight Center (MFSC), (2) inconsistent policies towards the removal of launch constraints and the signing off of waivers without ever finding a proper solution to the problem, (3) ambiguity in the way in which two different people understood the same conversation, and finally, (4) a lack of astronaut input into the launch decision and their not being informed of mechanical problems from previous flights.

Each factor, or milestone, which had a bearing on each particular item listed under Recommendations II and V, was cited from the Report and grouped under that item. Although not explicitly called out in the Report as a recommendation, a third set of milestones was tabulated under the heading of Flight Decision Process. This table dealt with the failure of the system to communicate critical safety-related issues to NASA management responsible for launch decisions. Ultimately, since all problems in management and communications can impact these decisions, all of the previously listed milestones can be placed under this heading as well, especially those regarding communication. However, these milestones were not listed twice in the tables. The eight milestone tables can be found in Appendix VI B.

3.0 AN INDUSTRIAL ENGINEERING PERSPECTIVE ON THE REPORT OF THE PRESIDENTIAL COMMISSION ON THE SPACE SHUTTLE CHALLENGER ACCIDENT

Based on the Rogers Commission Report, a paper was written and published in Industrial Management [1], a journal of the Institute of Industrial Engineers for industrial engineering managers. The paper illustrated that many of the problem areas cited in the Report such as processing problems, SR/QA, trend analysis, logistics, and communication and management problems are all areas in which the introduction of industrial engineering methods would help to rectify the situation. While the application of these IE principles may not have prevented the shuttle accident, they certainly would have improved the reliability of the shuttle, both in terms of safety and on-time performance. This paper can be found in Appendix VI C.

4.0 CROSS REFERENCE

As mentioned above, a number of committee's were formed in the aftermath of the Challenger accident to determine the cause of the accident and to propose changes in the shuttle program to avoid future mishaps. At the request of JSC, the UH team reviewed the conclusions and recommendations of each committee report and from them derived a Challenger Report Cross-Reference Matrix (Appendix VI D). The purpose of this matrix was to compare and contrast the findings of each committee as well as to ensure that NASA addressed each point raised in the various reports so that none of them were inadvertently overlooked.

The four reports used were those of the Rogers Commission [2], the U.S. House Committee on Science and Technology [3], the NRC Flight Rate Working Group [4], and a NASA internal investigation known here as the "Lessons Learned" Report [5]. The findings of each report were placed into three main categories: program management, the processing of the shuttle, and the design of the shuttle. Each main category is further divided into subcategories and individual entries. For each entry, a cross-reference indicates the citation in the appropriate report.

5.0 MAJOR PROBLEMS RESULTING FROM A REVIEW OF THE ROGERS COMMISSION REPORT - PRELIMINARY DISCUSSION

This section distills the findings of the Rogers Commission Report into nine specific problems involving management, communication, safety, and logistics and presents ten specific recommendations on how to remedy these problems. It can be found in Appendix VI E.

6.0 POSSIBLE LIST OF QUESTIONS AND ISSUES WHICH MAY BE POSED BY THE NRC COMMITTEE ON CRITICALITY REVIEW AND HAZARD ANALYSIS

The shuttle hardware is composed of several thousand critical components where failure in flight could have dire consequences. The last section of this chapter, Appendix VI F, contains a list of questions relating to SR/QA that was prepared to help NASA respond to the NRC investigation. These questions are meant to stimulate thought as to how safety and reliability issues can be implemented and monitored throughout the organization.

7.0 REFERENCES

[1] Hunsucker, John L., and Law, Japhet S. "Disaster on Flight 51-L: An IE Perspective on the Challenger Accident," Industrial Management, Vol. 28, No. 5, (1986).

[2] "Report to the President by the Presidential Commission on the Space Shuttle Challenger Accident," U.S.Government Printing Office, Washington, (1986).

[3] "Investigation of the Challenger Accident," Report of the Committee on Science and Technology House of Representatives Ninety-Ninth Congress Second Session, U.S. Government Printing Office, Washington, (1986).

[4] "Post-Challenger Assessment of Space Shuttle Flight Rates and Utilization," Prepared by a Panel Convened by the Committee on NASA Scientific and Technological Programs Reviews Commission on Engineering and Technical Systems National Research Council, National Academy Press, (October, 1986).

[5] "STS 51-L Data and Design Analysis Task Force Lessons Learned Report," NASA Internal Use Document, National Aeronautics and Space Administration, (June, 1986).

APPENDIX VI A

ROGERS COMMISSION REPORT OUTLINE

During the second quarter of our research project, the Rogers Commission released its findings on the investigation of the 51L accident. Our research team had reviewed part I of the Report in detail. The efforts resulted in the generation of a detailed outline of the Rogers Commission's opinions and findings as provided in the Report. From the outline, several milestone charts were prepared. The milestones were categorized according to their relationship to the main points of Recommendations II and V of the Report (which pertain to NASA's management structure and problems in communication) as well as to the flight decision process. These are presented in this appendix and in Appendix VI B.

Looking at the major problem areas as indicated in the Report, namely : management structure and communications, safety/reliability/quality assurance, data trending, transition from R/D to Operations, logistics support, documentation, and the actual design/testing problems with the SRB joint; all but the last item are closely related to the regular training and functions of an Industrial Engineer. It is also interesting to point out that those are areas which is barely covered, if at all, by the other 'traditional' engineering disciplines within their regular university training. We do intend to look somewhat further into this observation and will report on any further findings in our future reports.

PRESIDENTIAL COMMISSION ON THE
SPACE SHUTTLE CHALLENGER
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2. The people who made the decision were unaware of the history of problems concerning the seal and were unaware of the initial rec. of cont. against launch with temp. less than 53 F and the continuing opposition of MTI engineers.
3. Did not have a clear understanding of Rockwell's ice concern.
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2. Waiving of launch constraints appears to have been at expense of flight safety. etc.
3. Commission troubled at MSFC containment of serious problem, etc.
4. MTI reversed its position at the urging of MSFC and contrary to the views of its engineers. etc.

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2. Problem identified by ice team at 2 am, assessed throughout night, culminating with 9am MMT meeting.
3. Rockwell describes work done and explains concerns with Petrone's testimony, PAGE 114-115.
4. Glaysher's involvement and his testimony that Rockwell can not assure that it is safe to fly.
5. PAGE 115, Cioffoletti's testimony about his concern.
6. PAGE 115-116, pressure for more detailed description of Rockwell's launch recommendation and Petrone's response.
7. 2 things are clear: Rockwell did not feel it had sufficient time to research and resolve the ice on the pad problem and Rockwell's position on launch was not clearly communicated to NASA officials in the launch decision chain.
8. Lamberth's discussion on Rockwell's commit to launch language.
9. PAGE 116, testimony of Rockwell's Peller concerning telephone conversation with Moser confirms Lamberth.
10. PAGE 116-117, Aldrich testimony on meeting of ice team, Rockwell, Lamberth, and Colonna with Aldrich on problem.
11. Aldrich had reports from contractors other than Rockwell.
12. FINDINGS, PAGE 117-118.
    a. Rockwell's recommendation on launch was ambiguous.
    b. Commission concerned about NASA's response to Rockwell and finds the decision to launch questionable. NASA appeared to be requiring a contractor to prove that it was not safe to launch. Commission finds ice not a cause and does not conclude NASA over-rode a no-launch recommendation from a contractor.
    c. Freeze protection plan for pad was inadequate.

H. REFERENCES, PAGE 119.

VII. CHAPTER VI. AN ACCIDENT ROOTED IN HISTORY. PAGE 120-151

A. EARLY DESIGN, PAGE 120-122.

1. SRB problem began with design and continued through failure to recognize problem and treatment as acceptable flight risk.
2. MTI did not accept implication of early tests that design had serious flaw.
3. NASA did not accept judgment of its engineers that design was unacceptable and minimized problem as record grew.
4. MTI felt that condition was not desirable but was acceptable.
5. Small history of letting of SRB contract.
6. Costs were first concern of NASA selection bd.
7. MTI's joint was selected for special mention by selection bd.
8. Implies MTI's selection done primarily on cost basis.
9. Design of SRB based on Titan but there were differences.
10. FIGURE 1, PAGE 121. COMPARISON OF ORIGINAL DESIGN TO DESIGN USED.
11. MTI design changed before production and MTI believed seal had complete redundancy.
12. Pin problems.
13. Horizontal assembly required.
14. Testimony of MTI engineer McIntosh about concern with horizontal assembly.
15. Test vents, O-ring manufacture, multiple firing

B. EARLY TESTS, PAGE 122-123.

1. Tests on SRB's began in mid-70's. 1977 hydro-burst test shows joint rotation.
2. PAGE 122, MTI Thompson testifies to joint rotation but MTI believed problem was minor and scheduled no further tests.

C. DESIGN OBJECTIVES, PAGE 123-124.

1. MSFC's reaction to early tests opposite MTI's.
2. PAGE 123, Eudy's memo to McCool on design problems and suggested corrections.
3. 1977 Ray says not changing the design is unacceptable.
4. Miller's memo to Eudy describing joint problem.
5. Miller sends second memo objecting to seal design in January 79.
6. Ray authored Miller memos and Miller concurred.
7. Ray visited O-ring manufacturers and they tentatively felt O-ring was being asked to perform outside its intended design.
8. PAGE 124, Ray testimony on reasons for writing memos in 78 and 79.
9. MTI was not informed of visit to O-ring companies.
10. MTI's phase 1 certification review mentioned difficulties with tests but did not list as a failure or problem.

D. VERIFICATION AND CERTIFICATION COMMITTEE, PAGE 124-5

1. Early static tests show joint rotation greater than predicted.
2. NASA empaneles Space Shuttle Verification / Certification comm. and they express concern about joint design. Mentions wrong way pressurization of primary O-ring and

putty. Questions redundancy.

3. Comm says that from a telecon they felt redundancy was not a requirement.
4. PAGE 124, Hardy's testimony on committee's understanding conflicted with his.
5. Comm asks for for full-scale tests to verify joint. Quote on PAGE 124-125 further defines test and problems.
6. NASA seems to decline tests with appeal to previous testing and light weight case testing.

E. CRITICALITY CLASSIFICATION AND CHANGES, PAGE 125-128

1. NASA classes joint 1R. Definition of 1R and rational for classification (PAGE 125).
2. PAGE 125, Aldrich testifies rational presented means 1 to him.
3. Joint carries 1R from Nov 80 to Nov 82.
4. Early problems with O-rings and putty.
5. 1R changed to 1, Dec 82. PAGE 126 rational for change.
6. Rationale for retention of single O-ring seal by MTI's McIntosh has seeming conflict with rationale for crit 1.
7. MTI and NASA still considered seal to be redundant even with crit 1 change.
8. PAGE 126, McIntosh's testimony on felt was redundant due to tests.
9. Temp not considered in early tests. Disagreement over joint opening sent to ref.
10. PAGE 127, Lovingood's testimony on redundancy of seal in all but worst cases.
11. Hardy and Mulloy shared Lovingood's view.
12. Waiver of Crit 1 status granted by level 1 and 2 in March 83.
13. PAGE 127, QUOTE on redudancy requirements implying reason for waiver.
14. PAGE 127-128. Lunney's testimony on Crit 1 change and reason for waiver.
15. Waiver process outside PRCB. Aldrich and Kohrs say waiver approved so STS-6 could fly. Weeks denies this.
16. MTI officials denied notification of Crit change but MTI's ops manager at MSFC (Parker) has signature on documents. However several documents at MTI still have Crit 1R long after change.

F. STS 41-B O-RING EROSION, PAGES 128-132.

1. Prior to 41-B erosion/blow by infrequent.
2. Discussion of qualification motors, flight history, and tests.
3. PAGE 128, Coats memo to Hardy on problems.
4. PAGE 128, Marshall Problem Assessment System Report QUOTE.
5. FIGURE 2, PAGES 129-131. O-RING ANOMALIES COMPARED WITH JOINT TEMPERATURE AND LEAK CHECK PROCEDURE.
6. PAGE 132, Moorefield memo to Mulloy on Titan experience.
7. 41-B erosion taken to 41-C FRR as technical issue. Recommendation to fly approved with same rationale as used at Level III FRR.
8. Directive sent from Mark to Mulloy, signed by Weeks directing review of seals. This action preceded by Abrahamson letter to Lucas.
9. Mulloy had Wear send letter to MTI asking for review of

seals.

10. MTI responds with proposal in May 84 and completes response with HQ briefing in Aug 85.

G. LEAK CHECK AND PUTTY, PAGE 133-134.

1. FIGURE 3, PAGE 133. JOINT ANOMALY FREQUENCY VS. LEAK CHECK PRESSURE.
2. Miller writes memo to Hardy through Coats as result of 41-B
3. Blow hole through putty discussed.
4. Russell's letter to Ebling at MTI show erosion history, test data, and express concern with putty.
5. Comments on leak test pressure with erosion.
6. PAGE 134, Russell and Mulloy's testimony on awareness that increase in blow hole could contribute to erosion.
7. MTI and NASA accept increased pressure to insure passage of integrity test in spite of awareness of blow hole problems.
8. Documentary evidence presented on MSFC's concern for putty erosion/blow hole problem.
9. MTI identifies O-ring erosion as function of putty blow hole size and free volume in mid 84.
10. MTI response on tests for putty problems was slow. As late as March 85 there are MSFC memos on lack of MTI action in response to directive of Dec 83 on putty behavior vs leak check pressure.

H. STS 51-C AND COLD TEMPERATURES, PAGES 134-136.

1. TABLE, PAGE 135. Awareness of different NASA officials of O-ring problems.
2. 51-C launched with O-ring temp at 53 degrees. Discussion of O-ring problems.
3. PAGE 135, Boisjoly's description of 51-C blow by erosion.
4. Boisjoly's description of race between erosion and sealing.
5. MSFC's problem assessment report describes O-ring burns as bad or worse than previously experienced and changes are pending on test results.
6. URGENT message from Mulloy to Wear on including O-ring in 51-E FRR, PAGE 136.
7. On Feb 8 85 MTI presents MOST DETAILED ANALYSIS TO DATE on O-rings. Mentions temp as factor. Says condition is not desirable but is acceptable.
8. At Level I FRR on Feb 21, no detailed analysis on O-rings or temp presented. Erosion acceptable because of limited exposure time and redundancy.

I. STS 51-B AND THE LAUNCH CONSTRAINT, PAGES 136-139.

1. Joint problems continue on next 4 flights.
2. MTI conducts tests relating to temp in early 85
3. QUOTE, PAGE 136-137. Russell letter to Thomas on test report in Aug 85.
4. June 85, erosion of nozzel joint on 51-B (.171 in.) found by MTI.
5. PAGE 137, Mulloy testimony on 51-B problem.
6. Mulloy and Problem Assessment Committee place launch constraint.
7. QUOTE, PAGE 137, from MSFC letter on assigning launch constraints.
8. Mulloy's rationale for constraint. Applies to all

subsequent flights.

9. MTI testified they were not aware of constraint but subsequent letters referenced MSFC report which identified constraint.
10. Mulloy waived constraint for each subsequent flight.
11. PAGE 137-138, testimony of Mulloy and Wear on procedure.
12. Mulloy and Wear both testified the constraint was still in effect for 51-L but said two entries were in error on assessment report saying problem had been closed.
13. MTI's suggestion for closure had been rejected.
14. Level I and II unaware of launch constraint.
15. FIGURE 5, PAGE 139. AUGUST 19, 1985 HEADQUARTERS BRIEFING.

J. ESCALATING CONCERNS, PAGE 139-140.

1. Concerns begin to grow at HQ and MTI.
2. PAGE 139, QUOTE from July 31 letter of Boisjoly memo on erosion expressing real fear.
3. More partial quotes about growing concerns over erosion (mostly at MTI).
4. PAGE 140, Thompson's testimony on larger O-rings.
5. MTI's revised O-ring protection plan Aug 30 85 indicated lack of agreement between NASA and MTI on magnitude of joint rotation. A test to resolve this was to be devised.

K. DESIGN QUESTIONS RESURFACE, PAGE 140-142.

1. Late Aug MTI submits preliminary concepts for solving joint sealing problems.
2. In Sept MTI's plans call for static firing. Also 10 briefings given to MSFC on erosion with temp not discussed.
3. PAGE 141, QUOTE, Kingsbury to Mulloy on desire to be briefed on plans and the fact that seals require priority attention of MTI and MSFC.
4. Lack of test results linked to lack of MTI management concern.
5. PAGE 141, discussion and QUOTE from Ebeling's HELP memo on problems and need for support.
6. 61-A launched Oct 30 85, has O-ring erosion which is not mentioned in Level I FRR for 61-B. 61-B also has erosion.
7. MTI makes one test in Dec and decides chamber needs to be redesigned.
8. Ebeling becomes so concerned that he felt that MTI should not ship any more motors until problem is fixed.
9. PAGE 141-142, Ebeling's testimony on concern.

L. THE CLOSURE ISSUE, PAGE 142-145.

1. MTI requests closure of erosion issue includes 17 reasons for closure in Dec 85.
2. PAGE 142-143, Russell's testimony on reasons for closure.
3. CONTRACTOR CLOSURE RECEIVED entered on all MSFC problem reports. On Jan 23 another entry is placed on the same reports indicating that the problem is closed.
4. PAGE 144, Testimony of Mulloy and Wear that the above entries are in error.
5. PAGE 144-145, Testimony of Mulloy about original response to erosion.

M. TEMPERATURE EFFECTS, PAGE 145.

1. Only limited consideration was given to the past history of O-ring damage in light of temperature.
2. Number of flights but not frequency was considered.
3. History indicates that the probability of O-ring distress is increased to certainty if the temperature of the joint is less than 65.

N. FRR, PAGE 145-148.

1. Clear that both NASA and contractor felt erosion should be considered by FRR process.
2. PAGE 145-147, QUOTE from policy manuals listing objectives of FRR.
3. FIGURE 6, PAGE 146, PLOT OF FLIGHTS WITH AND WITHOUT INCIDENTS OF O-RING THERMAL DISTRESS.
4. Treatment of O-ring erosion in FRR's is presented in some detail including partial quotes.

O. FINDINGS, PAGE 148.

1. The genesis of accident began with decision in design and in failure by MTI and NASA's SRE project office to understand and respond to test results.
2. Neither MTI nor NASA responded adequately to internal warnings or developed a solution to unexpected occurrences. Both accepted problem as unavoidable and as an acceptable flight risk.
3. SPECIFIC FINDINGS.
   a. Joint test and certification program was inadequate.
   b. Neither NASA nor MTI understood the process by which joint sealing took place.
   c. Both accepted escalating risk because they got away with it last time.
   d. The FRR flight anomaly tracking mechanism failed.
   e. The briefing presented to NASA HQ in Aug 85 was sufficient to require corrective action prior to next flight.
   f. A careful analysis of history would have shown correlation of O-ring damage with temperature. Since no one had done analysis they were unprepared to evaluate the risk of 51-L launch.

P. REFERENCES, PAGE 149-151.

VIII. CHAPTER VII. THE SILENT SAFETY PROGRAM. PAGES 152-163.

A. INTRODUCTION, PAGE 152.

1. Commission surprised that NASA safety staff was not mentioned.
2. If exacting standards of Apollo program had been used then demand of accelerating schedule might have been met.
3. Alrich listed 5 communication failures, 4 of which related to safety. These 4 are lack of problem reporting requirements, inadequate trend analysis, misrepresentation of criticality, and lack of involvement in critical discussions.
4. Safety program fell short.

B. NASA'S SAFETY PROGRAM, PAGES 152-153.

1. Definitions of safety, reliability, and quality. Brief description of SR/QA.
2. Ability of HQ chief engineer to manage SR/QA is limited by structure. Details of staffing.
3. JSC with large number support SR/QA but expertise with MSFC hardware is absent.
4. KSC has large number who support SR/QA but they report to supervisors who are responsible for processing, a clear failure.
5. MSFC suffers from an equivalent lack of independence and also suffers from a lack of manpower.

C. MONITORING SAFETY CRITICAL ITEMS, PAGE 153.

1. Definition of Crit 1, 2, 3, 1R, 2R.
2. Discussion of how Crit's are assigned.
3. Component criticality is related to test requirements in OMR/S Document published and maintained by Level II.
4. For the orbiter, references from the Crit Items List to the requirements and specifications document is traceable in both ways and is complete; not so for the SRB.
5. Discussion of the Ops and Maintenance Instruction with suggestion that if this indicated when work was to be done on Crit 1 item then all would be alerted.
6. The same point applies to MTI production where criticality should be directly incorporated into manufacturing quality planning.

D. PROBLEM REPORTING, PAGE 154-155.

1. Prior to 83, Level III was required to report all flight critical problems, trends, and closeouts to Level II. This requirement was changed to include only common hardware or physical interface elements.
2. This change signed by Jackson for Lunney and submitted by Raines resulted in Level II losing insight into Level III problems.
3. In May of 86, Raines wrote memo to streamline system since old requirement was not productive for operational system.
4. Commission does not understand why memo written or why Level II approved.
5. The Level III open problems list was not distributed to Level II during 84 or 85 nor to Rockwell.
6. REPORTING OF IN-FLIGHT ANOMALIES, PAGE 154-155.
   a. Discussion of way in-flight anomalies are handled and responsibilities.
   b. PAGE 154, QUOTE from 81 letter on procedure mentions example from STS-1.
   c. Example furnished pertains to test data (first four flights). Also 83 change might have been interpreted as superseding 81 letter particularly since program became operational in 82.
   d. More on the reporting of anomalies.
   e. Crit 1 should reach all levels of management.
   f. NASA does not have concise set of problem reporting requirements.

E. SAFETY PROGRAM FAILURES, PAGE 155-160

1. MSFC SR/QA HAS dual role of assuring delivered hardware meets specs and of serving as a watchdog on engineering judgment on use and appraisal of hardware.
2. Watchdog role could have prevented accident.
3. TREND DATA, PAGES 155-156.
   a. Trend data is a standard function of SR/QA.
   b. Trend history took bad turn in Jan 84.
   c. PAGE 155, QUOTE from Bunn (director, SR/QA, MSFC) on ease of recognizing trend in retrospect.
   d. No trend analysis was done.
   e. Series of changes to SRB processing listed which has probable correlation to high anomaly rate.
   f. history of nozzle problems is similar to field joint problems.
   g. PHOTOGRAPH, PAGE 156. Pressure test putty bubble.
   h. Lack of trend awareness is QUALITY ESCAPE.
   i. Likely cause of O-ring erosion appears to be increased pressure test.
4. MANAGEMENT AWARENESS, PAGES 156-159.
   a. Commission heard a lot of argument on criticality of joint and references to redundancy. MSFC and MTI paper listed as Crit 1R.
   b. Failure of proper categorization of joint linked SR/QA failure and makes informed decisions by key managers impossible.
   c. NASA CHART, PAGE 157-158, SRB CRITICAL ITEMS LIST.
   d. PAGE 159, Bunn's testimony on error of using 1R.
5. THE IMPACT OF MISINFORMATION, PAGE 159.
   a. PAGE 159, Moore's testimony on impact of misinformation.
   b. No one told or reminded Moore that while nozzle joint was 1R the field joint was Crit 1, or about blow holes, or about new test procedure, or about erosion was the enemy and increased pressure was its ally.
   c. The reporting procedure was not making problems visible with accuracy and emphasis.
6. REPORTING LAUNCH CONSTRAINTS, PAGE 159.
   a. Commission was surprised to learn that constraint was imposed and no one outside of MSFC was informed.
   b. Discussion of launch constraint.
   c. Problem Reporting and Corrective Action document (JSC 08126A, para 3.2d) requires Level II to be informed of launch constraints and neither I or II was so informed.
7. IMPLICATIONS OF AN OPERATIONAL PROGRAM, PAGES 159-160.
   a. Declaration of operational found many SR/QA staffs reduced or reorganized.
   b. Less SR/QA required due to routine flights was apparent reason.
   c. Reasons why this is faulty are listed.
   d. 2 problems on 61-C (wheel brake and erosion) were not evaluated before next flight (51-L).
   e. SR/QA must be strengthened to come to grips with critical safety issues before next flight.
   f. Complacency and failures in supervision and reporting aggravate flight risk.
   g. NASA must elevate and strengthen SR/QA function and augment with flight safety program which oversees traditional functions.

F. AEROSPACE SAFETY ADVISORY PANEL, PAGE 160.

1. Discusses development, structure and function of Aerospace Safety Advisory Panel.
2. Efforts of panel were not sufficiently specific and immediate to prevent 51-L accident.

G. SPACE SHUTTLE PROGRAM CREW SAFETY PANEL, PAGE 161.

1. Panel formed in 74, expired in 81.
2. Discussion of composition and function of Panel.
3. Panel lost focus and leadership.

H. THE NEED FOR A NEW SAFETY ORGANIZATION, PAGE 161.

1. ASAP valuable but too broad.
2. The ability of any panel to function depends on focused scope of responsibilities.
3. Operational safety requires combination of NASA and contractors to work effectively on a coordinated basis at all levels.
4. Commission believes that top-to-bottom safety emphasis can best be accomplished by a combination of a strong central authority and a working level panel devoted to operational aspects of shuttle flight safety.

I. FINDINGS, PAGE 161.

1. Reduction in SR/QA at MSFC and HQ have seriously limited capability in those vital functions.
2. Organizational structure at KSC and MSFC have placed SR/QA under the supervision of those organizations whose efforts they are to check.
3. Problem reporting requirements are not concise and fail to get critical information to proper levels.
4. Little or no analysis was done on O-ring erosion/blow by.
5. As flight rate increased, MSFC's SR/QA staff was decreased which adversely affected mission safety.
6. 5 weeks after accident, criticality of SRM field joint was still not properly documented in the reporting system at MSFC.

J. REFERENCES, PAGE 162

K. PAGE 163, BLANK.

IX. CHAPTER VIII. PRESSURES ON THE SYSTEM. PAGES 164-177.

A. Introduction, PAGES 164-165.

1. NASA began a planned acceleration of schedule on completion of test flights in 82.
2. Early plan called for a flight a week which in 85 had evolved to 24 a year by 90.
3. Becoming obvious that even two flights a month was overly ambitious.
4. Due to inadequate provision of resources 9 mission rate of 85 was straining resources.

5. Evidence suggests that NASA would not have accomplished 15 flights scheduled for 86.
6. PAGE 164, Reagan QUOTE on policy for direction of space program.
7. From inception NASA advertised that shuttle would make space ops routine and economical which implies that a higher flight rate will yield greater routinization and economy which in turn increases pressure.
8. The build up to 24 brought difficulties: compression of training, lack of spares, focusing of resources on near term problems.
9. One effect of accelerated rate was dilution of resource which could be applied to a particular flight.
10. Part of system which converted mission requirements and objectives into software, trajectories, and crew training was hard put to keep up in 85 and would not meet milestones in 86 due to strained resources and having to respond to constant changes in schedule.
11. NASA had trouble changing from a single flight focus to a system which could efficiently support projected flight rate.
12. Slow to develop the capabilities that would allow it to handle higher volume of work associated with higher flight rate and in developing a hardware maintenance plan for a reuseable fleet.
13. Need to meet customer commitments which translates into launching a given number per year and launching on time generated pressure.
14. These considerations may have obscured engineering concerns.
15. Managers may have forgotten that Shuttle was still in R/D phase.
16. PAGE 165, Beggs' testimony on NASA commitment in May 82.
17. 16 months later Beggs say NASA can start on space station at any time and that shuttle is operational.
18. Managers were determined to prove shuttle operational.
19. Following sections discuss pressures generated by flight rate, optimistic schedule, and assumption of operational status.

B. PLANNING A MISSION, PAGE 165.

1. Discussion of mission planning.
2. Discussion of freeze points and what they entail.

C. DEVELOPMENT OF FLIGHT PRODUCTS, PAGE 165-166.

1. Discussion of production process.
2. Discussion of parallel and serial work.
3. Discussion change causing cascade effect.
4. System was falling behind. Analysis of training schedules and their projected trend shows this.
5. GRAPH, PAGE 166, SHUTTLE MISSION SIMULATOR TRAINING.
6. Production system disrupted by increased flight rate, lack of efficient production process, and manifest changes.

D. CHANGES IN MANIFEST, PAGE 166-170

1. Changes in 85 usually were mandatory, perhaps some of the manifest changes were not.

2. 4 different types of manifest changes listed.
3. 2 options to a change are to maximize the benefit to a customer or to minimize the impact on Shuttle ops.
4. Long and detailed discussion on changes and their impacts.
5. TABLE, PAGE 167, 1985 CHANGES IN THE MANIFEST.
6. GRAPH, PAGE 168, IMPACT OF MANIFEST CHANGES ON WORKLOAD AT JSC.
7. GRAPH, PAGE 169, SIMULATION TRAINING.
8. QUOTE, PAGE 170, from Hartsfield on less time than desired to train.

E. OPERATIONAL CAPABILITIES, PAGE 170-171.

1. Pressing immediate requirements divert attention from what is happening to system as whole.
2. Shuttle program tried to adapt philosophy, attitude, and requirements to operational era. But era came suddenly. In some cases not enough preparation for what operational might entail.
3. Lists examples of why system was not prepared to meet operational schedule.
4. Comprehensive requirements process with checks and rechecks was developed but was not capable of meeting flight rate goals.
5. System developed plans to support flight rate through streamlining process through automation, standardization, and centralized management and to carry from developmental to mature system without compromise in quality.
6. Increasing flight rate had priority and only what was left after supporting flight rate could be used.
7. In 85, NASA was attempting to develop a production system but was forced to do so while responding with the same personnel to an increasing flight rate.
8. Number of skilled personnel reduced by retirements, hiring freeze, transfers to other programs (space station) and transitioning to contractors.
9. Flight rate was not based on assessment of resources and was not reduced to accommodate the capacity of workforce.
10. STSOC transition discussed along with its impact as a disturbance.
11. Simulator problems discussed.

F. RESPONDING TO CHALLENGES AND CHANGES, PAGE 171-173.

1. Can-do attitude was a problem in achieving flight rate.
2. Retrieval missions discussed.
3. NASA cannot continue to accept spur of the moment missions and develop discipline required to operate on a routine and cost effective basis.
4. While NASA may can do anything it cannot do everything. Disruption generates cost.
5. Officials are not willing to say they do not have resources to respond to change.
6. PAGE 172, Draughon QUOTE on saying NO to achieve 86 flight rate.
7. Hardware problems generate choice of responses. Movement of commercial payload off of 41-D to next flight causing other flights to slip is listed as example. Draughon's QUOTE, PAGE 172, about not having to do it is included.
8. NASA was too bold in shuffling manifests and this increased

near-term focus.

9. NASA did not have a way to forecast the effect of a manifest change.
10. PAGE 172, Nicholson QUOTE on being spread to thin to get forecasting tool developed.
11. Even easy changes put demands on system. Mid-deck requirements listed. Not enforced. Payload specialists added after L-5. Draughon's QUOTE, PAGE 172 on spending large amount of time on unimportant items because of late changes.
12. Those directing change were not sensitive to the problem. Resources of system were being eaten up by late changes with low priority.
13. PAGE 173, Holloway QUOTE on flight rate vs. manifest flexibility.
14. PAGE 173, Nicholson QUOTE on bringing late change concerns to HQ.
15. NASA must establish realistic expectation and approach it carefully, based on realistic assessment and not on what is possible with maximum effort.
16. The ground rules should be firmly established and then enforced.
17. The word "operational" can mislead. Operational should not imply any less commitment to quality or safety.
18. Correct attitude listed as WE ARE GOING TO FLY HIGH RISK FLIGHTS THIS YEAR; EVERY ONE IS GOING TO BE A CHALLENGE, AND EVERY ONE IS GOING TO INVOLVE SOME RISK, SO WE HAD BETTER BE CAREFUL IN OUR APPROACH TO EACH.

G. EFFECT OF FLIGHT RATE ON SPARE PARTS, PAGE 173-174.

1. Brief history of logistics plans and problems.
2. Budget reductions caused logistic implementation problems.
3. Reductions in spares provided funds to meet revised budgets. PAGE 173, Aldrich QUOTE on fund contentions.
4. Actions result in spares shortage and this leads to cannibalization.
5. 45 out of 300 required parts cannibalized for Challenger.
6. PAGE 174, Weitz QUOTE on cannibalization concern.
7. KSC QUOTE on manpower drain cannibalization causes.
8. Prior to Challenger this had no flight impact but this was expected to come to a head in Spring 86.
9. PAGE 174, Lamberth QUOTE on problem coming to a head in Spring 86.
10. Logistics program one year behind in Spring of 86.
11. Spares problem another illustration Shuttle not prepared for operational schedule.

H. THE IMPORTANCE OF FLIGHT EXPERIENCE, PAGE 174-175.

1. Flight experience is important to developmental program.
2. Rapid succession of flights made it difficult to analyze data before next launch.
3. Problems with 61-C which were not considered for 51-L the next launch are discussed in some detail.

I. EFFECT ON PAYLOAD SAFETY, PAGES 175-176.

1. NASA policy is to minimize involvement in payload design process leaving responsibility for safe design to

developer.

2. Payload Safety Panel at JSC does phased series of safety reviews. Some problems are identified late. However process has worked well.
3. Discussion of Centaur along with safety issues.
4. Centaur had passed 3 of 4 safety reviews as of Challenger but unresolved problems from last two reviews remained. Safety waivers had been granted and others were pending.
5. Improvements in military version had not been incorporated because of press to get missions off.
6. After Challenger NASA allotted more than 75 million to incorporate improvements to Centaur.
7. Even though we will never know if safety program would have allowed flight in 86, had they done so, it would have been without level of protection deemed adequate after accident.

J. OUTSIDE PRESSURE TO LAUNCH, PAGE 176.

1. Long discussion on absence of political pressure to launch.
2. List of live telecasts scheduled from orbiter.

K. FINDINGS, PAGE 176-177.

1. The capabilities of system were stretched to limit to meet flight rate in winter of 85/86 and would have been exceeded in Spring/Summer of 86.
2. Spares are in short supply due to decision to decision to postpone procurement in favor of higher priority budget items. This would likely limit 86 operations.
3. Stated manifesting policies are not enforced. Changes have occurred. Some impacts are listed.
4. Scheduled flight rate did not accurately reflect capabilities and resources. Flight rate not reduced to accommodate periods of adjustment to work force capacity. No margin to accommodate unforeseen hardware problems. Resources were primarily directed toward supporting flights and not available to improve or expand facilities needed to support higher flight rate.
5. Training simulators supporting 12-15 flights a year may be limiting factor on flight rate.
6. With flights in rapid succession, current requirements do not ensure anomaly resolution from one flight to the next.

L. REFERENCES, PAGE 177.

X. CHAPTER IX. OTHER SAFETY CONSIDERATIONS. PAGES 178-197.

A. INTRODUCTION, PAGE 178.

1. Commission became aware of matters which played no part in 51-L but have potential for safety.
2. Some of these safety considerations were brought forward by the astronaut office which resulted in special hearing.
3. This chapter is in 2 sections: critical aspects of Shuttle flight and testing, processing, and assembling procedures.

B. ASCENT: A CRITICAL PHASE, PAGES 178-186.

1. Particular concern to commission are abort capabilities,

options to improve those capabilities, options for crew escape, and the performance of the range safety system.

2. Commission believes highly unlikely that any of systems discussed below would have save crew of 51-L.
3. ABORT CAPABILITIES, PAGE 178-180.
   a. Design requirement to abort to survivable landing if 1 SSME is lost has been met.
   b. Discussion of different type of aborts.
   c. RETURN TO LAUNCH SITE ABORT, PAGE 178.
   d. TRANSATLANTIC ABORT, PAGES 179-180.
   e. CHART, PAGE 179, SHUTTLE ABORT REGIONS.
   f. DESIGN, PAGE 180.
      i. Not designed to manage abort if 2 or more SSME's fail.
      ii. 2 or more failing in first 5-6 min. results in CONTINGENCY ABORT with landing in water.
      iii. Shuttle not designed to survive SRB failure.
      iv. Crew survival rest on assumptions:
         a) SRB will work from ignition to separation.
         b) If more than 1 SSME fails the crew must be able to survive a water landing.
4. SHUTTLE ABORT ENHANCEMENTS, PAGE 180.
   a. Discussion of abort provisions considered between 73 and 83.
   b. Philosophy that first stage ascent must be assured has been accepted and reviewed and is being reviewed again in light of 51-L.
5. EARLY ORBITER SEPARATIONS, PAGE 180.
   a. If orbiter must separate from SRB then this must occur extremely quickly.
   b. Normal separation of Shuttle from rest of system takes 18 sec., too long for use in first stage contingency.
   c. Discussion of fast separation of ET discussed and listed as impractical if SRB's still thrusting.
   d. Further discussion of use of fast separation.
6. THRUST TERMINATION, PAGE 181.
   a. Discussion of thrust termination which concludes with this might allow ejection or fast separation in first 2 min. of flight.
   b. Drawbacks of thrust termination listed and history discussed.
   c. QUOTE, PAGE 181, from Griffin letter on thrust termination justifying ceasing termination study. Says conditions requiring thrust termination are either very remote or a result of primary structure failure.
   d. ...POSSIBILITY OF SRB FAILURES WAS NEITHER VERY REMOTE NOR LIMITED TO PRIMARY STRUCTURAL FAILURE.
   e. Thrust termination is key to first stage abort.
   f. Further discussion on required safety issues for thrust termination.
7. DITCHING, PAGES 181-182.
   a. Ditching window 50-70 sec. after launch.
   b. Discussion of early tests at Langley and probable bad consequences.
   c. Crew Safety Panel and Orbiter flight techniques meetings conclude: ditching is more hazardous than suggested by Langley tests and that ditching is not survivable.
   d. QUOTE, PAGE 182, from Griffin letter to Abrahamson on ceasing studies on ditching or bailout due to technical

infeasibility.

e. No evidence to suggest crew would survive water impact.

f. PAGE 182, testimony from Weitz on inability of Orbiter to survive any ditching (water, land, or any unprepared surface) and necessity for means of getting crew out of vehicle before it contacts Earth.

8. CREW ESCAPE OPTIONS, PAGE 182-184.

   a. TABLE, PAGE 182, 1971 ROCKWELL DATA ON EJECTION SYSTEMS.
   b. Ejection seats, encapsulated ejection seats and separable crew compartment studied early.
   c. Discussion of problems with these.
   d. Remaining options fall into 3 categories: Escape Module, Rocket-assisted Extraction, and Bail-out System.
   e. Discussion of these terminates with Escape Module offering widest range of options with others being practical only during gliding.
   f. None of alternatives were implemented because of limited capability and program impact.
   g. Disagreement over which system is feasible or whether any provide protection.
   h. PAGE 184, astronauts seem to agree that impractical to modify Orbiter for escape module but disagree on other two. Weitz's testimony discusses disagreement.
   i. In 82 Annual report, ASAP lists crew escape as priority item warranting further study.
   j. Commission supports further study and believes crew should have means of escape in gliding.
   k. Should incorporate systems that provide some chance of escape in emergencies.
   l. Commission accepts Crippen's QUOTE, PAGE 184, on knowing of no escape system which would have saved crew of 51-L.

9. RANGE SAFETY, PAGE 184-186.

   a. Discussion of necessity of range safety and organization and control of same.
   b. SPACE SHUTTLE RANGE SAFETY, PAGES 184-185.
      i. Discussion of Space Shuttle range safety system.
      ii. DIAGRAM, PAGE 185, RANGE SAFETY SYSTEM COMPONENTS.
      iii. Removal of ejection seats,
      iv. Range safety still needed but should be re-exaimined by NASA and Air Force to see if destruct on ET might be removed.
   c. RANGE SAFETY ACTIVITIES, JAN 28, 86, PAGE 185-186
      i. Listing of range safety activities on day
      ii. QUOTE, PAGE 185, from range safety officer Maj. Bieringer's written statement on his activities.
      iii. More discussion on range safety activities that day.
      iv. While Eastern Space and Missile Center and NASA have initiated a review of range safety, this review should study combining range safety with thrust termination system.

10. POSTFLIGHT ANALYSIS, PAGE 186.

   a. Discussion of post-flight analysis of data done by flight controllers explains why they noticed no anomalies.
   b. Flight control system responded properly and continued to control vehicle until time of accident.

c. No indication that crew had any warning.

11. FINDINGS, PAGE 186.
    a. Space Shuttle System was not designed to survive SRB failure. No corrective action can be taken if SRB's do not work, i.e., separation or escape.
    b. Neither Mission Control Team or crew had any warning.
    c. Even if there had been a warning, no action available to mission control team or crew.

C. LANDING: ANOTHER CRITICAL PHASE, PAGES 186-192.

1. General discussion on importance of entry and landing.
2. ABORT SITE WEATHER, PAGE 186-187.
    a. Discussion of criticality of weather.
    b. Program decision to accept worse weather for abort sites is not consistent with conservative approach to flight safety.
    c. Commission recommended that subject be reviewed and those reviews are currently underway.
3. ORBITER TIRES AND BRAKES, PAGES 187-190.
    a. QUOTE, PAGE 187, on concern of ASAP in annual report of 82 for landing gear.
    b. ORBITER TIRES, PAGES 187-188.
        i. Discussion of tires, crosswinds, testing.
        ii. Tires are Crit 1.
        iii. Orbiter tire in use meets specs and has been certified in testing, however, testing has not reproduced KSC runway results.
        iv. Some improvements considered.
        v. 2 blown tires before nosewheel touchdown would be catastrophic, and potential should be minimized. NASA has directed testing for Fall 86.
    c. ORBITER BRAKES, PAGES 188-190.
        i. Response to problem with brake design was to extend runway.
        ii. Discussion of brakes.
        iii. Brake damage on most flights and this has required special crew procedures to be developed.
        iv. QUOTE, PAGE 188-189, Young describes problem commander has with procedure.
        v. History of problems and qualification testing did not point our current thermal problems.
        vi. Limits should be reinvestigated and 61-C damage should be understood and destructive testing accomplished to understand short runway limits and factors before brake design continues to fly.
        vii. NASA is considering improvements and testing is underway.
        viii. QUOTE, PAGE 189, from ASAP 85 annual report on NASA's efforts.
        ix. History of reviews and concern over brake problems.
        x. QUOTE, PAGE 189, ASAP 82 annual report over concern.
        xi. Conservative approach to landing phase demands reliable performance by all critical systems.
4. KSC LANDINGS, PAGES 190-192.
    a. Original plan called for routine landing at KSC to minimize turnaround and cost.
    b. Tires, brakes and weather call this plan into question.

c. Discussion of risks and cost of Edwards landing and concludes that they are minimal when compared with those of a space shuttle mission.
d. Discussion of KSC runway and fact that NASA felt that this was the best that could be built as of design in 73.
e. Discussion of weather predictability and shuttle systems wear influence on KSC landings.
f. PAGE 190, QUOTE by Charlesworth on his reaction to blown tire incident.
g. Minor improvements followed and led to deciding KSC was safe for landing for 61-C and subs.
h. 61-C landed at Edwards but there were still brake problems.
i. PAGE 190-191, QUOTE by Charlesworth on assessment of brake problem.
j. Nosewheel steering is fail-passive not fail-safe.
k. History of planned KSC landings and diverts indicates NASA must plan to use Edwards routinely and consequences.
l. PAGE 191, CHART, LANDING SITE CHANGES.
m. PAGE 191, QUOTE from Crippen on weather unpredictability at KSC.
n. Discussion of weather and the impact of unstable weather.
o. Landing routinely at KSC is not wise under present circumstances.
p. Decisions governing Space Shuttle Ops must be consistent with philosophy that unnecessary risks have to be eliminated.
q. Margins of safety cannot be assured if performance not understood and cannot be deduced from previous flight's success.
r. Program cannot afford to operate outside its experience in the areas of tires, brakes, and weather.

D. SHUTTLE ELEMENTS, PAGES 192-193.

1. Discussion of SSME's and their problems.
2. Number of test firings per month has decreased over last 2 years but program has not demonstrated limits of engine or included tests over operational envelope.
3. Discussion of problem with disconnect valve between ET and Orbiter.
4. Discussion of ET problems.

E. PROCESSING AND ASSEMBLY, PAGES 193-194.

1. The following are problems which the commission felt could bear on safety of future flights.
2. STRUCTURAL INSPECTIONS, PAGE 193.
   a. For 51-L waivers were granted on 60 of 146 structural inspections.
   b. Formal structural inspection plan for fleet had not been developed.
   c. Waivers requested by Level II to minimize flight delay.
   d. Inspection requirements are new and not mature.
   e. Commission feels that these inspections should not be waived.
3. RECORDS, PAGE 193.

a. Large number of errors in paperwork for SSME and Orbiter with problem lying in documentation and not with work which was usually accomplished.
b. Op Maintenance Instructions need review and update to be improved.

4. MISSED REQUIREMENTS, PAGE 193. Lists area where requirements were not met and were not formally waived or excepted.
5. INSPECTIONS BY PROXY, PAGES 193-194.
   a. Designated verifiers discussed.
   b. Independent check system declining in effectiveness because of this.
6. ACCIDENTAL DAMAGE REPORTING, PAGE 194.
   a. Removal of accidental damage forgiveness reporting policy by SPC is causing damage to go unreported.
   b. This situation has severe implications if left uncorrected.

F. LAUNCH PAD 39B, PAGE 194.

1. Anomalies of 39B are listed.
2. Loss of bricks discussed.

G. INVOLVEMENT OF DEVELOPMENT CONTRACTORS, PAGES 194-195.

1. Shuttle is clearly a developmental program and must be treated as such by NASA.
2. Chief difference between Shuttle and previous programs is that Shuttle is principally a transportation system and has reuseable hardware.
3. Reusability implies a new set of functions which must be addressed by program.
4. NASA is striving to implement processing procedures of transportation industry. While this is useful, there is not a direct analogue.
5. The demands of developmental aspects must be met with the following strategies:
   a. Maintain significant engr design and development capability among contractors and an ongoing engr capability within NASA.
   b. Maintain active analytical capability so evolving capabilities of Shuttle can be matched to demands of Shuttle.
6. In-house experience must be maintained for NASA and contractors.
7. Listing of development contractors with responsibilities along with discussion of SPC.
8. Discussion of Lockheed's performance and problems.
9. Some development contractors have been excluded from SPC and this causes difficulties.

H. REFERENCES, PAGE 196.

I. BLANK PAGE 197.

XII. PRESIDENTIAL COMMISSION ON THE SPACE SHUTTLE CHALLENGER ACCIDENT, PAGES 202-205. Listing of Commission members with brief biographies and listing of PRESIDENTIAL COMMISSION STAFF, PAGES 204, 205.

Recommendations

The Commission has conducted an extensive investigation of the Challenger accident to determine the probable cause and necessary corrective actions. Based on the findings and determinations of its investigation, the Commission has unanimously adopted recommendations to help assure the return to safe flight.

The Commission urges that the Administrator of NASA submit, one year from now, a report to the President on the progress that NASA has made in effecting the Commission's recommendations set forth below:

— I —

Design. The faulty Solid Rocket Motor joint and seal must be changed. This could be a new design eliminating the joint or a redesign of the current joint and seal. No design options should be prematurely precluded because of schedule, cost or reliance on existing hardware. All Solid Rocket Motor joints should satisfy the following requirements:

- The joints should be fully understood, tested and verified.
- The integrity of the structure and of the seals of all joints should be not less than that of the case walls throughout the design envelope.
- The integrity of the joints should be insensitive to:
  - Dimensional tolerances.
  - Transportation and handling.
  - Assembly procedures.
  - Inspection and test procedures.
  - Environmental effects.
  - Internal case operating pressure.
  - Recovery and reuse effects.
  - Flight and water impact loads.
- The certification of the new design should include:
  - Tests which duplicate the actual launch configuration as closely as possible.
  - Tests over the full range of operating conditions, including temperature.
- Full consideration should be given to conducting static firings of the exact flight configuration in a vertical attitude.

Independent Oversight. The Administrator of NASA should request the National Research Council to form an independent Solid Rocket Motor design oversight committee to implement the Commission's design recommendations and oversee the design effort. This committee should:

- Review and evaluate certification requirements.
- Provide technical oversight of the design, test program and certification.
- Report to the Administrator of NASA on the adequacy of the design and make appropriate recommendations.

— II —

Shuttle Management Structure. The Shuttle Program Structure should be reviewed. The project managers for the various elements of the Shuttle program felt more accountable to their center management than to the Shuttle program organization. Shuttle element funding, work package definition, and vital program information frequently bypass the National STS (Shuttle) Program Manager.

A redefinition of the Program Manager's responsibility is essential. This redefinition should give the Program Manager the requisite authority for all ongoing STS operations. Program funding and all Shuttle Program work at the centers should be placed clearly under the Program Manager's authority.

Astronauts in Management. The Commission observes that there appears to be a departure from the philosophy of the 1960s and 1970s relating to the use of astronauts in management positions. These individuals brought to their positions flight experience and a keen appreciation of operations and flight safety.

- NASA should encourage the transition of qualified astronauts into agency management positions.
- The function of the Flight Crew Operations director should be elevated in the NASA organization structure.

Shuttle Safety Panel. NASA should establish an STS Safety Advisory Panel reporting to the STS Program Manager. The charter of this panel should include Shuttle operational issues, launch commit criteria, flight rules, flight readiness and risk management. The panel should include representation from the safety organization, mission operations, and the astronaut office.

— III —

Criticality Review and Hazard Analysis. NASA and the primary Shuttle contractors should review all Criticality 1, 1R, 2, and 2R items and hazard analyses. This review should identify those items that must be improved prior to flight to ensure mission success and flight safety. An Audit Panel, appointed by the National Research Council, should verify the adequacy of the effort and report directly to the Administrator of NASA.

— IV —

Safety Organization. NASA should establish an Office of Safety, Reliability and Quality Assurance to be headed by an Associate Administrator, reporting directly to the NASA Administrator. It would have direct authority for safety, reliability, and quality assurance throughout the agency. The office should be assigned the work force to ensure adequate oversight of its functions and should be independent of other NASA functional and program responsibilities.

The responsibilities of this office should include:

- The safety, reliability and quality assurance functions as they relate to all NASA activities and programs.
- Direction of reporting and documentation of problems, problem resolution and trends associated with flight safety.

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— V —

Improved Communications. The Commission found that Marshall Space Flight Center project managers, because of a tendency at Marshall to management isolation, failed to provide full and timely information bearing on the safety of flight 51-L to other vital elements of Shuttle program management.

- NASA should take energetic steps to eliminate this tendency at Marshall Space Flight Center, whether by changes of personnel, organization, indoctrination or all three.
- A policy should be developed which governs the imposition and removal of Shuttle launch constraints.
- Flight Readiness Reviews and Mission Management Team meetings should be recorded.
- The flight crew commander, or a designated representative, should attend the Flight Readiness Review, participate in acceptance of the vehicle for flight, and certify that the crew is properly prepared for flight.

— VI —

Landing Safety. NASA must take actions to improve landing safety.

- The tire, brake and nosewheel steering systems must be improved. These systems do not have sufficient safety margin, particularly at abort landing sites.
- The specific conditions under which planned landings at Kennedy would be acceptable should be determined. Criteria must be established for tires, brakes and nosewheel steering. Until the systems meet those criteria in high fidelity testing that is verified at Edwards, landing at Kennedy should not be planned.
- Committing to a specific landing site requires that landing area weather be forecast more than an hour in advance. During unpredictable weather periods at Kennedy, program officials should plan on Edwards landings. Increased landings at Edwards may necessitate a dual ferry capability.

— VII —

Launch Abort and Crew Escape. The Shuttle program management considered first-stage abort options and crew escape options several times during the history of the program, but because of limited utility, technical infeasibility, or program cost and schedule, no systems were implemented. The Commission recommends that NASA:

- Make all efforts to provide a crew escape system for use during controlled gliding flight.
- Make every effort to increase the range of flight conditions under which an emergency runway landing can be successfully conducted in the event that two or three main engines fail early in ascent.

— VIII —

Flight Rate. The nation's reliance on the Shuttle as its principal space launch capability created a relentless pressure on NASA to increase the flight rate. Such reliance on a single launch capability should be avoided in the future.

NASA must establish a flight rate that is consistent with its resources. A firm payload assignment policy should be established. The policy should include rigorous controls on cargo manifest changes to limit the pressures such changes exert on schedules and crew training.

— IX —

Maintenance Safeguards. Installation, test, and maintenance procedures must be especially rigorous for Space Shuttle items designated Criticality 1. NASA should establish a system of analyzing and reporting performance trends of such items.

Maintenance procedures for such items should be specified in the Critical Items List, especially for those such as the liquid-fueled main engines, which require unstinting maintenance and overhaul.

With regard to the Orbiters, NASA should:

- Develop and execute a comprehensive maintenance inspection plan.
- Perform periodic structural inspections when scheduled and not permit them to be waived.
- Restore and support the maintenance and spare parts programs, and stop the practice of removing parts from one Orbiter to supply another.

Concluding Thought

The Commission urges that NASA continue to receive the support of the Administration and the nation. The agency constitutes a national resource that plays a critical role in space exploration and development. It also provides a symbol of national pride and technological leadership.

The Commission applauds NASA's spectacular achievements of the past and anticipates impressive achievements to come. The findings and recommendations presented in this report are intended to contribute to the future NASA successes that the nation both expects and requires as the 21st century approaches. ■

XIII. APPENDIX A, COMMISSION ACTIVITIES, PAGES 206-213.

A. AN OVERVIEW, PAGES 206-208. Listing of charge from President, organization, and activities.

B. TABLE 1, PAGES 208-210, COMMISSION INVESTIGATIVE INTERVIEWS.

1. INTERVIEWS OF JAN 27 86, TELECON PARTICIPANTS, 8:15 PM EST
2. INTERVIEWS OF PERSONNEL INVOLVED IN STACKING RT SRB FOR 51-L.
3. INTERVIEWS ON ICE ON PAD.
4. INTERVIEWS ON HISTORY OF SRB JOINT DESIGN AND PROBLEMS.
5. INTERVIEW ON LAUNCH COVERAGE CAMERA FAILURE.
6. INTERVIEWS ON OUTSIDE PRESSURE TO LAUNCH.
7. INTERVIEWS ON SR/QA.
8. INTERVIEWS ON MANAGEMENT STRUCTURE.
9. INTERVIEWS ON HUMAN FACTORS.
10. INTERVIEW ON WRECKAGE RECONSTRUCTION.
11. INTERVIEW ON CREW ACTIVITIES.

C. TABLE 2 COMMISSION PANEL SESSIONS, PAGE 211.

D. EXECUTIVE ORDER 12546 DATED FEB 3 86 WHICH ESTABLISHED COMMISSION, PAGES 212-213.

XIV. APPENDIX B, COMMISSION DOCUMENTATION SYSTEM, PAGES 214-218. Rather detailed discussion of way Commission handled documents.

XV. APPENDIX C, OBSERVATIONS CONCERNING THE PROCESSING AND ASSEMBLE OF FLIGHT 51-L, PAGES 219-223.

A. Examples of Op Maintenance Requirements and Specifications Documents violations are listed.

B. Of 121 O/M instructions taken as a sample from Orbiter Processing paper, 47% had paper errors. 13% had incomplete, incorrect, or missing data. 32% were missing Quality Control buy-off stamps.

C. 479 Work Authorization Documents in Interim Problem Report, Problem Report, and Test Preparation Sheet categories were reviewed. 70% had anomalies.

D. 96% of Work Authorization documents had administrative or format errors.

E. Nearly all types of paperwork had equivalent lace of completeness and accuracy.

F. About 50% of paper work was flawed and this is unacceptable.

G. Reasons why system is not a useful tool are listed.

H. FLIGHT 51-L BOOSTER PROCESSING, PAGES 220-223.

1. Discussion of booster processing including previous flight history of booster segments done in some detail.
2. CHART, PAGE 221, VAB AFT SEGMENT TO AFT CENTER SEGMENT

STACK.

3. TABLE 1, PAGE 222, RT AFT CENTER SEGMENT TANG TO AFT SEGMENT CLEVIS DIAMETER MEASUREMENT DIFFERENTIALS TAKEN ON DEC 7, 1985.
4. TABLE 2, PAGE 222, ALIGNMENT TOOL USE HISTORY.
5. TABLE 3, PAGE 223, NEGATIVE DIAMETER DIFFERENCES GREATER THAN .320 IN. FOR FIELD JOINTS: STS 51-C THROUGH 61-C.

I. REFERENCES, PAGE 223.

J. PAGE 224, BLANK.

XVI. APPENDIX D, PAGES 225-256, SUPPORTING CHARTS AND DOCUMENTS REFERRED TO DURING THE COMMISSION INVESTIGATION AND REPORT.

A. TABLE OF CONTENTS, PAGE 225.

B. RELEVANT ORG CHARTS OF NASA AND MTI, PAGES 226-231.

1. NASA HQ.
2. OFFICE OF SPACE FLIGHT.
3. JSC.
4. KSC.
5. MSFC.
   a. CENTER ORGANIZATION.
   b. SCIENCE AND ENGINEERING DIRECTORATE.
   c. SHUTTLE PROJECTS OFFICE.
   d. KEY MARSHALL PERSONNEL RELATED TO SRB.
6. MTI.
7. MTI 27 JAN 85 MEETING PARTICIPANTS.

C. TEMPERATURE DEFINITIONS, PAGE 232.

D. EARLY MSFC DOCUMENTS AND MEMOS RAISING DESIGN OBJECTIONS, PAGES 233-238.

1. 1977 BRIEFING CHART BY RAY.
2. MEMO WRITTEN BY RAY, SIGNED BY MILLER TO EUDY URGING JOINT REDESIGN. 1978.
3. 79 MEMO WRITTEN BY RAY SIGNED BY MILLER TO EUDY QUESTIONING JOINT DESIGN.
4. 79 MEMO FROM RAY TO DISTRIBUTION DOCUMENTING VISITS TO O-RING MANUFACTURERS.

E. DOCUMENTS RELATING TO THE CHANGE FROM CRIT 1R TO 1 AND THE WAIVER OF THE REDUNDANCY REQUIREMENTS FRO THE SRM SEAL, PAGES 239-244

1. ORIGINAL SRB CRITICAL ITEMS LIST. 1980
2. SRB CRITICAL ITEMS LIST, 82, SHOWING CRIT 1R TO 1 CHANGE.
3. 83 CONFIGURATION CONTROL BOARD DOCUMENT SHOWING MULLOY APPROVED CHANGE.
4. LEVEL II DIRECTIVE SIGNED BY LUNNEY, 83.

F. MEMOS WRITTEN FOLLOWING FIELD JOINT EROSION ON STS 41-B, PAGES 245-247.

1. 84 ROUTING SLIP SENT BY MILLER TO HARDY.
2. 84 US BOOSTERS MEMO FROM MOREFIELD TO MULLOY ON TITAN

JOINT.

G. MARSHALL URGENT REQUEST FRO BRIEFING AFTER THE STS 51-C MISSION, PAGE 247.

H. INTERNAL NASA HQ MEMO AFTER VISIT TO MSFC, PAGE 248.

I. THIOKOL LETTERS AND MEMOS WRITTEN AFTER O-RING CONCERN ESCALATES, PAGES 249-255.

1. BOISJOLY LETTER TO LUND 31 JULY 85.
2. THOMPSON MEMO TO STEIN, 22 AUG 85.
3. EBELING WEEKLY ACTIVITY REPORT TO MCDONALD, HELP, 1 OCT 85
4. STEIN MEMO ECHOES CONCERN ON LACK OF SUPPORT, 1 OCT 85.
5. BOISJOLY ACTIVITY REPORT 4 OCT 85.

J. MARSHALL INTERNAL MEMO IN THE FALL OF 85, PAGE 256.

APPENDIX VI B

ROGERS COMMISSION REPORT MILESTONES

The intent of the development of milestones for recommendations II, V, and the Flight Decision Process is to outline the relevent references in the Roger's Commission's Report Volume I (here-to-fore referred to as the Report) pertaining to the above, and to provide a reference to the location of such material within the Report.

To facilitate the task, recommendations II and V were broken down into their major parts. References in the Report pertaining to these parts were noted in addition to those relating to the Flight Decision Process. These were then later grouped under the following headings:

Recommendation II
- Management Structure (M)
- Astronauts in Management (A)
- Shuttle Safety Panel (S)

Recommendation V
- Communication problems at Marshall (C)
- Launch Constraint Policy (LCP)
- Flight Readiness Review (FRR)
- Flight Crew Representation (FCR)

Flight Decision Process (F)

In the following pages, these milestones are presented in tabular form, preceeded by a summary and explanation of the tabulated information where applicable. No references to the Appendices were included directly in the milestone tables as key quotes/information of the Appendices are provided in the main body of the Report referenced by the milestones, and all milestones are listed in order of appearance in the Report.

COMMISSION RECOMMENDATION II

The Commission's Recommendation II addresses the need to review the STS management structure, encourage the transition of qualified astronauts into agency management positions, and establish a STS Safety Advisory Panel reporting to the STS Program Manager. In order to determine what evidence was presented to the Commission that led to these recommendations, the Rogers Commission Report was reviewed to find this information. This evidence is presented here in the form of milestone charts. Each chart is labeled using the following convention: management structure, code "M"; astronauts in management, code "A"; and Safety Advisory Panel, code "S".

The Commission states in Recommendation II that the project managers for the various elements of the Shuttle program felt more accountable to their center management than to the Shuttle program organization, and that shuttle element funding, work package definition, and vital program information frequently bypass the NSTS Program Manager. Also, a definition of the Program Manager's responsibility is necessary, giving him the requisite authority for all ongoing STS operations and program funding. However, it was noted that the bypassing of information from the NSTS Program Manager could also be considered as pertaining to Recommendation V, which deals with improved communications.

Therefore, all Recommendation II type "M" references allude to the lack of information flow between Level III management and upper management Levels I and II.

Another point in Recommendation II concerned the transition of qualified astronauts into agency management positions. It also suggested that the function of the Flight Crew Operations director should be elevated in the NASA organization. Recommendation II type "A" citations primarily indicate evidence that increased astronaut input would improve the NASA decision making process. Also, passages that suggest possibly detrimental effects on shuttle crews through the lack of astronaut input have been noted. However, these citations do not indicate every specific mention of shuttle crews in the Report.

On the subject of the Shuttle Safety Panel, the key issues raised in the Report immediately relating to this subject are given in pages 160 to 161, where the Commission considers the efforts of the Aerospace Safety Advisory Panel to be "not sufficiently specific and immediate", and that the merger of the Space Shuttle Program Crew Safety Panel in 1981 left the STS program with "no focal point for flight safety", thus the need for a new safety organization.

It should be noted that from a broader perspective, the Commission's recommendation on the need for the Shuttle Safety panel basically arises from the many safety related issues uncovered during the investigation and review, the majority of which appears in chapter VII of the Report.

Therefore, in generating the milestones, all references to safety related items are considered. Milestones pertaining to problems in management, astronaut concerns, communication failures, and other flight decision process inadequacies are deemed to be related to the Shuttle Safety Panel issue but are not repeated again in the milestone table on safety unless it is considered to be of special significance.

Milestone	Page	Col.	Para.	Lines
Those Making The Decision To Launch Were Unaware Of The SRB O-Ring Problem And Did Not Have A Clear Understanding Of Rockwell's Concern About Ice On The Pad	82	1	1	2-15
Testimony Revealed NASA Management Structure That Permitted Internal Flight Safety Problems To Bypass Key STS Managers	82	1	3	1-7
Relevant Concerns Of Level III NASA Mgmt. Not Adequately Communicated To The NASA Level I and II Mgmt.	83	2	2	2-16
Launch Constraints Imposed By Mulloy Not Communicated To Level I Or II Mgmt.	84	2	1	1-5
Separate and Independent Paths Of System Reporting Of SRB Joint Anomalies	84	2	2	1-17
Discussion Between Mulloy, Lucas, And Reinartz On Temperature Effects On O-Rings	100	1	3	1-8
Lucas Statement Saying Mulloy-Lucas-Reinartz Meeting Was Not A Proper Reporting Channel	101	1	6	1-7
MTI-Lucas Discussion 53F Launch Temp. Limit For SRBs	101	2	6	1-6
Aldrich Statement That SRB Data Not Sent To Level II Mgmt. By Levels I Or III	102	1	2	1-13
Aldrich Statement That Budget Does Not Come Through Level II Mgmt.	102	1	5	1-9
Commission Findings Of Management Isolation And Bypassing	104	2	1	1-10
Conversation Between Mulloy, Lucas, And Kingsbury On Temperature Effects On O-Rings And Final Resolution	109	3	14	1-3
Lovingood-Lee Conversation On The Events Surrounding MTI's Written Recommendation To Launch 51L	110	3	8	1-3

Shuttle Management Structure Milestones - Page 2

Milestone	Page	Col.	Para.	Lines
STS-2 SRB O-Ring Erosion Not Reported In Level I FRR For STS-3 On 3/9/82	125	2	3	9-13
Marshall Monthly Problem Reports Not Distributed To Level II Management	154	1	4	1-4
SRB Launch Constraint Not Communicated To Level I Or II Management Contrary To Problem Reporting & Corrective Action Report	159	2	3	1-5

Astronauts in Management Milestones

Milestone	Page	Col.	Para.	Lines
Rogers Commission Concern For Shuttle Astronauts	1	1	5	5-9
Compressed Training Time Of 51L Crew Resulted In Peaks Of 65 To 70 Work Hours Per Week	15	1	3	1-8
51L Launch Weather Conditions And Effects Not Discussed With The Crew	17	2	3	3-8
51L Crew Unaware Of Hazardous, Icy Emergency Escape Routes	118	1	2	1-10
Chief Astronaut John Young's Description Of His Awareness Of SRB O-Ring Problems	135	Figure	4	1-2
51L Crew Unaware Of Orbiter Wheel Brake Failure On Mission 61C	160	1	2	3-7
Space Shuttle Program Crew Safety Panel Discussion	161	1	1-4	all
Crews On Flights Scheduled After 51L Would Have Had Significantly Less Training Time For Their Flights	170	1	1	8-12
Astronaut Henry Hartsfield Testimony On Extremely Short Training Time	170	1	2	1-11
Commission Findings Of An Unacceptable Compression of Time For Accomplishment Of Crew Training	176	2	3	7-10
Crew Members Recommend That The Orbiter Nosewheel Steering System Be Modified To Achieve Full Redundancy	187	2	4	22-25
John Young Testifies That Shuttle Brakes Are Difficult To Use	188	2	4	1-9
Captain R. Crippen Testifies That The Astronaut Office Would Not Disagree With The Premise That One Is Safer Landing At Edwards AFB Than Kennedy	191	1	3	4-12

MILESTONES OF RECOMMENDATIONS ON SAFETY PANEL - PAGE 1

Milestone	Page	Col.	Para.	Lines
Commission's mandate	1	1	5	1-5
Commission's focus	1	2	1	6-10
Compressed training time	15	1	3	all
No indication of problems during 51-L	18	1	1	1-3
//	18	2	1	1-3
No survivable abort options during SRB thrusting	18	2	2	all
Flt. safety problems bypass key Shuttle managers	82	1	3	all
O-ring erosion not believed to be critical	85	1	3	all
Findings on flawed decison process	104	1	1	3-6
//	104	1	2	1-2
Findings on ambiguous decision process	117	2	4	13-15
//	118	1	1	6-7
Accepting O-ring design problem as acceptable flight risk	120	1	1-3	all
No further testing of O-ring performance when "joint rotation" was observed	122	2	6	20-25
//	123	1	1	all
NASA flying "not well understooded" motors	132	1	1	25-28
Increasing joint test pressure	134	1	11	all
Assumption of backup available when system classified with criticality 1	136	1	4	4-9
Limited/incorrect consideration of past O-ring damage(temperature) data	145	1	10	all
//	146	all	all	all
Findings on past O-ring damage(temperature) data	148	2	5	all
Lack of representation of safety staff on significant launch related decisions	152	1	1	all
Ineffective safety, reliability, and quality assurance programs after the lunar program	152	1	2	all
4 out of 5 "failures" of NASA as described by Aldrich to the commission relates directly to faults in the safety program	152	1	3	all
//	152	2	1	all
Commission's overview of SR/QA's role in NASA	152	2	2-5	all
Commission's overview of the faults of SR/QA in JSC, KSC, and Marshall	153	1	1-4	all
Lack of reference from the SRB critical item list to the Operational Maintenance Requirements and Specifications	153	2	2	8-14
Operations and Maintenance Instruction doesnot indicate criticality of components	153	2	3	6-9
Level II lost insight into safety issues resulting from a change in problem reporting approved by Level II in 1983	154	1	1-4	all

MILESTONES OF RECOMMENDATIONS ON SAFETY PANEL - PAGE 2

Milestone	Page	Col.	Para.	Lines
Lack of clear and concise reporting for in-flight anomalies	154	1	5	all
//	154	2	1-2	all
Commission's view on reporting for in-flight anomilies	154	2	3	all
//	155	1	1-2	all
Inadequate SR/QA resources and its inappropriate location in Marshall limited its effectiveness to prevent the accident of 51-L	155	1	3-4	all
Inadequate/inappropriate trend analysis	155	1	5	all
//	155	2	1-4	all
//	156	1	1-2	all
//	156	2	1	all
Misrepresentation of criticality and lack of management awareness	156	2	2	all
//	157	all	all	all
//	158	all	all	all
//	159	1	all	all
//	159	2	1	all
Failure in reporting launch constraints to Levels II and I by Marshall	159	2	2-3	all
Faulty implications of an "Operational" program reduced SR/QA functions in NASA	159	2	4	all
//	160	1	1	all
Shuttle program moving too fast relative to its SR/QA support	160	1	2	all
Strengthening of NASA's SR/QA functions	160	1	3-4	all
Overview of the Aerospace Safety Advisory Panel and its duties	160	2	1-3	all
Functions of the Aerospace Safety Advisory Panel, and that the Panel's "efforts were not sufficiently specific and immediate to prevent the 51-L accident"	160	2	4	all
Overview of the Space Shuttle Program Crew Safety Panel, and that after the merger of the panel in 1981, "the NASA Shuttle Program had no focal point for flight safety"	161	1	1-4	all
The need for a new safety organization	161	2	1	all
Findings on NASA's SR/QA organization	161	2	2-7	all
Pressure to meet customer commitments may have obscured engineering concerns	165	1	1	1-6
Changes in manifest pushes the system to its limits	170	1	1-2	all

Milestone	Page	Col.	Para.	Lines
Lack of "operational" capabilities to support increased flight rate placed strain on the system, depicted by a liquid oxygen depletion incident on 1-6-86	171	1	2	all
NASA's "can-do" attitude towards challenges	171	2	1	all
Commission's view on attitude towards NASA's challenges	173	1	2-3	all
Lack of spare parts to support the flights due to fund contentions	173	2	3-4	all
Cannibalization is threat to flight safety	174	1	1-2	all
Post flight inspection should preceed subsequent launch	174	2	4	5-12
//	175	1	1	14-17
Payload safety concerns	175	2	1	all
Findings on pressures on the system to support the flight rate: system capability stretched to the limit, spare parts shortage, late manifest changes, training simulator could be the bottleneck, and lack of review of preceeding flight's anomilies	176	2	3-5	all
//	177	1	1-3	all
Other safety concerns not related to the 51-L accident	178	1	1	all
Shuttle design do not require survivable abort options in certain cases during ascent	180	1	1-2	all
Philosophy of assured first stage ascent	180	1	5	1-6
Orbiter seperation not useful during SRB burn	180	2	3-4	all
Thrust termination is key to successful first-stage abort	181	2	2	all
Orbiter ditching not survivable, as expressed by Griffin and Weitz	182	1	1-4	all
Further study of crew escape options warranted	184	1	3	all
Range safety data inadequate for decision	185	2	2	all
Mission control had no warning of 51-L problem before vehicle disintegrate	186	1	1	1-3
//	186	1	3	6-9
Findings on the ascent flight safety	186	2	1	all
Abort site weather concerns	186	2	3	10-13
//	187	1	1	all
Orbiter brakes have little safety margin	188	1	5	all
Brakes difficult to use as expressed by Young	188	2	4	all
Aerospace Safety Advisory Panel's concerns over the Orbiter braking system	189	2	1	all
//	189	2	3-4	all
KSC landings concerns	191	2	5	all

MILESTONES OF RECOMMENDATIONS ON SAFETY PANEL - PAGE 4

Milestone	Page	Col.	Para.	Lines
Overall views on Orbiter landing concerns	191	2	6	all
//	192	1	1-2	all
Implementation of high-pressure pump improvements important	192	2	1	all
Increase engine tests	192	2	2	all
Concerns over disconnect valves between ET and Orbiter	192	2	3	all
Concerns over vent valves in ET	192	2	4	all
Structural inspection concerns	193	1	3-4	all
Errors in records	193	1	5	all
Missed documentation/requirements	193	2	1-7	all
Inspection by proxy	193	2	8	all
Accident damage not consistently reported	194	1	1	all
Launch pad 39B safety issues	194	1	2	all
//	194	2	1	all
Direct involvement of contractors in pre and post flight processing desirable	195	2	2	all

COMMISSION RECOMMENDATION V

The commission's recommendation V on improved communication primarily focuses around four general areas of concern:

i. First, the commission points toward the management isolation at Marshalls. It point at the various flaws in decision making process and the failure to inform and report numerous anomalies and launch constraints to level I and II. The commission concludes that the failure of Marshalls to communicate flight constraints, anomalies and concerns by Thiokol resulted in the bad decision by NASA management. It recommends that energetic steps should be taken to eliminate this tendency at Marshalls.

ii. Second, the commission found an incohesive policy toward the imposition and removal of launch constraints. It found that the waivers were repeatedly signed without informing level I and II. Similarly some of the problems were being closed without actually finding a proper solution. The commission also found it mandatory to have a post-flight inspection list.

iii. Third, the commission found a lot of ambiguity in the way people understood the same conversation. In this regard, it specifically refers to Rockwell and NASA incidence in which each understood the other in a different way. It therefore recommends that the proceedings of the Flight Readiness Review and Mission Management meetings should be recorded.

iv. Fourth, the commission found a surprise absence of astronauts from all of the Flight Readiness Review process. It found that the crew was not informed of the effect of low temperatures and were unaware of the anomalies in the system. The commission found that the crew of 51-L, which was to land at KSC, was also not informed of the brakes problem in the previous landing at KSC. It therefore saw the need for a new safety panel with crew given proper representation. The commission also recommends that the flight crew commander, or a designated representative, should attend the Flight Readiness Review, participate in acceptance of the vehicle, and certify that the crew is properly prepared for the flight.

The first and the last recommendations are deemed necessary by the commission to improve communication within the organization so that a better decision can be made and a disastrous decision such as that of 51-L can be avoided. The other two recommendations on communication are more in line of providing a safeguard for such a plan.

LIST OF ABBREVIATIONS

C	--	COMMUNICATION
LCP	--	LAUNCH CONSTRAINT POLICY
FRR	--	FLIGHT READINESS REVIEW
FCR	--	FLIGHT CREW REPRESENTATION

MILESTONES OF RECOMMENDATIONS ON COMMUNICATION

Milestone	Page	Col.	Para.	Lines
Flaws in the decision making process	82	1	1-3	all
Inadequate communication to level I and II	83	2	2	2-16
Marshall failure to inform level I and II	84	2	2	all
//	85	1	1-2	all
//	85	2	1	all
//	88	1	7	all
Thiokol's reasons for reversing the decision	94	2	3	9-17
Mulloy's reasons for not communicating to L-I	98	1	2-4	all
Management isolation at Marshalls	101	1-2		all
//	102	1	1-2	all
//	103	2	11-12	all
Commission's findings on decision making flaws	104	1	1	all
//	104	2	2	all
Marshalls failure to report previous anomolies	125	2	3	all
NASA's awareness to O-ring problems	135	2	4	Figure 4
//	136	2	1	all
//	138	2	3	13-21
Marshalls failure to report previous anomolies	141	2	1	all
//	147	1	1	all
//	147	2	2	all
Marshalls failure to report launch constraints	147	2	3	13-20
//	148	1	1	19-23
Commission's findings on joint design	148	1	2	all
Description of comm. system failure by Aldrich	152	1	2	all
Management isolation at Marshalls	154	1	3	all
Anomalies reporting at NASA	155	1	1-2	all
Management awareness of the seal problem	156	2	2	4-19
Misinformation about joint seals	159	1	5	all
Misinformation about seal launch constraint	159	2	2	1-9
//	159	2	3	all
Improper documentation of problems	161	2	4,7	all

MILESTONES OF RECOMMENDATIONS ON LAUNCH CONSTRAINTS POLICY

Milestone	Page	Col.	Para.	Lines
Six consecutive waivers prior to 51-L without informing Moore or Aldrich	84	1	5	5-12
	84	2	1	all
Commission's findings on launch constraints waivers	104	1	2	all
	104	2	1	all
Signing-off of waivers on previous occasions	128	1	1	all
Launch constraints and sub. waivers by Mulloy	137	1	6-7	all
//	137	2	1-2	all
//	138	2	3	1-12
Closing of unsolved O-ring problems	142	1	7	all
//	143	2	4-9	all
Commission's findings on waivers record	148	2	4	all
Need for mandatory post-flight inspection list	175	1	1	all

MILESTONES OF RECOMMENDATIONS ON FLIGHT READINESS REVIEW

Milestone	Page	Col.	Para.	Lines
Flight Readiness Review for flight 51-L	15	2	1	all
Confusion in communication between Rockwell	115	1	2	all
// and NASA	115	2	1-4	all
//	116	1	1-6	all
//	117	1	6	all
Commission's findings about comm. confusion	117	2	3	1-6
//	117	2	4	all

MILESTONES OF RECOMMENDATIONS ON FLIGHT CREW REPRESENTATION

Milestone	Page	Col.	Para.	Lines
No information to 51-L crew about low temp.	17	2	3	3-8
//	118	1	2	all
Chief Astronaut's infor. about O-ring problem	135	2	1	Figure 4
No brake problem information to 51-L crew for KSC landing	160	1	2	1-7
Program crew safety panel's role	161	1	1,3,4	all
Need for new safety organization	161	2	1	all
Compression of the training schedules	164	2	1	6-11
//	165	2	6	8-14
//	170	1	1-2	all

FLIGHT DECISION PROCESS

The Commission's criticisms on the Flight Decision Process are concentrated in chapter V of the Report (pg. 82 to 119). Major issues seemed to center around the failure of the system to communicate critical safety related issues to management responsible for launch decisions, and that NASA's decision to launch given the data that they had is flawed.

In generating the milestones for this subject, all milestones included in Launch Constraint Policy, Flight Decision Review, and Flight Crew Representation are considered to be part of the milestones for Flight Decision Process but are not seperately listed here. Similar rational applies to the milestones pertaining to problems in communication, management structure, astronaut issues, and other safety issues if one takes a broader view of the decision process.

Description of the "informal decision process" (outside of formal meetings) during the pre-flight activities of 51-L given in chapter V are not included in the milestones. The part of the decision process between MTI and Marshall is also not included here.

MILESTONES OF FLIGHT DECISION PROCESS - PAGE 1

Milestone	Page	Col.	Para.	Lines
Overview of flight preparation activities for 51-L	13	1	5-6	all
//	13	2	all	all
//	14	1-2	all	all
//	15	1	1-4	all
Overview of Level I FRR for 51-L	15	1	5-6	all
//	15	2	1-3	all
Three launch delays of 51-L	17	1	1-4	all
Description of pre-launch activities of 51-L	17	1	5-6	all
//	17	2	1-5	all
The launch decision was flawed, those who made the decision were not aware of critical safety problems and contractor concerns	82	1	1	all
//	82	1	2	1-6
Failure in communication and management structure resulted in the flawed decision to launch	82	1	3	all
Overview of the FRR	82	2	1-3	all
//	83	1	all	all
//	83	2	1	all
Crucial contractor concerns not communicated from level III to Levels I and II	83	2	2	all
Notifications of FRR sent for 51-L	84	1	1-2	all
Post FRR directives from Moore and Aldrich	84	1	3-4	all
O-ring launch constraint waivers	84	1	5	all
//	84	2	1	all
O-ring anomilies not included in FRR	84	2	2	12-17
O-ring problems not included in Certification of Flight Readiness	85	1	1-2	all
Mission management team's meetings, discussions on weather related matters	85	2	2-4	all
Mr. Reinartz admitted his decision of keeping MTI's concern on temperature effects on O-ring problems to level III	88	1	3-8	all
MTI being put in a position to prove that NASA shouldnot launch (Boisjoly's opinion)	93	1	5	all
//	93	2	1	3-8
MTI being put in a position to prove that NASA shouldn't launch (Lund's opinion)	94	2	2-4	all
Mulloy's rationale for not discussing O-ring problem with Aldrich	98	1	4	all
Aldrich's testimony on failure of the decision/ communication system	101	2	9-11	all
//	102	all	all	all
//	103	1	all	all
//	103	2	1	all

Milestone	Page	Col.	Para.	Lines
Thomas's comments on not launching should the relationship of temperature and seal was available to him	103	2	8-13	all
Findings on the flawed decision process	104	1-2	all	all
Freeze protection plan for launch pad not followed for 51-L	114	1	1	9-24
Rockwell felt unsafe to launch due to ice conditions (testimony by Petrone, Glaysher, and Cioffoletti)	114	2	1-7	all
//	115	1	1-5	all
//	115	2	1-2	all
Ambiguity in the flight decision process (Rockwell's unsafe-to-fly position)	115	2	3-7	all
//	116	1	1-6	all
Ambiguity in Rockwell's position (Lamberth's testimony)	116	1	7-8	all
//	116	2	1	all
Aldrich's testimony concerning the decision to launch in view of Rockwell's ambiguity	116	2	2-5	all
//	117	1	1-6	all
//	117	2	1	all
Findings on the decision to launch, that Rockwell's position was ambiguous, that NASA didnot considered Rockwell's input appropriately, that the freeze plan was inadequate, and that ice on the crew emergency slide wire baskets was harzardous	117	2	2-4	all
//	118	all	all	all
O-ring criticality change and subsequent waiver by NASA (lunney's testimony)	127	1	5-6	all
//	127	2	1-10	all
//	128	1	1	all
41-B O-ring erosion briefed as "technical issue" in Level I FRR	132	1	6	1-6
O-ring blow-by and erosion considered "acceptable" in Level I FRR	136	2	1	all
61-A O-ring anomalies not mentioned in Level I FRR for 61-B	141	2	1	all
Overview of FRR and its objectives	145	2	3-6	all
//	147	1	1-2	all
FRR inattention to O-ring problems from STS-2 through 41-B	147	1	3-4	all
Discussion of O-ring problems from 41-B through 51-F in FRR's	147	1	5-6	all
//	147	2	all	all

MILESTONES OF FLIGHT DECISION PROCESS - PAGE 3

Milestone	Page	Col.	Para.	Lines
Commission's observation of trends in the treatment of O-ring problems in FRR's	148	1	1	all
Finding's on the historical developments contributing to the 51-L accident	148	2	2-4	all
Lack of SR/QA in the flight decision process	152	1	1	all

APPENDIX VI C

AN INDUSTRIAL ENGINEERING PERSPECTIVE ON THE REPORT OF THE PRESIDENTIAL COMMISSION ON THE SPACE SHUTTLE CHALLENGER ACCIDENT

1.0 INTRODUCTION

On reviewing the Rogers' Commission Report to the President, time and again, citations were listed which deal with typical industrial engineering functions. The intent of this paper is to point out many of the findings of the Commission which relate to functions of a modern, typical industrial engineer. Additionally, the intent is to give some idea of the scope and breadth of the Commission's work.

Being a relatively young discipline, industrial engineering has sometimes suffered from a lack of recognition and identification for its unique and increasingly important role in this complex and ever changing environment in which we operate. While the contributions of industrial engineering to the industrial sector, particularly manufacturing and service, have been well recognized, most other engineers seem to have little awareness or understanding of the work effort, education, and skill content of the profession. Those who do profess to an understanding often associate the profession with work study and time and motion analysis, and have little appreciation of the scope and depth of the skills that the modern industrial engineer possesses. One of the real strengths of industrial engineering which often is not recognized is its unique qualifications to serve as an interface between the engineering design community and the business or production world. Paradoxically, the inability to smooth the interface between design and production is one of the recurring themes of the Rogers' Report. Most IE's, because of their education and work experience, have an understanding of both the design and production sides of the system. For these and other reasons, the Commission Report should be both educational and useful to industrial and other engineers, and to engineering managers.

It should be noted that the authors do not in any way intend this paper to be critical of NASA or the Shuttle Program, and certainly hope to avoid the twenty-twenty perfection of hind sight. The comments contained herein are simply an in-depth examination of the Commission findings concentrating on factors which are related to industrial engineering and engineering management, and those related to smoothing the interface between design and production. It should also be pointed out that NASA has made 24 successful flights with the Shuttle in an extremely hostile environment with austere fiscal constraints. Their record of high performance under difficult circumstances should not be buried as an aftermath of the accident.

2.0 THE REPORT

The Commission Report consists of five volumes, the last four of which consist primarily of appendices to support volume one which contains the findings of the Commission. It is the first volume which will be addressed in this paper. The contents of volume one are illustrated in Table 1. The first four chapters discuss the accident and its investigation, leading to the conclusion that the failure of the pressure seal in the aft field joint of the right Solid Rocket Motor was the cause of the accident. These motors are manufactured in segments by Morton Thiokol, shipped by rail to Kennedy Space Center, and assembled there. The O-rings in one of these field joints leaked and caused the accident. The Commission went on to say that the failure was due to a faulty design unacceptably sensitive to a number of factors including temperature, physical dimensions, the character of the materials, the effects of reusability, processing, and the reaction of the joint to dynamic loading.

While all of the report is interesting and informative, the first four chapters were primarily factual descriptions of the Shuttle Program, the Challenger accident, and the analysis of its mode of failure. It is from Chapter V onwards that the root causes of the accident and other contributing factors are discussed. These issues will be discussed in the later parts of the paper.

Chapter I INTRODUCTION	* Covers the topics of design, funding history, development, elements of the shuttle, and flight of a space shuttle
Chapter II EVENTS LEADING UP TO THE CHALLENGER MISSION	* Deals with the events leading leading up to the Challenger mission including crew assignments, preparations for flight, flight readiness review, launch delays, and the actual flight of the Challenger
Chapter III THE ACCIDENT	* Reports the actual accident with numerous photographs showing what happened
Chapter IV THE CAUSE OF THE ACCIDENT	* Presents the analysis of the accident by identifying all possible faults that could originate in the flight elements of the space shuttle * Commission concludes that the cause of Challenger accident was the failure of the pressure seal in the aft field joint of the right Solid Rocket Motor
Chapter V THE CONTRIBUTING CAUSE OF THE ACCIDENT	* Deals with the flaws and ambiguities in in the decision making process leading to the launch of Flight 51-L * Presents the testimony of the people involved which shows failure in the communication process * Commission expresses concerns about safety
Chapter VI AN ACCIDENT ROOTED IN HISTORY	* Discusses the historical roots of the Solid Rocket Motor joint seal problems from the early designs, tests, design objectives, verification and certification committee to criticality classification and changes * Commission concludes that both NASA and the contractor failed to understand and respond to facts obtained during the testing and internal warnings of joint problems
Chapter VII THE SILENT SAFETY PROGRAM	* Covers problems found by the commission with the safety program * The commission recommends the formation of a new safety organization in NASA
Chapter VIII PRESSURES ON THE SYSTEM	* Pressures relating to increased flight rate were uncovered by the commission * Logistics problems and changes in the manifest were important items
Chapter IX OTHER SAFETY CONSIDERATIONS	* Discusses the safety considerations like abort capabilities, crew escape options, landing options, etc.

TABLE 1 - ROGERS' COMMISSION REPORT CONTENTS

3.0 RECOMMENDATIONS

The Commission concluded its work with nine recommendations. These are illustrated in Table 2. A few observations about these should help to illustrate the scope of the Commission's work.

The work of the Commission was rather broad, and their recommendations ranged from design considerations to astronauts in management. The Commission called upon the National Research Council to serve in an oversight capacity in several places. The Commission did not confine itself to just the accident; some of the recommendations deal with issues that the Commission felt would be future problems and some deal with things the Commission felt NASA just ought to do. The Commission also urged NASA to respond to the President in one year with a report showing the progress that they had made in effecting the recommendations.

4.0 THE PROBLEMS

In order to bring perspective to the Commission findings, a different organization of topics than those used in the Report is beneficial. While the failure of the joint in the aft segment of the Solid Rocket Motor was the cause of the accident, there were numerous underlying problems identified by the commission related to both the joint problem and other safety or performance issues. The attempt

Recommendation I SOLID ROCKET MOTOR DESIGN	• The Solid Rocket Motor joint and seal must be changed • List of standards that the SRM design must meet • Formation of an independent National Research Council Solid Rocket Motor committee to oversee the redesign effort
Recommendation II • MANAGEMENT STRUCTURE • ASTRONAUTS IN MGMT. • SAFETY PANEL	• Shuttle Program Structure should be reviewed • Project Managers made to feel more responsible to the Program Manager than to the various center where they are located • The Program Manager's responsibility should be redefined • Funding should be placed under the Program Manager's authority • Astronauts should be used more in management • A Safety Advisory Panel should be formed which reports to the Program Manager
Recommendation III CRITICALITY REVIEW	• NASA and contractors should review all critical items and to seek improvements • An National Research Council Audit Panel should verify the adequacy of the effort and report directly to the Administrator of NASA
Recommendation IV SAFETY ORGANIZATION	• NASA should establish an Office of Safety, Reliability, and Quality Assurance • The office should be headed by an Associate Administrator reporting directly to the NASA Administrator • The org. should be independent of other NASA responsibilities
Recommendation V IMPROVED COMMUNICATIONS	• Management isolation at Marshall should be eliminated • Development of a policy for the imposition and removal of launch constraints • High level mgmt meetings just prior to launch should be recorded • The flight crew commander should participate in these meetings accepting the vehicle for flight and certifying the crew is properly trained
Recommendation VI LANDING SAFETY	• The tire, brake, and nosewheel steering systems must be improved • Criteria for Kennedy landings, tires, brakes, and nosewheel steering must be established
Recommendation VII LAUNCH ABORT & CREW ESCAPE	• NASA should make all efforts to provide a crew escape system for use during controlled gliding flight • NASA should increase the range of flight conditions under which an emergency runway landing can be made if the engines fail
Recommendation VIII FLIGHT RATE	• Reliance on a single launch capability should be avoided • The established flight rate must be consistent with resources • Establishment of a firm payload assignment policy
Recommendation IX MAINTENANCE SAFEGUARDS	• Establishment of a system that analyzes and reports performance trends for critical items • Development of a comprehensive maintenance inspection plan • Performance of periodic structural inspections when scheduled and not permit them to be waived • Restore and support the maintenance and spare parts programs • Stop the practice of parts "cannibalization"

TABLE 2 - ROGERS' COMMISSION RECOMMENDATIONS

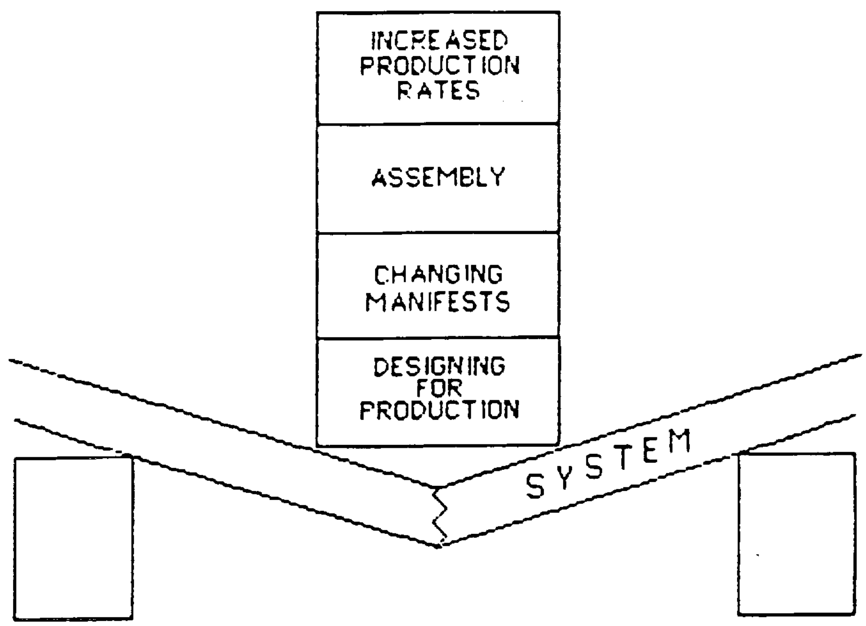
here is to divide the discussion germane to this paper into categories which should be familiar to the industrial engineer or industrial manager. These are: processing; safety, reliability, and quality assurance; trending analysis; logistics; and communications and management.

5.0 PROCESSING PROBLEMS

The processing of the Shuttle comes in two separate parts. First there is the manifesting and integration of the cargo, training, flight definition, data and control development, and related items most of which are done at Johnson Space Center (JSC). This processing is very complex and involves long lead times, with the bulk of the work being done in the 18 to 20 month time frame. At Kennedy Space Center (KSC), the actual physical parts of the processing are accomplished with some of the hardware such as Solid Rockets and External Tanks being furnished as sub-assemblies by contractors. Solid Rocket Motors are assembled, inspections on equipment are performed, the Solid Rockets and external tank are mated with the Orbiter, propellants are loaded, and other processing steps are performed, leading up to the actual launch. The control of the design and quality of some of the sub-assemblies resides at other centers. As an example, Marshall Space Flight Center (MSFC) has control of the Solid Rocket Motors, the External Tanks, and the Space Shuttle Main Engines. For the most part, it is only when the interface between a sub-assembly at one center and a sub-assembly at another center is affected that exchanges of information between the centers about changes or problems occur.

Designing for production. One of the common problems of processing is that of having a design which is conducive to production. With NASA, as the Shuttle Program matured, the fact that items were to be reused gave the agency a new set of problems which they had not dealt with before. In addition, the Shuttle is still developing and changing, yet some of the early developmental contractors were excluded from the processing contracts, thereby losing to NASA a valuable experience base. Both of these are related to the adage of "get the operators into the design and get the designers into the operation".

Assembly. The Commission listed the following problems which they felt would bear on the safety of future flights in their discussion of assembly: for flight 51-L (Challenger) 40%+ of the structural inspections were waived: a formal structural inspection plan for the fleet had not been developed; waivers were requested by Program management to minimize flight delay; the inspection requirements were new and not mature; there was a large amount of errors in the work control papers; the operations maintenance instructions needed reviewing and updating; some requirements were not met,



INCREASED LOAD AND PRESSURE ON
SYSTEM INCREASES RISK OF FAILURE

waived or excepted; some inspections were done by proxy thereby reducing the effectiveness of independent inspection of contractor work by NASA; and the damage reporting procedure was changed, removing the forgiveness clause which was thought to encourage reporting. Most of these comments refer to common problems found in any routine processing or manufacturing industry. However, routine processing is new to NASA.

The above problems related to work documentation and work control become more significant in light of the sensitivity of the proper performance of the joint on the Solid Rocket to its assembly. This assembly of sections of the Solid Rocket could at best be described as tricky with considerations having to be given to proper seating and testing of O-rings, insulating putty, and segments becoming out-of-round because of reusability. In fact one of the conclusions of the Commission was that, among other things, the joint design was unacceptably sensitive to processing.

Shoot the engineer / Manifest Changes. A comment often heard in the operations world is that someone should shoot the engineer so that operations could get on with the job of producing the product without having to deal with never-ending design changes. In the Shuttle Program, these changes bubble up as changes in the manifest. With the long lead times of work at JSC, manifest changes occurring relatively late in the process cycle cause a large amount of lost work and rework. These changes were occurring routinely in the Shuttle Program. Some of these changes had a low priority and all were using up the resources of the system. This in turn increased the pressure on the system. While any product requires some degree of flexibility in order to remain responsive to user needs, the Shuttle Program, being relatively young, was having difficulty dealing with the large amount of variability induced by late changes to the manifest. The stated lack of sensitivity of those directing the changes to the impact of the changes is reminiscent of the usual conflict between sales and production in many industries.

Increasing the production rate. There are numerous reasons why NASA wishes to have an increased flight rate: meeting customer demand; flying scientific experiments; funding considerations; supporting the space station; defense needs etc. For whatever the reason, NASA has been planning and moving to meet an accelerated flight rate and this has caused processing problems. The beginning of these was perhaps when NASA declared the Shuttle Program to be operational. Operational to NASA seems to mean that a program has moved out of the phase where the primary emphasis is on design development and testing into a phase where the emphasis is shifted towards satisfying the needs of users. What is new for NASA with the Shuttle Program is the consideration of having routine timely performance. While many managers may have, in the Commission's view, forgotten that the Shuttle was still in an R/D phase, others were determined to prove that it was operational. This concept of operational may be misleading and may have lead to a reduction of safety and quality considerations. Then the flight rate being increased and projected to go higher caused the system to get further and further behind. Time was being devoted to immediate problems with little time left for long range problems. The capabilities of the system were stretched to the limit to meet the flight rate of the winter of 1985/1986, and would have been exceeded in the spring/summer of 1986. Training of astronauts and flight controllers was becoming inadequate because of the increased rate. Projected schedules in the Commission's view did not accurately reflect capabilities and resources. Logistics fell behind. There was no margin in the system to accommodate hardware problems. The flight rate was not adjusted to accommodate periods of adjustment for the workforce. These problems were acerbated by the cascade effect of a delayed launch. When a launch is delayed, other than the obvious problems with some work at KSC having to be put on hold until the current flight is out of the way, there are design considerations concerning launch constraints which must be reworked. Even a small delay ripples through the system, causing an enormous amount of problems and unplanned work. These problems are in turn increased if the time to the next launch is short.

So the problem here is the common one of pressure on operations to produce and to get the most out of a system. With NASA, the processing system is young, particularly regarding routine timely operations, and difficulties were being encountered in dealing with this pressure and in developing the capabilities to cope with the increasing rate.

One of the manifestations of this increased pressure was the willingness by NASA to accept escalating risk. With the joint seal, this meant that when the seal did not perform as expected, they were willing to believe that this would not lead to problems since the last poor performance did not lead to any. Another manifestation was the willingness to fly flight 51-L even though the launch pad was covered with ice from the night before due to an inadequate ice protection system. Along this same line, the increased rate was causing anomalies from the immediately preceding mission to go unresolved and misunderstood before the next mission was launched.

6.0 SAFETY, RELIABILITY, AND QUALITY ASSURANCE (SR/QA)

The Rogers' Commission "focused its attention on safety aspects ... with the objective being to return to safe flight" (page 152). The fact that SR/QA is of prime importance to the Space Shuttle Program, and that its failure was one of the underlying causes of the Challenger accident is repeatedly reinforced by the Rogers' Commission throughout the Report. It should be noted that from a broader perspective, one could argue that all problems pointed out in the Report, including those in management structures, communications, flight decision process, engineering design and testing, logistics etc. are inevitably safety issues since one of the main emphasis on the Shuttle Program should be safety. We will, however, limit our discussion on the SR/QA problems to those where the Commission explicitly stated them as such.

The Commission was surprised to find the lack of SR/QA representation on critical issues and launch decision processes, that the "extensive and redundant" safety program during the Apollo era had become "ineffective". In fact, the Commission was amazed when they realized after many hours of testimony that no SR/QA staff was ever mentioned. The structure of the SR/QA organizations within NASA and its centers, placing SR/QA under Engineering and Processing, the very organizations whose functions SR/QA was to monitor, significantly reduced the independence and effectiveness of SR/QA in its "watch dog" role. This was compounded by the lack of commitment in resources, and a lack of centralization and focus of the SR/QA activities within the NASA organization. In fact, the SR/QA staff was significantly reduced in NASA after the Shuttle Program was declared "operational" after the four test flights. The need for a "top-to-bottom" emphasis on SR/QA was deemed necessary by the Commission in order for NASA to re-establish the key role that SR/QA should play in the Space Program. Recommendations

II, III, and IV by the Commission specifically addressed these issues (see Table 2), pointing to the need for a new, independent SR/QA organization in NASA, headed by an associate administrator, together with other related panels to ensure the proper functioning of SR/QA and criticality related issues.

The extent of the SR/QA involvement, or lack of it, in the Challenger accident is further depicted in the testimony given to the Commission by Arnold Aldrich, the Space Shuttle Program Manager. He identified five major organizational / communications problems in the program that had contributed to the eventual failure in launching 51-L, four of which relate directly to failure in the SR/QA program: inadequate reporting requirements of problems; trend analysis problems; criticality representation and tracking in the system; and a lack of SR/QA involvement in the discussion of critical issues. The Commission further reflected on its emphasis on SR/QA at several points in the Report, and went as far as stating that "an effective functioning SR/QA organization could have taken action to prevent the 51-L accident" (page 155), and that "if the program (SR/QA) had functioned properly, the Challenger accident might have been avoided" (page 156). It is important to note that no other causes had been identified by the Commission in the Report, the correction of which could have prevented the accident.

Another rationale for strengthening the SR/QA function was tied to the need for an increased flight rate. As pointed out in the previous discussion, NASA currently lags behind in its capability to move into the "operational" era. As it attempts to move into the operational mode from a traditionally R/D based posture, both R/D to operations and SR/QA efforts must be significantly improved. It should be noted that both SR/QA and operations management are part of the regular IE's training and function. One does not have to look too far to see that courses such as Quality Control/Assurance, Reliability Engineering, and Safety Engineering being regular, and very often required, courses in the IE curriculum. The rigorous, mathematically based analysis in these courses ensures the competence and dominance of the IE in the practice of SR/QA relative to other engineering disciplines.

Take Quality Control for example: besides the statistically based methods developed for sampling and inspection, IE's also place emphasis on human reliability aspects through their thorough understanding of human factors. The fact that it is not uncommon to find error figures of 25% or more among the experienced quality inspectors [G. K. Bennett, 1975] would certainly substantiate the need for the modeling of human factors into Quality Control schemes. One may even be able to apply these concepts to the solution of the documentation error problems as discussed earlier. The many theories developed in IE need to be thoroughly understood before a successful SR/QA program can be implemented.

7.0 TRENDING ANALYSIS (TA)

"Development of trend data is a standard and expected function of any reliability and quality assurance program" (page 156). This was reiterated in the Report at several points. It was also linked to the possible prevention of the 51-L accident. Although considered to be part of the SR/QA function, the importance of trending analysis as reflected in the Report necessitates the separate discussion of the topic.

The main concern around trending analysis, or rather the lack of such, has to do with the effect of temperature and the amount of blow-holes in the insulating putty on the O-ring performance. The asbestos-filled putty was used in the SRB to prevent the hot combustion gas from damaging the O-ring. Early on in the Shuttle Program, it was believed that blow-holes in the putty contributed to O-ring erosion problems. It was also believed that pressurized checks of the O-rings created more blow-holes in the putty. There had been changes in the pressurized checks from 50 psi to 200 psi, and if one was to plot the leak check pressure against flight anomaly frequency (in terms of O-ring performance) as the Commission did, the trend is rather apparent that O-ring anomalies increase with higher leak check pressures.

The Commission found that out of 20 launches with ambient temperatures of 66 degree Fahrenheit or greater, only three showed signs of O-ring thermal distress; however, each of the launches below 65 degrees Farenheit resulted in one or more O-rings showing signs of thermal distress. The ambient temperature at the time of launch of 51-L was 36 degrees Farenheit, 15 degrees colder than any previous launches. Of the limited considerations given to temperature effects on the O-ring performance by NASA managers, the amount of O-ring thermal distress per flight was charted against temperature for ONLY those flights with O-ring anomalies. In such a comparison, no trends were detected. However, when all the flights were included in the chart by the Commission, the effect of low temperature on the O-ring performance was obvious, that "the probability of O-ring distress is increased to almost a certainty if the temperature of the joint is less than 65" (page 145).

Other than the above mentioned trending/analysis scenarios as discussed in the Report, one could extrapolate the application of similar types of trending or data analysis that would be of significant importance to the Space Shuttle program as it matures into the operational phase. One item that comes to mind is the development of learning curves for the various components of the system, which will enhance the accurate planning for the operations mode in the future. It will also be very useful in the analysis of flight rate capability, an issue of major concern to the Commission. Trending analysis can also be used to assist in logistics and inventory control, which is also a key problem area as discussed by the commission.

8.0 LOGISTICS

The problems in logistics within the Space Shuttle program are best illustrated through the spare parts provisioning in support of the flight plans. Examples were cited where a three-to-one ratio of future cost to current savings in the deferral of spare parts provisioning was common, and this ratio has gone up as high as seven-to-one in some instances. The fact that NASA management devoted funds to cover "other more pressing activities" rather than implementing the logistic plans to support the intended flight rate again reflects a lack of appreciation of the importance of a system's view point in the planning and implementation within the operations environment, where long term, sustained and stable operating environment should take precedence.

The practice of "cannibalization", in which parts were removed from one orbiter to another as replacements, has significantly threatened flight safety as extra handling and installation are required. Extra time and cost are also involved in the processing of the flights. The extent of such practice can be seen if one considers the fact that 45 out of approximately 300 required parts, ranging from nuts and bolts to a control actuator, were cannibalized for the 51-L flight.

The Commission is of the opinion that the Shuttle program is still in an R/D stage, instead of being "operational". As such, the many problems the program experienced could be attributed to a lack of an operational capability, which in our opinion must be based on a sound knowledge of operations management and logistics based planning and analysis. "Cannibalization" is one example which illustrates the project type management philosophy still operating in NASA, amid many other operations management type problems.

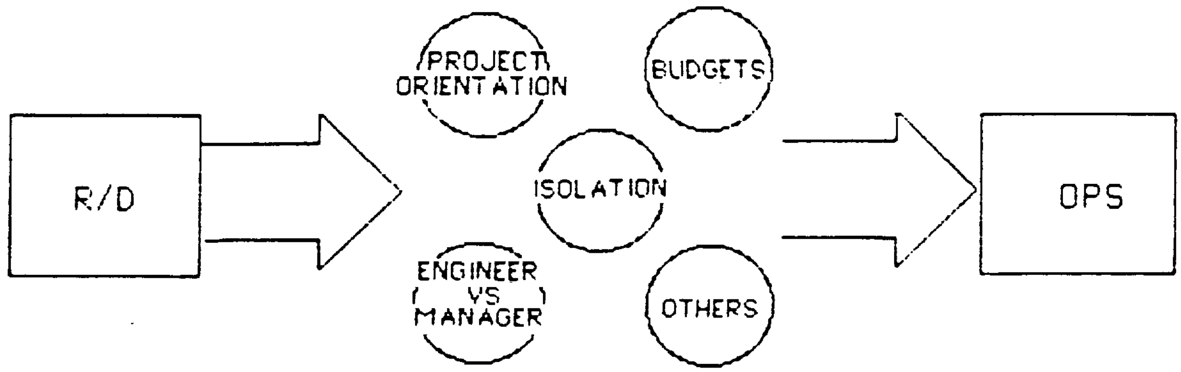
9.0 COMMUNICATION AND MANAGEMENT PROBLEMS

The Commission showed its concern for management and communication problems with 2 of the 9 recommendations addressed specifically to these issues. Several of the others refer less directly to these type of concerns.

Project versus process management. A comment of the Commission was that NASA was having difficulty getting away from a single flight focus; in other words, NASA could not leave project management and engage in process management. Much of the work at NASA is on a per flight basis. The increased flight rate made this problem more severe. This situation is similar to smoothing the flow of any product from its design stage into production. While this is a familiar problem to industry, it should be recalled that few products have the complexity, cost, visibility, and potential for impact on the reputation of the Nation as does the Shuttle.

Budgets. Budgets and money with this program, as with any program, caused problems. Here the problems included budgets for some of the projects going through center directors and not going through the Program Manager. In addition, money had to be diverted from spare parts support in order to meet the perceived more pressing needs of the increasing flight rate. Another budgetary aspect was that costs and their control was the first and most important concern of the selection board which chose Morton Thiokol (MTI) as the contractor for the Solid Rocket Motor.

Management isolation. The problem with isolation was increased by the fact that the project managers often times felt more responsibility towards center directors at JSC, KSC, or MSFC, for example, than they do to the Program Manager. In light of the budget structure, this is not too surprising. In the Commission's view, the isolation at Marshall was particularly severe and resulted in the Program Manager, along with other key managers, not receiving critical information from Marshall. As an example, Marshall had information indicating that the joint design was performing poorly and this was not brought to the Program Manager's direct attention.



OBSTACLES IN THE PATH OF SMOOTH MANAGEMENT TRANSITION FROM R/D TO OPERATIONS

Engineer versus manager conflict. In any program which is moving towards an operational environment, there are numerous difficult decisions and judgement calls which must be made. The question with an engineer turned manager often reverts to: When should one think like an engineer and worry with design considerations, and when should one think like a manager and worry with operational considerations? On the evening preceding the launch, the engineers at Morton Thiokol became concerned with the effects of the predicted cold temperature on the joints. The meeting that was held was at the tail end of a long chain of concern by MTI engineering. The result was that the engineers recommended not to launch at the predicted cold temperature. Subsequently, several meetings and tele-conferences were held with MTI management and their NASA managers from Marshall. The result was that management decided the temperature concerns were not sufficient to cancel the launch. None of these concerns were ever brought to the Program Manager's attention until after the accident.

As a related problem, Rockwell, the contractor which built the Orbiter, was also concerned about the ice on the launch pad. In particular Rockwell felt that they did not have sufficient time to research and resolve the ice problem. However, in the Commission's view, their recommendation on launching was ambiguous and poorly communicated to the NASA officials in the flight decision process.

Perturbations in the system. On January 1, 1986, JSC consolidated its entire contractor workforce under a single company. This came at a time when the system was performing at its full capacity to meet its 1986 flight rate. In some of the areas, many of the contractor employees chose not to change companies, leaving the consolidated contractor short of needed critical skills.

Another problem was that NASA was experiencing a reduction in skilled personnel caused by retirements, hiring freezes, transfers to other programs such as the space station, and transitioning to contractors. So the system was changing while responding to an increased production rate with a reduced number of skilled personnel.

Flaws in the decision process. The Commission concluded that there was a serious flaw in the decision making process leading up to the launch. They felt that the rising doubts about the joint seal should have been flagged and brought to management attention. A specific place where this should have occurred was in the Flight Readiness Review meetings where contractors meet along with NASA project offices, the Program Manager, and Headquarters to consider the upcoming launch.

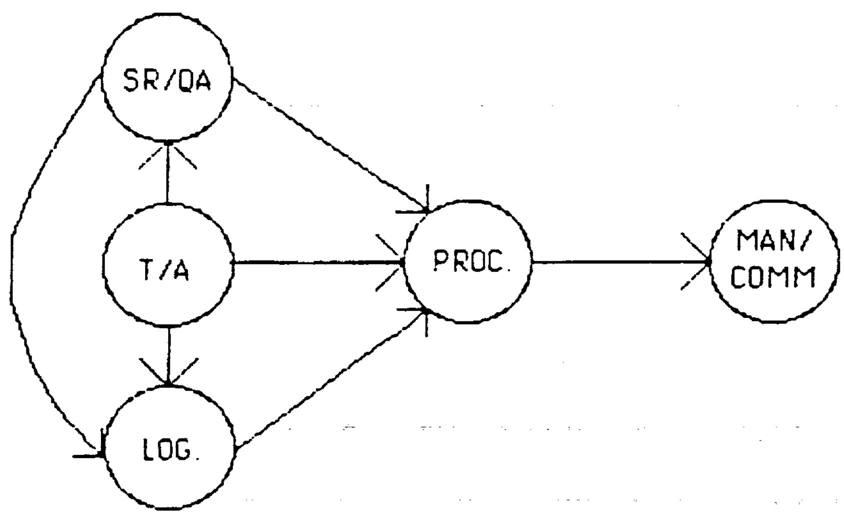
Because of increased erosion in the seals in the Solid Rocket Motor joints, the project office at Marshall imposed a launch constraint against launches after July of 1985. However this constraint was subsequently waived for each launch and the constraint was never communicated upward to the Program Management or to Headquarters. All of these are examples of communication problems in the system.

10.0 CONCLUSIONS

Among the root problems identified by the Commission, there is a close relationship and similarity between these problems and the focus and functions of the industrial engineer. Many of the problems are related to the transition of a program and its related product from an R/D environment to an operational one. As the flight rate increased and pressure developed, the system was having a difficult time changing from the comfortable environment which it knew and understood, that of research, design, testing, and development to the relatively new world of operations with which it had little experience. In fact, most of the problems outlined in the Report are operational in nature.

It would be difficult to say that the involvement of IE's in the above situations could have changed the course of events. However, one cannot deny the emphasis in industrial engineering education on concepts related to these problems. Processing, safety, work control, statistical modeling and analysis, operations analysis, management, quality control, and forecasting, to name a few are all IE subjects.

To pick a specific example, the emphasis in both the training and practice of the profession on statistical skills



SYSTEM RELATIONS BETWEEN PROBLEMS

will increase the awareness to develop and analyze trends. The normal undergraduate curriculum has two courses in statistics not to mention the application of these statistical concepts and skills in most of the other upper division courses. Conversely, it is common to find no statistics course requirements in some other engineering disciplines. A lack of statistical concepts could be detrimental to an engineer who has to practice in an ever changing and stochastic environment. It would be only fair to point out that the statistical modeling and analysis skills of a typical IE would go beyond the simple trending of data, and lead to the ability to perform an in-depth analysis of the relevant factors involved.

Of course, the various problems identified by the Commission as contributing causes of the 51-L accident are interrelated. One can see that almost all of the problems are common to the practice of industrial engineering, indicating a strong need for an increase of IE awareness in the NASA organization.

11.0 REFERENCES

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APPENDIX VI D

CHALLENGER REPORT CROSS-REFERENCE MATRIX

I. PROGRAM MANAGEMENT

Sub-category	Concept	Lessons Learned	NRC Report	Comm. On Sci/Tech	Rogers' Report
Pressures on the System	Pressure to push unrealistic flight rate jeopardizes promotion of "safety first" attitude.			II-1, III-15, 16	Y
	The Committee, the Congress and the Administration have played a contributing role in creating the pressure of flight rate.			II-1, III-15	Y
	Pressure to go operational from R&D to increase productivity caused realignment of priorities.			II-1	Y
Causes of Failure	Safety, reliability and quality assurance programs within NASA were grossly inadequate.			II-2, III-3	Y
	Fundamental problem was poor technical communication over a period of several years by top NASA and contractor personnel.			II-2, III-2, 24	
	Failure in communication between NASA and contractors during launch preparation.	17		III-3	Y
	NASA management waived its own launch commit criteria without a valid technical reason.	27		III-3	Y
	Deficiencies of SRM testing and certification persisted despite many reviews.			III-5	Y
Short-Comings of the System	The possibility of deficiencies in testing and certification of other hardware components.			III-6, 13	Y
	NASA regularly violates its own certification requirements.			III-6	Y
	Reduction in personnel has effected SR&QA.			III-25	Y
Some Concerns of the Future	Concerns about the ability of NASA to detect similar breakdowns in future.			II-4	
	Concerns about adequacy of scientific and technical expertise, and salary incentives at NASA			II-4, III-21	Y

I. PROGRAM MANAGEMENT

Sub-category	Concept	Lessons Learned	NRC Report	Comm. On Sci/Tech	Rogers' Report
Things NASA Must Do.	NASA's shuttle management structure, safety organization, communication procedures, and maintenance policies should be scrutinized and improved.	7, 14	29	II-2	Y
	Special attention to cost and risk of transferring heavy shuttle payloads to expandable vehicles.			III-9	Y
	New associate administrator for SR&QA must assure that any pressure to increase flight rate do not effect mission preparedness.			III-16	
	Develop descriptive concept of overall risk management.			III-18, 25	
	Exercise extreme caution in waiving launch constraint.			III-19, 20	Y
	Make reasonable efforts to record meetings where key technical decisions are made.			III-20	Y
	Require principal contractor to make a clear, unambiguous statement concerning launch readiness just prior to launch.			III-21	Y
	Review the number of key technical and management positions.			III-21	
	Reconsider its efforts to categorize shuttle as operational.	14	33	III-22	Y
	Review its control process to differentiate major and minor changes.			III-22	
	Restructure shuttle program management.			III-23	Y
	The Flight Readiness Review process should be reviewed and structured to ensure that it is assuring readiness of flight	14			Y

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I. PROGRAM MANAGEMENT					
Sub-category	Concept	Lessons Learned	NRC Report	Comm. On Sci/Tech	Rogers' Report
	Rigid manifesting criteria need to be established and enforced	38			Y
	Whenever an operation involves other elements of Government, Public Affairs from that organization should be involved as a resource for the NASA Public Affairs Office	50			
Photo / TV Support	Establish a contingency plan for imagery	53			
	Establish contingency photo teams which are parallel to those of the teams currently in Center Contingency Plans	54			
	KSC should have its' own photo facilities	56			
	Review the role of the SPC in closeout photos	59			
Difference with Rogers Commission	The committee disagrees with Rogers Commission that NASA's decision making process was flawed.			II-2	N
	Committee finds no evidence that astronauts are denied opportunity to enter management, if they so desire.			II-3, III-21, 23	N

II. PROCESSING OF SPACE SHUTTLE

Sub-category	Concept	Lessons Learned	NRC Report	Comm. On Sci/Tech	Rogers' Report
Causes of Failure	Neither NASA, nor Thiokol fully understood the operation of aft field joint.			II-2	Y
	The joint certification program were inadequate, and neither NASA nor Thiokol responded adequately to available warning signs about defective joint.			II-2	Y
	Shuttle Processing Contractor performance plagued by excessive overtime, persistent failure to follow work procedure, and inadequate logistical support from NASA.	20		III-14	Y
	No evidence of problem during stacking procedure.			III-2	Y
	Lack of statistical data to perform risk analysis.			III-18	
Things NASA Must Do.	Review its certification testing to ensure all critical items are adequately tested.	4		III-19	Y
	Establish rigorous procedures for identifying and documenting launch constraints.			III-19	Y
	NASA should require manufacture of critical items to be designated "critical" processes.			III-11	
	Consider reinstating full X-ray inspection of the propellent.			III-11	
	Methods should be developed which assure more direct design contractor involvement in the processing and testing effort at the launch sites.	10			Y
	Spare parts must be available; cannibalization must be stopped	13	5, 8, 29	III-15	Y
	A personnel training program should be conducted, with an emphasis on the importance of using the Work Control documentation properly.	18			Y
	The two launch pads should operate as similarly as possibly	19			

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II. PROCESSING OF SPACE SHUTTLE

Sub-category	Concept	Lessons Learned	NRC Report	Comm. On Sci/Tech	Rogers' Report
	In critical systems, an aggressive supporting ground test program should be a firm requirement and should be maintained	26			
	The Critical Items List should be identified in all work papers so that the work force and quality personnel know when they are working with such an item.	27			
	A method of verifying SRM segment roundness at the MTI plant should be developed.	28			
	Consideration for a back-up system should be undertaken to preclude the inability to monitor fire and gas hazards.	29			
	Perform a NASA review of all operational instrumentation on the STS vehicle for adequacy.	30			
	A review of performance against the design requirements and implementation considering flight experience along with new technology and test methods should be instigated on a periodic basis.	33			
	A joint review of measurements and computer models shall be conducted with a goal of producing high fidelity preflight and postflight reconstructions.	34			
	A computer program that provides current information on environmental certification of each element and subsystem should be developed.	35			
	The Ops and Maintenance Plan (OMP) should verify that positive feedback to Level II management is implemented.	39			
	Provide uninterruptible communications to essential positions	46			
	Review all KSC, ESMC, DDMS, Navy, and Coast Guard documents relating to salvage operations.	48			

II. PROCESSING OF SPACE SHUTTLE

Sub-category	Concept	Lessons Learned	NRC Report	Comm. On Sci/Tech	Rogers' Report
	Outfit rescue vehicles to be able to enter areas where debris may be falling.	49			
	Launch visibility for photographic purposes should be a primary mission rule until the hardware fixes are proved operational.	57			
	More simulators and training craft needed		29		
Safety	NASA should establish and maintain effective SR&QA program.		29	III-25, 26, 27	Y
	Instruments should not be placed in service until their operation and function are thoroughly understood, and personnel have been trained in their use.	16			
	A joint NASA/DOD review of the Range Safety System should be conducted prior to the next Space Shuttle launch.	42			Y
	The NSTS program shall operate with at least two landing sites for end-of-mission.	43			Y
	Review in-place emergency preparedness plans to determine needed updates for probable industrial accidents	47			
Process Capacity	3 Orbiters can fly 8-10 flights / year		29		
	4 Orbiters can fly 11-13 flights / year		29		

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III. DESIGNING OF THE PRODUCT

Sub-category	Concept	Lessons Learned	NRC Report	Comm. On Sci/Tech	Rogers' Report
Causes of Failure	The failure in the Field Joint of the right-hand Solid Rocket Motor caused the Challenger accident.			II-2	Y
	The failure was because of the faulty design.			II-2, II-1	Y
	Insufficient testing to permit understanding by Thiokol and NASA about functioning of SRM joint.			III-5	Y
Short-Comings of Design	Concerns about relative safety of Space Shuttle main engine.			II-3, III-6, 9	Y
	Concern about inadequate landing gear and landing.	40		II-3, III-7, 16, 17	Y
	SRM motor not adequately certified to meet natural and induced environmental conditions.			III-5	
Things NASA Must Do.	A thorough review on all criticality 1 and 1R items and hazard analysis.	7, 17		II-2, III-11, 19	Y
	A study to provide Space Shuttle crews with means of escape during controlled gliding flight.			II-2, III-18	Y
	More accurate performance specification for SRM.	6		III-1	Y
	Redesign of Solid Rocket Motor field joint.			III-1	Y
	NASA and its contractors thoroughly reassess the adequacy of all testing and certification on each element of Space Shuttle hardware.	24		III-6	Y
	NASA continues developmental program for main engines to increase operating margins.			III-7	Y
	Reassess NASA's policy of its "2X" rule for main engine flight hardware.	8		III-7	Y
	Accelerate program to design landing gear.			III-8	Y
	Ensure that serious in-flight anomalous behavior is understood and corrected.			III-8	Y
	NASA review its O-ring mfg./inspect/repair policy.	5, 31		III-12	Y

III. DESIGNING OF THE PRODUCT

Sub-category	Concept	Lessons Learned	NRC Report	Comm. On Sci/Tech	Rogers' Report
	NASA and contractor resolve through analyses and testing, the cause of SRM case size growth and roundness on booster and shuttle performance.	28, 32		III-12	Y
	Operational procedural documentation should be complete and should checked for consistency with engineering and test data.	4, 9			Y
	All reusable hardware should be assessed for fitness of refurbishment and reuse.	32			Y
	Engineering & Operations should rigidly adhere to the principle that a catastrophic failure during powered flight is unacceptable.	41			Y
Safety	Emphasis on safety before flying again.			III-13	Y
	The ability to assess the effects of adverse environmental conditions on pad systems must be improved, and appropriate launch constraints imposed.	21			Y

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APPENDIX VI E

MAJOR PROBLEMS RESULTING FROM A REVIEW OF THE ROGERS COMMISSION REPORT PRELIMINARY DISCUSSION

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1. OPERATIONAL CONTROL IS HELD TOO CLOSELY TO THE TOP.

The control of the day-to-day running of the organization is held too closely at the top of the management structure. As long as the manager of the program is deeply immersed in the day-to-day affairs of the program, then there is insufficient time for the development of plans. Somehow the manager needs to find the time to get out in front of the organization. In order to do this it is essential that the every day running of the organization be delegated to a deputy manager. The manager's time should be spent dealing primarily across and up the organizational structure and only rarely down. I know of no other industry where the manager spends anywhere near an equivalent amount of time with daily operations as that spent by the manager of NSTS.

2. THERE IS A LACK OF DISCIPLINE IN THE SYSTEM.

The commission report, time and again, pointed out instances of less than satisfactory paperwork in work control documents, certification documents, and safety documents. The facts that these errors would occur and be allowed to go uncorrected is indicative of a lack of discipline in the system. This item will be further addressed in the SRQA section.

3. NASA'S CONCEPT OF OPERATIONS CAUSED AND WILL CONTINUE TO CAUSE SEVERE PROBLEMS.

NASA has very limited experience with open ended programs. The more extensive programs prior to the shuttle all had a limited horizon and had been closed ended. A specific number of flights was to be flown and the program closed out thereafter. In addition, very little, if any, of the hardware was to be reused. The Shuttle program, on the other hand, is relatively open ended and uses reuseable hardware. Another difference is that the Shuttle is basically a transportation system.

The engineers at NASA are relatively old and relatively inexperienced in a true operational environment. In addition at this point in time it does not seem if the organization is willing to change its outlook and learn operational skills.

Once the program was considered to be operational the SR/QA function was assigned a diminished importance. This concept is described by Rogers as if SR/QA was important as long as the program was felt to developmental but an operational program did not require the same amount of safety structure or rigor within that structure.

NASA has a large amount of experience in project management but almost none in process management. In a truely operational era the mind set will have to be changed to one of managing processes as opposed to thinking of the work on a flight by flight basis. NASA would look at its history but only consider how it applied to the next flight as opposed to the process of flying as a whole. This leads to a short term view point and works against developing an overview of the work.

There is little if any crosstraining between the design and the operations function. In addition there seems to be no real awareness of the importance of this crosstraining or any movement to initiate any such training.

4. THE SR/QA FUNCTION IS NOT EFFECTIVE.

The fact that numerous errors in the paper work were allowed to go uncorrected is an important indicator of the lack of effectiveness of the SR/QA function. The absence of trend analysis and flying with unresolved anomalies also lends strength to this conclusion. Having the SR/QA offices report to the operations management is an error of large magnitude and generates significant pressure to reduce the effectiveness of the SR/QA function.

5. THE LOGISTICS FUNCTION IS WELL BEHIND.

A well accepted principle in operations management is that cannibalization is almost always a mistake since it causes lost work and increases turnaround time. The inability of top level management to get out in front of the program was probably the reason why logistics got so far behind. In addition inadequate funding had a part in this problem.

6. THERE WERE AND MAY CONTINUE TO BE SEVERE COMMUNICATION PROBLEMS.

These problems include the joint problem, the flight decision process and extend deeper into the system. The management isolation at Marshall is an example of the magnitude of this problem.

7. THE MODERN MANAGERIAL ANALYTICAL SKILLS SEEM TO BE ABSENT OR IN LITTLE USE. THIS CONCEPT PARTICULARLY EXTENDS TO TRADITIONAL INDUSTRIAL ENGINEERING CONCEPTS.

No trends analysis, distrust of statistics, little if any knowledge of process management are a few of the examples leading to this conclusion.

8. THE LINES OF AUTHORITY AND OF RESPONSIBILITY ARE DIFFERENT.

The budget of the program manager goes through the center director. The elements that support the program at different centers have their budgets go through different centers. This helps to enforce isolation and can lead to confused lines of responsibility.

9. THE SHUTTLE PROGRAM IS DIFFERENT FROM ANY OTHER PROGRAM

THAT NASA HAS DONE. THE ATTEMPT TO RETREAT TO METHODS WHICH WERE SUCCESSFUL WITH PREVIOUS PROGRAMS MAY LEAD TO DIFFICULTIES.

The shuttle program is different as has been mentioned previously. The natural tendency will be to retreat to methods which were successful in the past. However the workforce is different and the problem is different. Great care should be used before older methods are employed particularly if they are not adapted to the current environment and problem.

RECOMMENDATIONS:

1. A DEPUTY MANAGER OF NSTS SHOULD BE ASSIGNED THE EVERY DAY RESPONSIBILITY OF RUNNING THE PROGRAM.

2. SR/QA SHOULD BE ORGANIZED AS AN INDEPENDENT GROUP WHICH REPORTS ONLY TO MANAGEMENT AT THE VERY TOP, PERHAPS TO A DEPUTY MANAGER OF NSTS. THIS GROUP SHOULD HAVE SUFFICIENT AUTHORITY, RESPONSIBILITY AND SUPPORT TO INSURE SAFETY. THIS RESPONSIBILITY SHOULD INCLUDE TRENDS ANALYSIS AND REPORTING.

3. TRAINING IN OPERATIONAL CONCEPTS SHOULD BE BEGUN IMMEDIATELY.

4. CROSS TRAINING, CENTER TO CENTER, AND OPERATIONS TO DESIGN SHOULD BE BEGUN IMMEDIATELY.

5. A PROGRAM TO INFUSE NEW BLOOD WITH INDUSTRIAL ENGINEERING SKILLS INTO THE ORGANIZATION SHOULD BE BEGUN IMMEDIATELY. IN ADDITION, AN OFFICE OF INDUSTRIAL ENGINEERING SHOULD BE ESTABLISHED AND REPORT DIRECTLY TO THE MANAGER OF THE PROGRAM. THIS GROUP COULD THEN BE USED TO ADDRESS ISSUES AND PROBLEMS AS THEY ARISE.

6. NSTS SHOULD BE PULLED OUT OF THE CENTER ORGANIZATIONAL STRUCTURE WITH THE MANAGER OF NSTS GIVEN BUDGETARY CONTROL OF ALL ORGANIZATIONAL ELEMENTS. A STRUCTURE TO CONSIDER HERE IS SUGGESTED BY THE WAY UNITS OF THE ARMED FORCES ARE HOUSED ON BASES BUT ARE INDEPENDENT OF THE BASE COMMANDER.

7. TRAINING IN MODERN MANAGERIAL COMMUNICATIONS SKILLS AS WELL AS IN EMPLOYEE INVOLVEMENT NEED TO BE STARTED FOR TOP LEVEL MANAGEMENT. THE TENDENCY FOR MANAGEMENT ISOLATION AS WELL AS CLOSET DECISION MAKING WITH LITTLE EMPLOYEE INVOLVEMENT MUST BE CHANGED.

8. THE U OF H TEAM, IN PARTICULAR, DR. HUNSUCKER, NEEDS TO BE TIED CLOSER TO THE PROGRAM OFFICE AND HAVE ITS EXPOSURE INCREASED. NO NEW EXPERIENCE, NO NEW INSIGHT.

9. NSTS NEEDS TO HAVE A DEPUTY MANAGER IN CHARGE OF

PLANNING.

10. A TASK FORCE NEEDS TO BE ASSIGNED THE DUTY OF EVALUATING THESE RECOMMENDATIONS, AS WELL AS EQUIVALENT RECOMMENDATIONS FROM OTHER SOURCES, AT A VERY HIGH LEVEL. DR. HUNSUCKER NEEDS TO APPEAR BEFORE THIS GROUP AND GIVEN THE OPPORTUNITY TO OFFER SUPPORTING EVIDENCE FOR EACH OF THESE RECOMMENDATIONS. EVALUATIONS FROM OTHER SOURCES INDEPENDENT OF NASA SHOULD ALSO BE SOUGHT.

APPENDIX VI F

POSSIBLE LIST OF QUESTIONS AND ISSUES WHICH MAY BE POSED BY THE NRC COMMITTEE ON CRITICALITY REVIEW AND HAZARD ANALYSIS

CRITICALITY REVIEW AND HAZARD ANALYSIS

1. How is what NASA is currently doing different from what it did originally? If there is no substantial difference will not NASA go down the same path as before? Will new issues really be found from this process?

2. How does what NASA is doing in this area compare with state of the art techniques? Is there any correlation between the NASA work and the work done in other critical industries such as nuclear power?

3. How does the work of the contractors factor back into or interface with the NASA management decision structure?

4. How is the work of original contractors integrated into the current process, particularly if these contractors are no longer involved?

5. What management path is used to bring test results or flight experience back into the FMEA/CIL process? Is this path adequate to surface essential concerns?

6. How is data that shows an increasing degree of failure surfaced to managerial attention?

7. Why does NASA not use some of the quantitative statistical techniques for failure mode analysis? As a specific example how is trending data dealt with, quantitatively, and how is it surfaced to managerial attention.

8. How do items get either on or off the FMEA/CIL list? Are the rules for this procedure the same now as previously? How are these rules changed?

9. Is special attention paid to the items on the FMEA/CIL list as regards flight history? What office has the responsibility to check the flight history of these items and to do whatever trend analysis that is needed? If abnormalities occur, how is this information surfaced?

10. How are items waived and why? Will the FMEA/CIL list grow longer? Will the number of items waived grow longer? Why?

11. Who assesses the inter-relationship of items on the FMEA/CIL list? How is this inter-relationship assessed?

12. How does FEMA/CIL and HA differ? How are they integrated and coordinated?

13. It may well be true that a minor item might fail causing another minor item to fail which causes another minor item to fail and so on. None of these items might be on the list. However, the combination of them all might cause a significant failure. Has any analysis of this type reflecting the inter-relationship of systems been done? If so, by who and how?

14. What is a FMEA and what is a CIL? How can you do a CIL before a FMEA?

15. As a result of the reviews, how do the current Crit 1 lists stand? What is the change, both numerically and percent wise, on the various subsystems? Why have the lists changed this way?

16. How is human error being dealt with? Of particular concern is the error which will occur in processing a complex piece of equipment. Is there some sort of FMEA/CIL or HA equivalent to deal with human error?

17. Is there a rational way to priortize concern on the CIL list?

18. Should the whole FMEA/CIL-HA system be scrapped and another more responsive system be introduced?

19. How does NASA's history in these areas compare with industry in general?

20. How is the overall FMEA/CIL HA process related to the general SR/QA structure?

21. Is the FMEA/CIL HA process uniform, center to center, and contractor to contractor?

GENERAL QUESTIONS ON SAFETY WHICH MAY SURFACE.

1. Who do the SR/QA people report to and what authority do they have? Is all the safety work integrated and coordinated?

2. How is the SPC rewarded? Is it based on flight rate?

3. Who is going to integrate all of the safety reviews and concerns to insure nothing gets omitted?

4. What guarantee is there that NASA is not going down the same track as before 51-L?

5. Will flight rate issues emerge to apply substantial pressure on processing?

6. Will manifest instability do the same thing?

7. How does all of this relate to the commit to launch criterion and the launch decision process?

CHAPTER VII

MANAGEMENT AND STRUCTURE

APPENDICES

CHAPTER VII. MANAGEMENT AND STRUCTURE

1.0 INTRODUCTION

This year has been a year of turmoil and change. Much, but not all of this turmoil has been due to the Challenger accident in January of 1986. Also contributing to the turmoil has been the high workload complicated by the late, downstream changes in the manifest. A lot of the non-Challenger turmoil was natural and should be expected in any organization going through a major transition period.

During this year, the management structure has been changed and most of the major players have been moved. These include the head of NASA, the AA for space flight, and the directors of Johnson, Kennedy, and Marshall. These personnel changes have, of course, rippled through the program areas that support the shuttle program.

The normal work of flying the shuttle has, to some degree, been put on hold while the agency responds to the needs of its own investigation as well as those of the Rogers' Commission, Congress, and the National Research Council. A large amount of time has been spent and will continue to be spent on both supporting these investigations and on responding to the recommendations of the investigatory bodies.

During this time the agency seems to have held up well. There has been little, if any, finger pointing or evident internal political turmoil as a result of the accident. There have, of course, been some morale problems. Some personnel have left the agency perhaps as a result of this.

The work in the rest of this chapter is influenced by the above comments. This work is divided into 3 sections: responses to the investigations, management philosophy, and the need for an operational arm.

2.0 RESPONSES TO THE INVESTIGATIONS

Chapter VI contains most of the work of this team on the analysis of the Challenger accident. However, there are some additional comments which need to be emphasized.

The Changes Must be Coordinated: There are several problems which may surface as a result of the investigations. One is that of separating the important concepts from those of less importance. Another is insuring that the important concepts receive action. Yet another is that of coordinating all of the efforts so that the right office and person receive the action items.

The Same Path Should not be Traveled: One of the messages that seems to be clear from the various investigations is that even without the accident, NASA was having difficulty in dealing with the high flight rates. This issue is also discussed in the management philosophy section. Hopefully, NASA will not travel down the same path as before, but will find new methods of managing the shuttle program.

3.0 MANAGEMENT PHILOSOPHY

Work Harder and Faster: There is a natural tendency with any management to believe, during the time of increased workloads, that by working harder and faster new, increased production can be met. This will not happen with NSTS. The research bears this out. The investigations address this issue to some degree as does Appendix VII A of this chapter. In this appendix, "Work Loading, JSC Professional Employees, Fiscal 1985", it is predicted that some of the JSC organizations would require as many as 10% or more additional employees to meet the scheduled flight rate in 1986. Working harder and faster will not be enough. Major structural changes must be made. This lends weight to the operational arm argument presented in section 4. As a specific example of why this philosophy will not work, the large amount of time that the shuttle and all of its parts and pieces spend in transportation must be reduced if the flight rate is to be substantially increased. Working harder and faster is not going to move a major piece of hardware over a long distance any quicker. The real resolution lies in changing the process structure and having this change accomplished by individuals who understand and appreciate processing problems.

Management Changes: In Appendix VII B, "Program and Fiscal responsibility", the problem of divergence of program responsibility and fiscal responsibility is discussed. This leads to Appendix VII C,"General Comments on Assessing Management Structure and Operations", and Appendix VII D, "Application of General Comments on Assessing Management Structure and Operations". In these two appendices, a general assessment strategy is discussed and its application is outlined. These two then lead to Appendix VII E, " A Proposed Reorganization of the NSTS Managerial Structure". This last appendix was written as a partial response to the Crippen committe work on the Rogers' Commission recommendation. It is the type of problem discussed in Appendix VII B that must be corrected and it is the structure outlined in the other appendices that must be used, before major operational roadblocks are overcome.

Risk and Control: In Appendix VII F, "Risk and Control" the concept is presented that NASA should go to school on the investigations and the resulting analysis of entire system. The intent of this process would be to evaluate the risk management system while the orbiter is standing down. The question to be addressed is whether the risk management system would have identified problems found during the stand down in a timely manner if the system was still flying. If the answer is no then the risk management system is inadequate to meet the needs of the system and must be changed.

4.0 THE NEED FOR AN OPERATIONAL ARM

In Appendix VII G, "An Operational Arm for the Space Shuttle", an argument is presented in 3 parts for the establishment of a NASA operational arm. The first part of this appendix lists complicating factors effecting the choice of a management structure for the shuttle. The second part lists criteria for the evaluation of different options and uses this criteria in the analysis of the major options. The conclusion of this part is that there are only two viable alternatives: business as usual and an operational arm. Of these two, the analysis prefers the operational arm. The last part of the appendix lends weight to the argument of separating R/D from operations. This appendix is the major theoretical thrust of the efforts of the research team for this year and should be read in detail.

APPENDIX VII A

WORK LOADING JSC PROFESSIONAL EMPLOYEES

FISCAL '85

1.0 INTRODUCTION

This report is an attempt to determine the level of effort of the professional work force at JSC. In this sense, the real question is to determine how close to capacity this work force has been performing during the year. As the flight rate increases, a reasonable assumption is that the work load will increase, i.e., the work force will become more loaded. With professional employees, work load is very difficult to determine.

There is a certain amount of elasticity in the work of professional employees. Their work is not necessarily uniform with time. A typical employee should experience surges of effort and also periods of relatively quieter times. If the work load increases to a point where it can not be contained in the usual work week, then various methods such as overtime, compensation time, and volunteer time are used to finish the required work. Even a small amount of extra work may have negative effects on work produced. Extra work induces stress in employees by requiring them to spend unplanned time at the work place and by reducing the amount of time available for family and recreational activities, among other factors. Work which is highly technical in nature would seem to have a greater probability of suffering from this induced stress.

2.0 METHOD

In this report the following organizations were studied over the pay periods of fiscal 85 (with the exception of the third pay period):

CA	FLIGHT CREW OPERATIONS
D	MISSION OPERATIONS
E	ENGINEERING
F	MISSION SUPPORT
L	NSTS PROGRAM OFFICE
M	SPACE SHUTTLE PROJECTS OFFICE
S	SPACE AND LIFE SCIENCES.

The variable, extra work, was defined each pay period as the comptime earned less the comptime used plus the overtime.

EW=COMP EARN - COMP USED + OVERTIME.

The following are all problems with the EW variable:

- Different organizations handle comp time, overtime, and volunteer time differently.

- In some organizations, comp time converts to overtime while in others it is used or lost.
- Professional employees are, as a rule, unconcerned with regularly reporting extra work. Therefore the EW variable will be biased in the conservative direction.

Even with the problems mentioned above, the trending of the extra work variable should give some indication of the load on the work force as the flight rate increases.

The common unit throughout this paper is EP's. The final two variables of interest are:

- CAE=cumulative average EW in EP's
- %EP=CAE as a % of cumulative average number of employees.

CAE for any given pay period shows the number of additional employees which are required to compensate for the extra work from pay period 1 to the period under consideration. In other words, had there been CAE(j) additional employees present from per 1 to per j then the cumulative extra work at period j would be 0.

%EP shows CAE as a % of the work force for comparative purposes.

3.0 RESULTS

TABLE 1

ORG	CA		D		E		F	
PER	CAE	%EP	CAE	%EP	CAE	%EP	CAE	%EP
1-flt	9.29	7.43%	28.29	8.76%	14.00	2.22%	8.66	1.98%
2	8.73	6.99%	16.07	4.97%	7.50	1.19%	8.01	1.83%
3-flt	****	*****	*****	*****	****	****	***	***
4	6.18	4.92%	12.96	4.02%	4.75	0.75%	5.30	1.21%
5	5.89	4.68%	9.95	3.09%	4.57	0.73%	6.90	1.57%
6	5.33	4.27%	7.99	2.50%	3.58	0.57%	6.16	1.42%
7	4.24	3.41%	5.69	1.79%	2.30	0.37%	3.76	0.88%
8	4.43	3.58%	5.85	1.85%	2.50	0.40%	5.15	1.21%
9-flt	5.24	4.24%	7.08	2.19%	3.15	0.51%	6.08	1.46%
10	5.61	4.55%	6.90	2.07%	3.01	0.49%	6.87	1.70%
11	5.72	4.65%	6.81	2.00%	2.89	0.47%	6.90	1.74%
12	5.59	4.55%	6.16	1.77%	2.91	0.47%	6.37	1.65%
13	5.40	4.39%	6.01	1.70%	3.00	0.49%	6.33	1.66%
14-flt	5.40	4.39%	6.60	1.85%	3.21	0.52%	6.15	1.64%
15	5.62	4.57%	7.55	2.09%	3.73	0.61%	6.28	1.70%
16-flt	5.92	4.82%	9.07	2.49%	4.23	0.69%	6.54	1.78%
17	5.96	4.85%	9.30	2.53%	4.28	0.70%	6.69	1.84%
18	6.05	4.91%	9.17	2.48%	4.62	0.76%	6.45	1.79%
19-flt	6.36	5.16%	9.85	2.64%	4.96	0.81%	6.34	1.77%
20	6.54	5.30%	9.41	2.51%	4.71	0.77%	5.71	1.61%
21	6.67	5.40%	9.28	2.46%	4.81	0.79%	5.70	1.61%

22-flt	6.93	5.59%	9.82	2.59%	4.85	0.79%	5.65	1.61%
23	6.98	5.62%	9.74	2.56%	4.83	0.79%	5.55	1.59%
24-flt	7.06	5.67%	10.47	2.74%	5.10	0.83%	5.33	1.53%
25	7.19	5.75%	10.49	2.73%	5.23	0.85%	5.39	1.55%
26	7.27	5.81%	10.27	2.67%	5.12	0.83%	5.49	1.59%

The amount of loading for organizations L, M, and S was considered to be insignificant in comparison to that of the ones listed in the table above.

In figures 2-7, the extra work variable is plotted as a function of the pay period. In Figure 1, a composite chart of CA, D, E, and F is presented.

4.0 INTERPRETATION

The figure of interest in the above table is the last figure in each column:

TABLE 2

CA		D		E		F	
CAE	%EP	CAE	%EP	CAE	%EP	CAE	%EP
7.27	5.81%	10.27	2.67%	5.12	0.83%	5.49	1.59%

In organization CA, for example, 7.27 EP's were require for the entire fiscal year in order to have the extra work for that year to total to 0.

While the magnitude of the numbers presented may be considered by some to be of little if any consequence, the trending of the data is disturbing. In figures 2-4, for instance, there is a definite trend upwards of the data. In Figure 1, the composite chart, the flights are marked on the pay period scale. The organizations show an increase in load immediately prior to a flight and then a slighter decrease after a flight. Specifically, CA, D, and E do not seem to be able to recover back to their pre-flight loading.

In fiscal 85, 8 flights were flown. In November of 85, 15 flights were planned for 85. A conservative assumption is that the extra work variable is linear with the flight rate. An assumption which is perhaps more accurate but one which is not used here is that extra work is exponential with flight rate. The linear flight rate assumption changes the figures in Table 2 to:

TABLE 3

PREDICTED LOADING FOR '86

CA		D		E		F	
CAE	%EP	CAE	%EP	CAE	%EP	CAE	%EP
13.63	10.89%	19.26	5.01%	9.6	1.56%	10.29	2.98%

5.0 CONCLUSIONS

The above figures in Table 3 are disturbing. They are even more disturbing when their conservative nature is considered. Perhaps their major use is as part of the argument which supports two conclusions:

- o The flight rate will not be significantly increased simply by working harder and faster in the same manner as in the past. Significant changes in the way work is done are necessary.
- o In order to increase the flight rate significantly, everything in reason must become standardized. Regular and timely performance requires routine work. Routine work requires standard work.

FIGURE 1

CUMM AVG EXTRA WK FISCAL 85

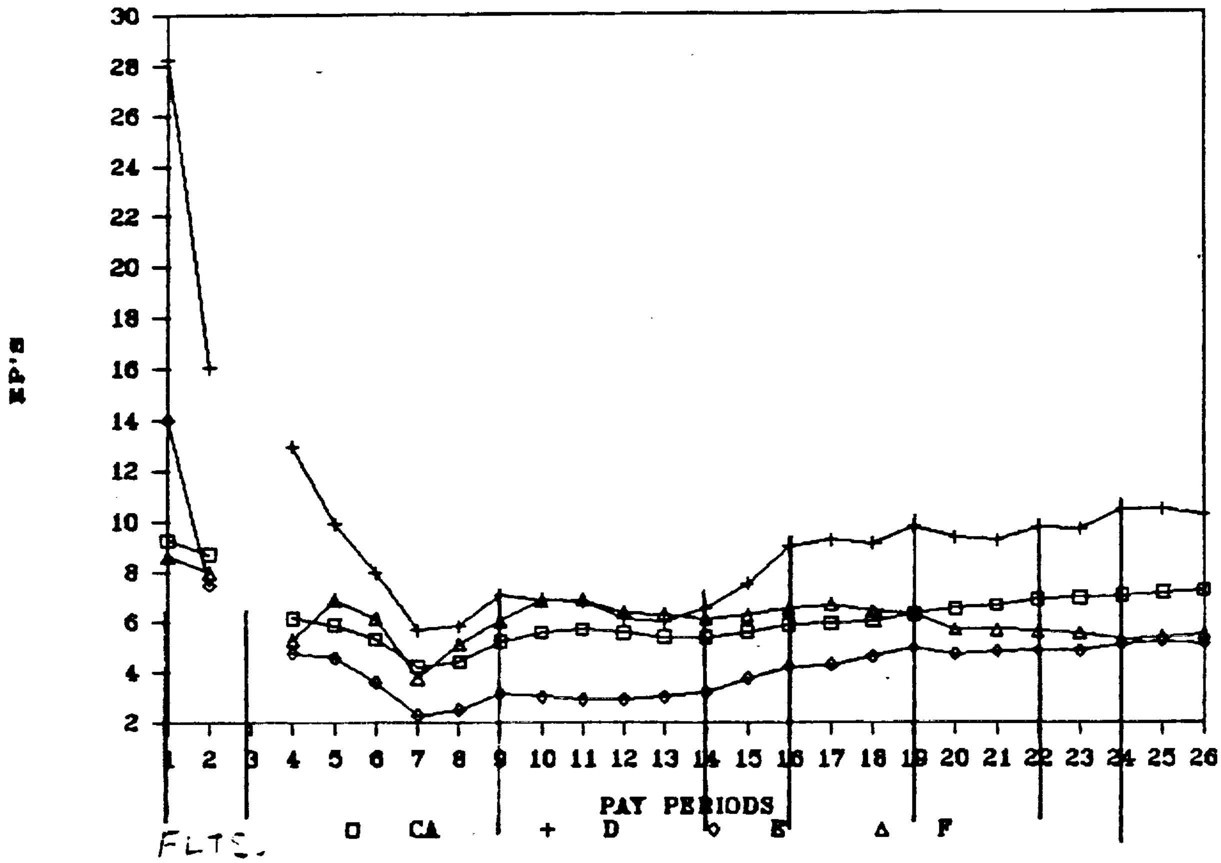


FIGURE 2

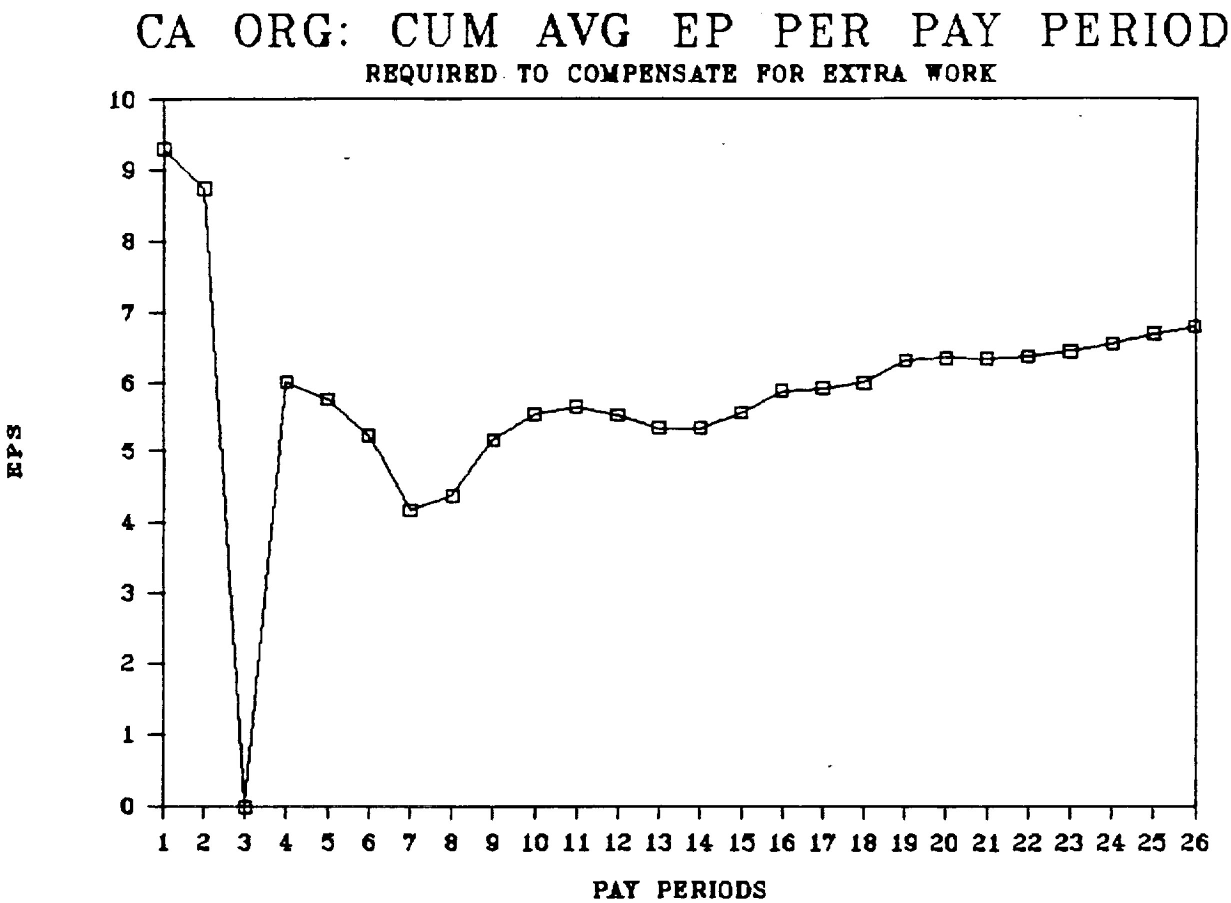

CA ORG: CUM AVG EP PER PAY PERIOD
REQUIRED TO COMPENSATE FOR EXTRA WORK
EPS
0
1
2
3
4
5
6
7
8
9
10
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26
PAY PERIODS

FIGURE 3

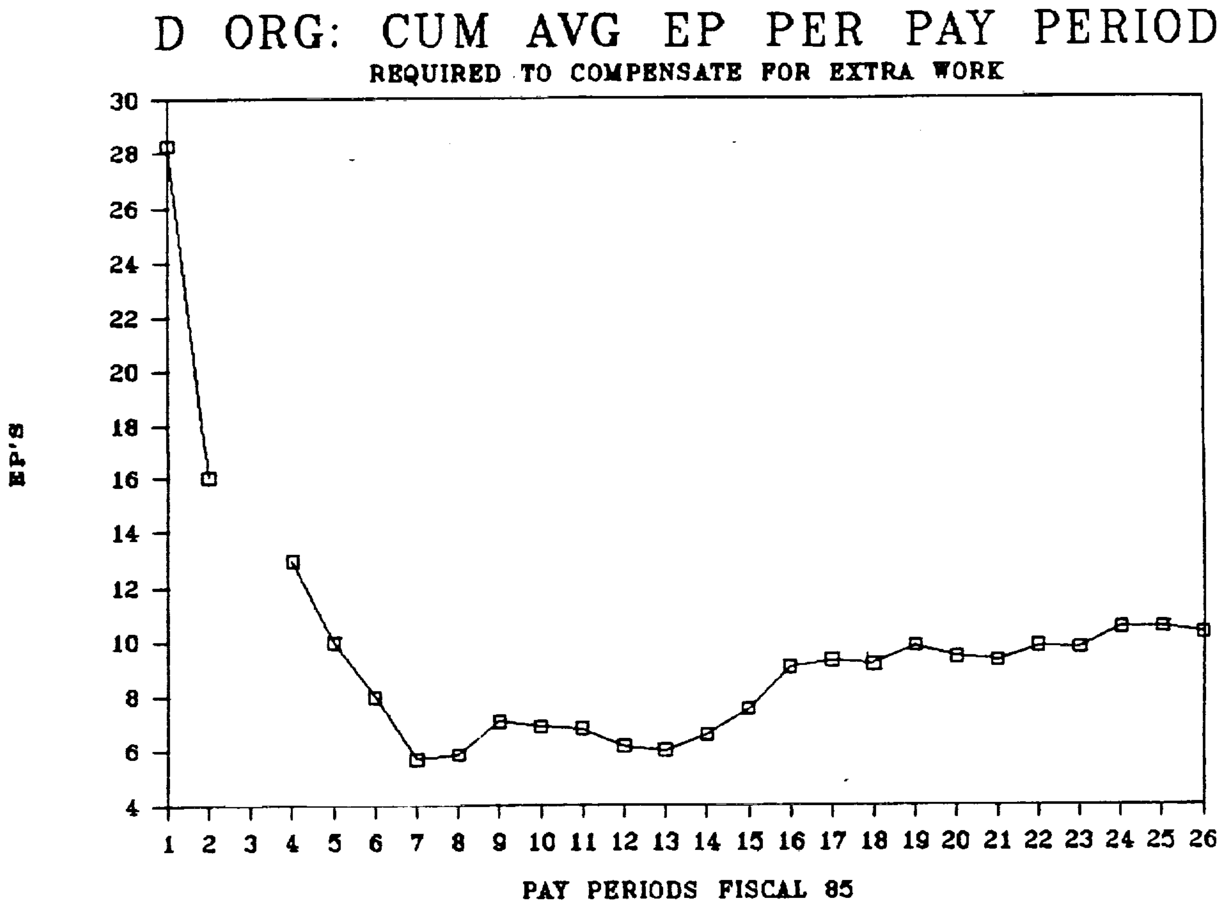

D ORG: CUM AVG EP PER PAY PERIOD
REQUIRED TO COMPENSATE FOR EXTRA WORK
EP'S
30
28
26
24
22
20
18
16
14
12
10
8
6
4
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26
PAY PERIODS FISCAL 85

FIGURE 4

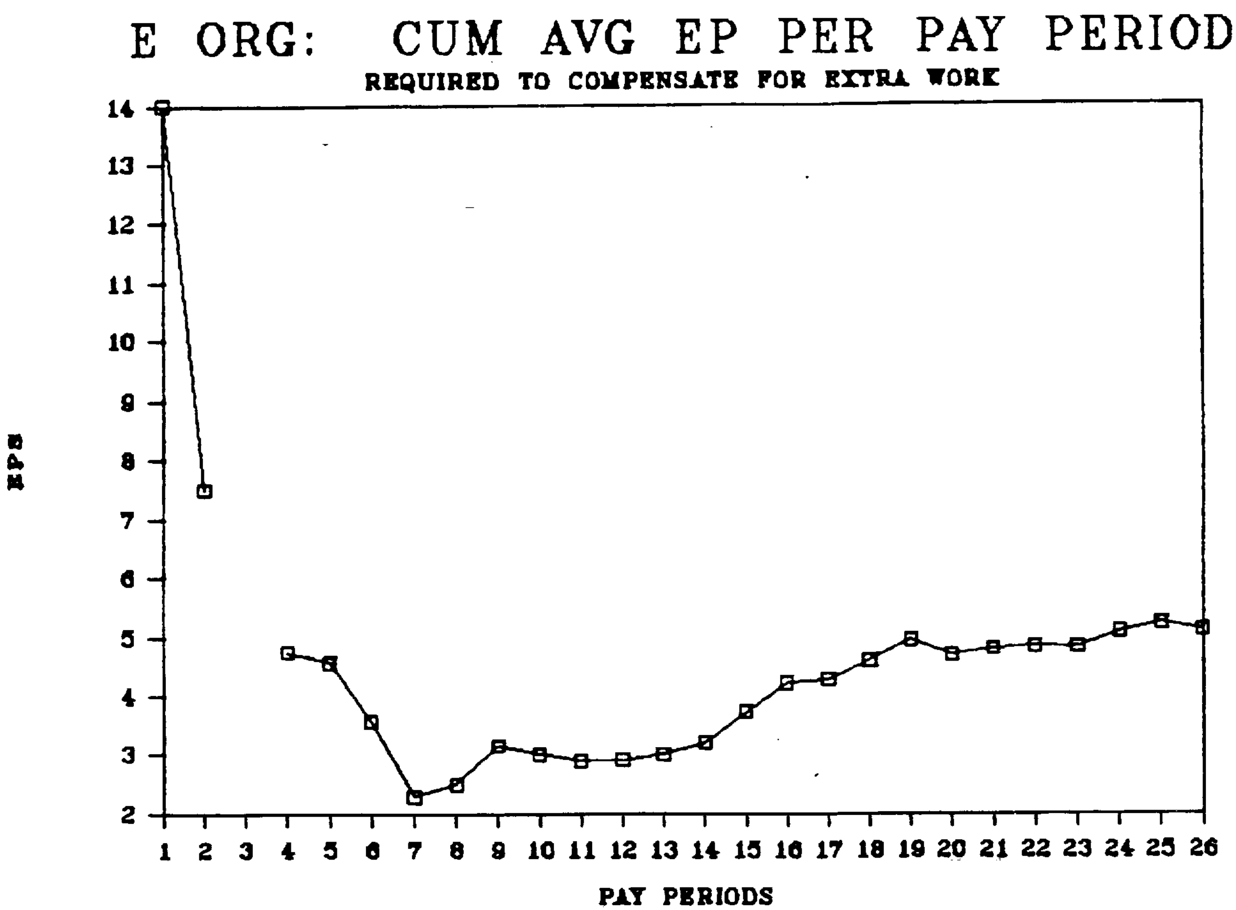

E ORG: CUM AVG EP PER PAY PERIOD
REQUIRED TO COMPENSATE FOR EXTRA WORK
EPS
14
13
12
11
10
9
8
7
6
5
4
3
2
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26
PAY PERIODS

FIGURE 5

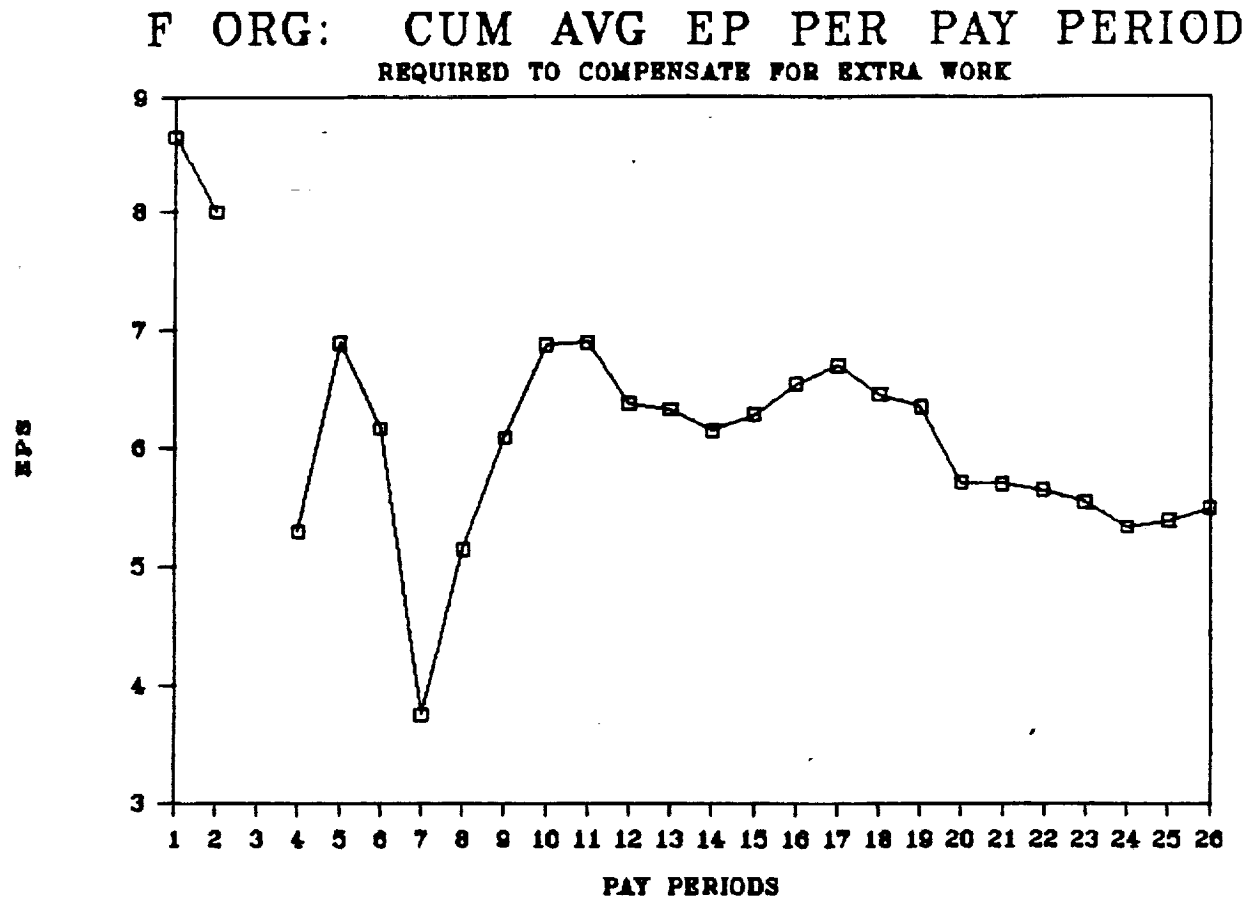
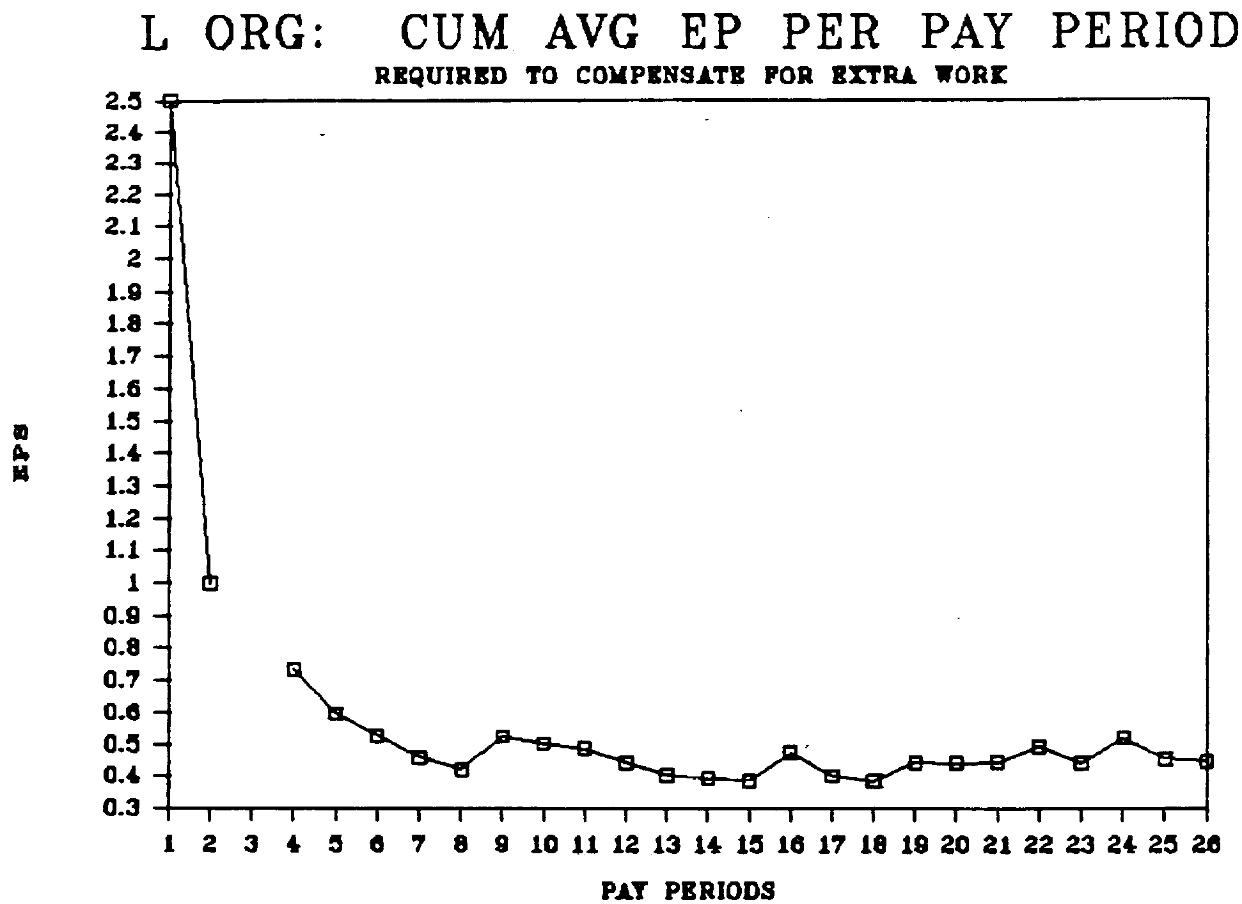

F ORG: CUM AVG EP PER PAY PERIOD
REQUIRED TO COMPENSATE FOR EXTRA WORK
EPS
9
8
7
6
5
4
3
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26
PAY PERIODS

FIGURE 6


L ORG: CUM AVG EP PER PAY PERIOD
REQUIRED TO COMPENSATE FOR EXTRA WORK
EPS
2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26
PAY PERIODS

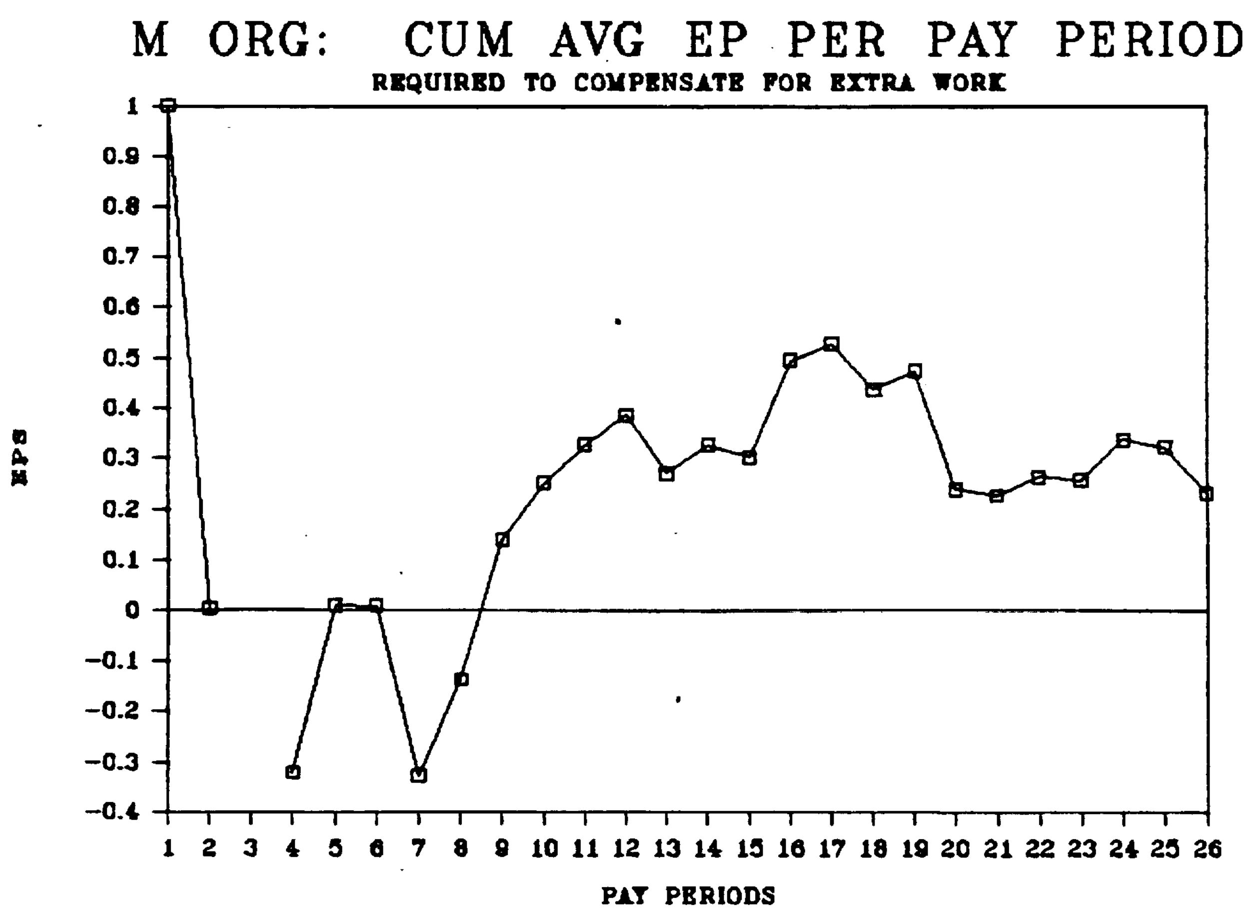
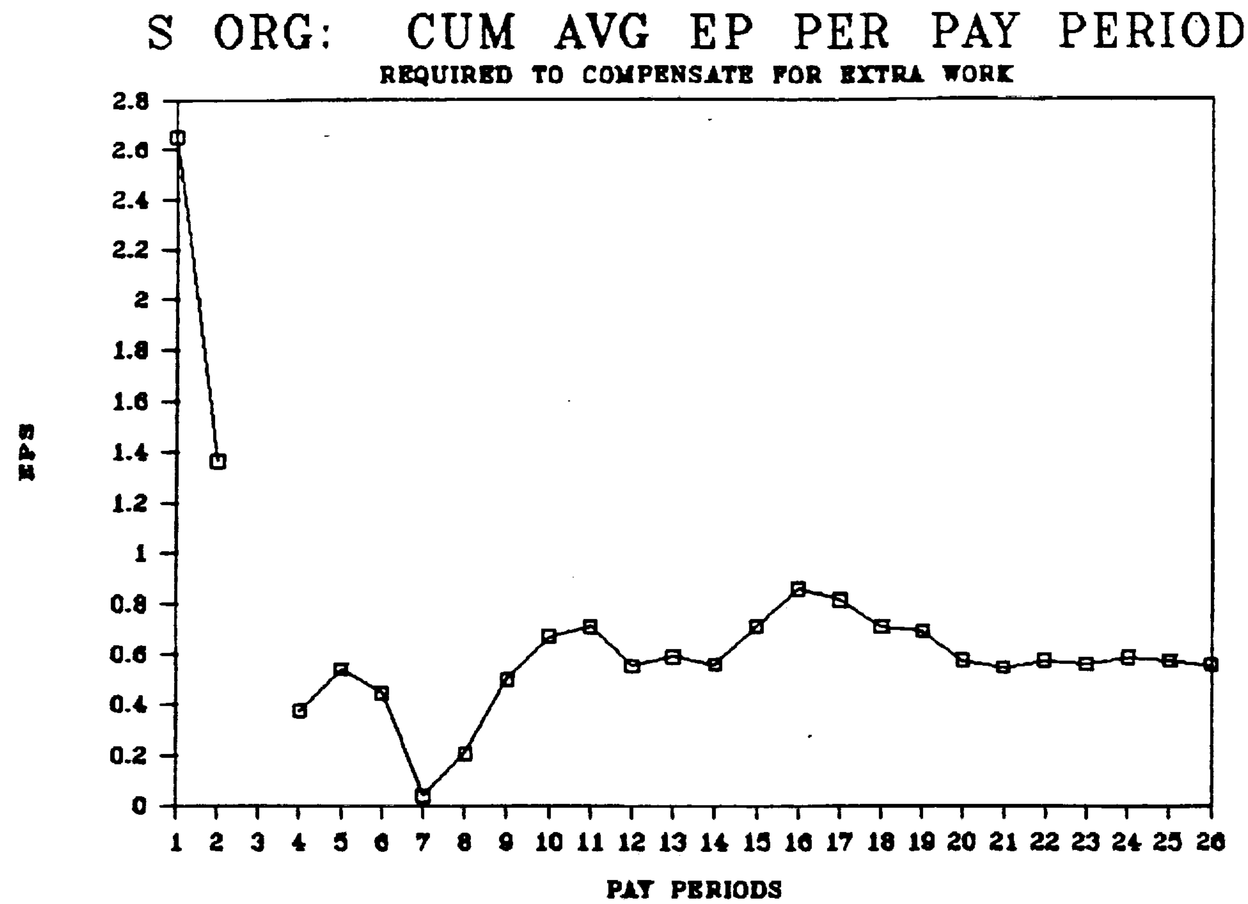

M ORG: CUM AVG EP PER PAY PERIOD
REQUIRED TO COMPENSATE FOR EXTRA WORK
EPS
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26
PAY PERIODS

FIGURE 7


S ORG: CUM AVG EP PER PAY PERIOD
REQUIRED TO COMPENSATE FOR EXTRA WORK
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
EPS
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26
PAY PERIODS

APPENDIX VII B

PROGRAM AND FISCAL RESPONSIBILITY

PROBLEM 1: The span of control for the manager of NSTS is between 9 and 12 and could be construed to be as high as 14.

A span of control of this size from diverse elements of the organization can be difficult to control. Consideration might should be given to introducing a step between the 3 KSC offices and the NSTS manager. Another thought is to have a JSC shuttle manager, a KSC shuttle manager, a MSFC shuttle manager, and a VLS shuttle manger to deal with the various elements at each center. All of these managers would report to the manager of NSTS. One of the dangers of lengthening the management structure in any of these fashions is that sensitivity might be lost to lower level problems.

PROBLEM 2: In many cases, the authority or responsibility comes from one place and the money from another.

Any time an organization has its authority and budget coming from different places, major problems are introduced. At the very least, it would seem that budgets should flow through the manager of NSTS in so far as they impact NSTS. This could of course cause a lower level manager to have to satisfy more than one upper level manager about a budget request. This last concept can have both positive and negative ramifications. Jurisdictional conflicts could be negative. Having more than one upper level manager support an item can apply effective budget control and well as needed support.

APPENDIX VII C

GENERAL COMMENTS ON ASSESSING MANAGEMENT STRUCTURE AND OPERATIONS

1.0 DEFINITIONS

For the purpose of the rest of this paper the following definitions will be used:

- o STRATEGIC PLANNING-long range planning.
- o TACTICAL PLANNING-planning affecting the immediate or short term.
- o GOAL-a desired future state, oft times stated in philosophical terms.
- o OBJECTIVE-a specific action the accomplishment of which will help to obtain a goal.

NOTE: The above definitions may not be uniformly accepted or understood by the members of a management assessment team.

2.0 METHOD

In the beginning one must attempt to well-define the term assessment. What is to be assessed and in what light? How? The following steps constitute one method of doing an assessment.

2.1 DETERMINE THE EXISTING STRUCTURE AND METHOD OF OPERATION

There will be some difference between the specified formal structure and the actual working structure. Without some determination of the specified structure and the actual structure, with political considerations thrown in, the assessment team may not be all working with the same set of ground rules.

2.2 SEEK COMMONALTY ON THE CURRENT GOALS AND OBJECTIVES OF THE ORGANIZATION

To assess structure and operation of a management system one must have a yardstick to compare them against. This yard stick consists of the goals and objectives of the organization. The assessment team, again, must be working under the same set of ground rules. This demands commonality on the definitions of the goals and objectives of the organization. As a specific example, if the goals and objectives of an organization have changed then a change in the structure or method of operation may be required.

2.3 DEFINE THE WORKING PARAMETERS FOR THE ASSESSMENT

At this step the assessment team begins to decide specifically under what light they are going to examine the structure and operation. Most of these parameters are multi-dimensional. As an example, suppose cost is a parameter used to review the structure and operations. Then there will be short term (tactical) and long term (strategic) considerations.

2.4 DETERMINE HOW WELL THE SYSTEM IS PERFORMING IN LIGHT OF THE WORKING PARAMETERS

Many of the parameters used will be chosen because there is concern for inadequate performance under these parameters. Others will be chosen because of their significance. For whatever reason they are chosen, this step involves the determination of performance of the system in light of these parameters.

2.5 DEVELOP ALTERNATIVES FOR OPERATION AND STRUCTURE IN LIGHT OF THE WORKING PARAMETERS

Some consideration needs to be given here for the working principle that "if it ain't broke then don't fix it." However, in contrast to this last statement, even if the system is performing well under a specific parameter alternatives might be considered to make it perform better. Typical methods to develop alternatives include brainstorming and some sort of Delphi technique involving the power structure of the organization. Great care must be used here to filter out self-serving suggestions.

2.6 CATEGORIZE THE ALTERNATIVES IN LIGHT OF THE WORKING PARAMETERS

This step involves the placing of the alternatives in specific categories. As a specific example will this alternative have a long term or a short term effect on a particular parameter. In addition, at this point it may become necessary to re-define the parameter list.

2.7 ANALYZE THE ALTERNATIVES IN LIGHT OF THE WORKING PARAMETERS WITH REGARD TO THE IMPACT ON THE GOALS AND OBJECTIVES OF THE ORGANIZATION

The usual methods such as pro and con lists or perhaps a Delphi technique may be useful here.

2.8 ANALYZE THE ALTERNATIVES IN LIGHT OF THE WHOLE SYSTEM

Once the list has been narrowed down to a set under consideration for implementation, consideration needs to be given as to how these alternatives play one against the other.

2.9 IMPLEMENT THE SET OF ALTERNATIVES WHICH HAS A POSITIVE IMPACT ON THE GOALS AND OBJECTIVES OF THE ORGANIZATION

APPENDIX VII D

APPLICATION OF GENERAL COMMENTS ON ASSESSING MANAGEMENT STRUCTURE AND OPERATIONS TO NSTS

1.0 GOALS AND OBJECTIVES

From the 1985 Long-Range Program Plan, "Develop a fully operational and cost effective Space Transportation System to provide routine access to space for domestic and foreign commercial and governmental users." This may be the most current statement of the goal of NSTS. As example of the importance of commonality of definitions, some individuals may not feel that routine is either appropriate or desirable. Surely there are other specified and working goals in existence.

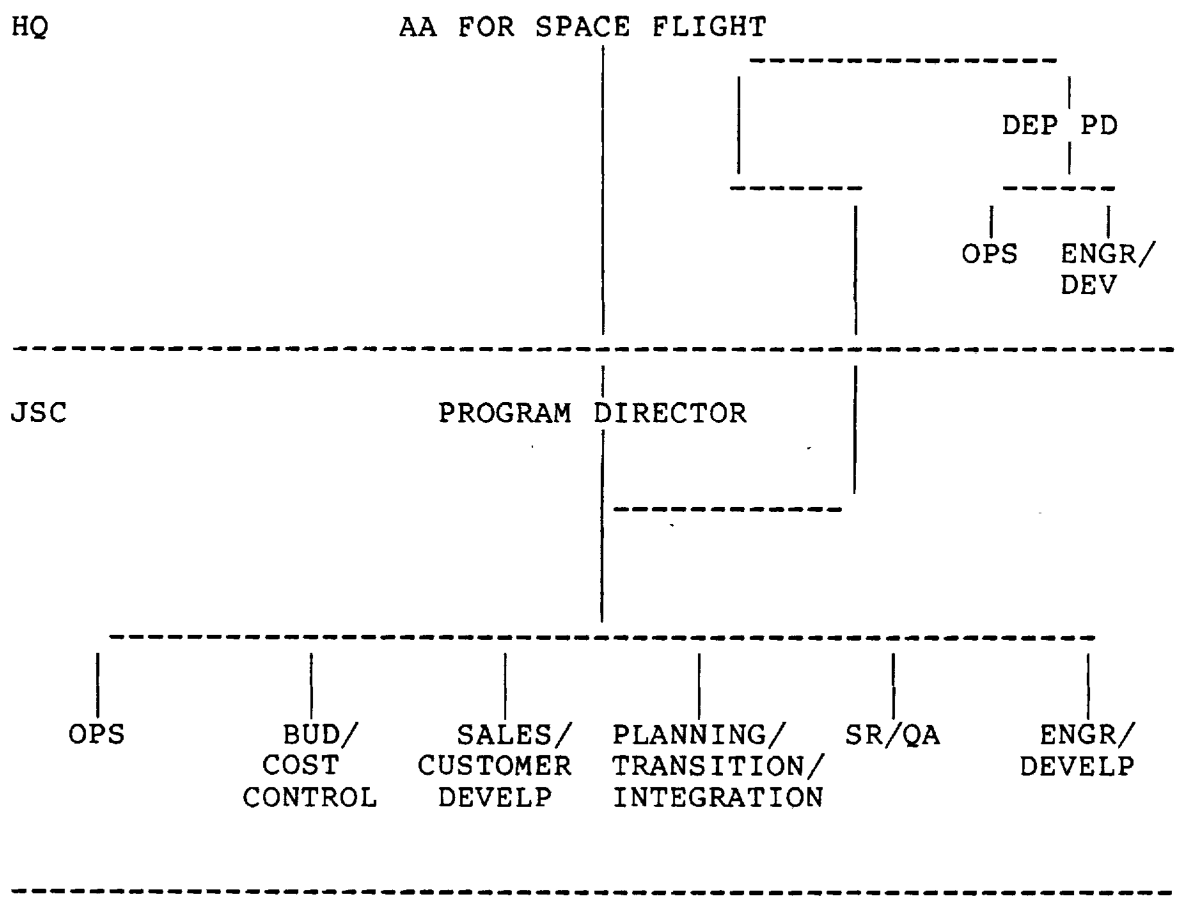
2.0 WORKING PARAMETERS

- o Safety. Perhaps the most important of the variables and one which should permeate the entire discussion.
- o Strengthening of public confidence in and image of NSTS. Consideration should be given to evaluating the system in light of the perception of safety and reliability.
- o Effective and efficient utilization of resources. Here resources can be subdivided into three categories: physical objects such as computers, equipment,

buildings, orbiters, etc.; people; and money.

- <u>Ability to determine and maintain a realistic schedule.</u> This parameter is somewhat related to public confidence and commercially viable. It is directly related to the part of the goal statement addressing routine access.
- <u>Strengthening commercial viability.</u> This parameter is directly related to the part of the goal statement which addresses routine access to commercial users.
- <u>Improve communications, particularly in the decision loop.</u> This parameter is related to the effective and efficient utilization of resources and to the improvement of image.

APPENDIX VII E



ALL CENTERS — CURRENT LEVEL III PROJECTS ARE SEPARATED INTO AN OPERATIONAL ASPECT AND A DEVELOPMENTAL ASPECT. THE OPS PART REPORTS TO PROGRAM OPS, THE DEVELOPMENT PART REPORTS TO PROGRAM ENGR AND DEVELOPMENT.

IN ADDITION, ALL PROJECT OFFICES WILL INTERACT WITH THE OTHER 4 OFFICES AT THE PROGRAM LEVEL.

ROLES AND RESPONSIBILITIES

PROGRAM DIRECTOR

ROLES: TO DIRECT NSTS IN THE DEVELOPMENT OF GOALS, TO CONTROL PROGRESS TOWARDS THESE GOALS, TO ORGANIZE RESOURCES FOR THEIR ATTAINMENT, TO PLAN FOR FUTURE DEVELOPMENT, AND TO MOTIVATE THE WORK FORCE.

THE PROGRAM DIRECTOR SERVES AS THE CEO OF THE NATIONAL SPACE TRANSPORTATION SYSTEM.

RESPONSIBILITIES: FOR THE FUNCTIONING OF THE SPACE TRANSPORTATION SYSTEM AND FOR SEEING THAT THE SYSTEM SATISFIES THE GOALS AND OBJECTIVES OF THE SYSTEM.

FOR REPORTING TO AND SUPPORTING THE AA FOR SPACE FLIGHT.

DEPUTY PROGRAM DIRECTOR, HQ

ROLES: TO SUPPORT THE PD BY SERVING AS A LIAISON BETWEEN THE PD AND THE AA FOR SPACE FLIGHT.

TO DIRECT AND CONTROL THE HQ OFFICE OF THE PD.

TO SUPPORT THE AA BY SERVING AS AN INTERFACE BETWEEN THE PROGRAM OFFICE AND HQ.

RESPONSIBILITIES: FOR EFFECTIVE AND TIMELY INFORMATION FLOW BETWEEN THE PD AND THE AA.

FOR REPORTING TO THE PD.

OPERATIONS OFFICE

ROLES: TO OPERATE THE NSTS ON A DAY-BY-DAY BASIS.

TO ACHIEVE THE OPERATIONAL GOALS ESTABLISHED BY THE PD.

TO CONTROL, DIRECT, ORGANIZE, PLAN AND MOTIVATE FOR ALL ASPECTS OF PRODUCING FLIGHTS IN ACCORDANCE WITH SCHEDULES DETERMINED BY THE PD INCLUDING THOSE ASPECTS OF THE OPERATIONAL PROGRAM WHICH ARE LOCATED AT DIFFERENT CENTERS.

TO PERFORM THE MANAGEMENT OF OPERATIONS JOB SIMILAR TO AN OPS MANAGER IN INDUSTRY.

RESPONSIBILITIES: FOR SUPPORTING THE PD. FOR PROVIDING OPERATIONAL INPUTS INTO OTHER AREAS OF THE PROGRAM.

ENGINEERING AND DEVELOPMENT OFFICE

ROLES: TO PROVIDE THE SUSTAINING ENGINEERING AND DEVELOPMENT NECESSARY TO INSURE SAFE AND EFFICIENT FLIGHTS.

TO INSURE THAT SOUND ENGINEERING JUDGEMENT IS INCLUDED IN ALL DECISIONS.

TO DESIGN, DEVELOP, AND TEST NEW CONCEPTS WHICH LEAD TO SAFER AND MORE EFFICIENT FLIGHTS.

RESPONSIBILITIES: FOR SUPPORTING THE PD. FOR CONTROLLING ENGINEERING IN ALL PROJECTS REGARDLESS OF THEIR LOCATION.

PLANNING, TRANSITION, AND INTEGRATION OFFICE

ROLES: TO PROVIDE LONG RANGE PLANNING FOR NSTS.

TO SMOOTH THE TRANSITION TO AN OPERATION ENVIRONMENT.

TO SERVE AS A FOCAL POINT FOR THE RESOLUTION OF THE CONFLICTS BETWEEN OPERATIONS AND ENGR/DESIGN.

TO SERVE AS AN AD HOC TEAM TO INVESTIGATE PROBLEMS AS ASSIGNED BY THE PD.

RESPONSIBILITIES: FOR SUPPORTING THE PD.

FOR DETERMINING REALISTIC PRODUCTION RATES IN BOTH THE NEAR TERM AND THE FAR TERM.

FOR CONTROLLING PLANNING, TRANSITION, AND INTEGRATION ASPECTS OF ALL PROJECTS.

SR/QA

ROLES: TO INSURE SAFETY AND QUALITY IN ALL ASPECTS OF THE FLIGHT PRODUCTION PROCESS.

RESPONSIBILITIES: FOR DEVELOPING ADEQUATE REPORTING PROCEDURES FOR THE ASSURANCE OF SAFETY AND QUALITY.

FOR SUPPORTING THE PD.

FOR SUPPORTING THE HQ SR/QA OFFICE WITH TIMELY AND ADEQUATE INFORMATION FLOW.

FOR COORDINATING THE SR/QA WORK AT LOWER LEVELS.

SALES/CUSTOMER DEVELOPMENT

ROLES: TO PROVIDE FOR THE DEVELOPMENT OF THE COMMERCIAL ASPECTS OF SHUTTLE FLIGHT.

TO FACILITATE THE INTERACTION OF THE USER COMMUNITY WITH NSTS.

RESPONSIBILITIES: FOR SUPPORTING THE PD.

FOR SUPPORTING THE PLANNING OFFICE WITH REALISTIC PROJECTIONS OF USER NEEDS IN BOTH THE NEAR TERM AND THE LONG TERM.

FOR SERVING AS AN INTERFACE BETWEEN THE USER COMMUNITY AND NSTS.

FOR FINDING NEW MARKETS FOR SHUTTLE SERVICES.

BUDGET AND COST CONTROL OFFICE

ROLES: TO SERVE AS THE MAIN FISCAL OFFICE OF NSTS.

RESPONSIBILITIES: FOR SUPPORTING THE PD.

FOR DEVELOPING BUDGETS AND MAKING BUDGET PROJECTIONS.

FOR COORDINATING AND INTEGRATING ALL BUDGETARY INFORMATION FROM LOWER AND PARALLEL OFFICES.

NOTES:

1. SALES AND CUSTOMER DEVELOPMENT SHOULD BE UNDER THE CONTROL OF THE PD. THIS WILL HELP TO STABILIZE MANIFEST CHANGES AMONG OTHER THINGS.

2. THERE WILL PROBABLY BE AN SR/QA OFFICE AT HQ. THEREFORE THE PROGRAM SR/QA OFFICE WILL HAVE TO COORDINATE WITH THEM.

3. THE INTENT WITH THE 6 OFFICES UNDER THE PD IS TO GIVE ALL OF THESE OFFICES A SAY IN WHEN AND WHAT TO FLY. IN OTHER WORDS, THIS IS TO PUT THE OPERATIONAL PRESSURE TO MEET THE IMMEDIATE FLIGHT NEEDS IN PERSPECTIVE WITH OTHER FORCES WHICH SHOULD HAVE AN EQUAL DEGREE OF INPUT. A FLIGHT CANCELED THIS YEAR MAY ALLOW MORE FLIGHTS TWO YEARS FROM NOW.

4. THE LOCATION OF THE DEP PD AT HQ IS AN ATTEMPT TO CLEAN UP THE DECISION CHAIN BETWEEN THE CEO OF THE PROGRAM AND HQ. PEOPLE IN THIS OFFICE SHOULD BE THERE ONLY ON A TEMPORARY BASIS OF ONE TO THREE YEARS.

5. ALL CURRENT PROJECTS WILL BE BROKEN UP UNDER THIS ARRANGEMENT INTO THEIR OPERATIONAL ASPECT AND THEIR ENGINEERING/DEVELOPMENT ASPECT AND REPORT TO THE APPROPRIATE OPS OR ENGR OFFICE AT THE PROGRAM LEVEL.

6. THE FUNCTIONS OF THE PLANNING/TRANSITION/INTEGRATION OFFICE ARE RELATIVELY NEW. THIS OFFICE SHOULD SERVE AS A FOCAL POINT FOR PLANNING. AS SUCH THE CHANGES WHICH ARE NECESSARY TO MOVE INTO THE OPERATIONAL ERA COME NATURALLY INTO ITS PURVIEW. INTEGRATION REFERS TO RESOLVING THE NATURAL CONFLICTS WHICH WILL DEVELOP BETWEEN CHANGES SUGGESTED BY SR/QA AND ENGR TO THE OPS OFFICE AND THE CHANGES SUGGESTED BY THE PLANNING FUNCTION. THE INTEGRATION FUNCTION ALLOWS THEM TO STAY TIED TO THE REAL WORLD. HOWEVER, GREAT CARE MUST BE EXERCISED TO INSURE THAT INTEGRATION DOES NOT BECOME THEIR ONLY REAL FUNCTION. IN ADDITION, THIS OFFICE COULD SERVE AS AN INVESTIGATORY AGENT OF THE PD AND BE ASSIGNED ON AN AD HOC BASIS TO DEVELOP INFORMATION NEEDED TO MAKE TIMELY DECISIONS.

7. THE PD WOULD BE EXPECTED TO SPEND A CONSIDERABLE AMOUNT OF TIME AT HQ. ONE WEEK IN FOUR, AS AN EXAMPLE, WOULD SEEM TO BE NECESSARY.

APPENDIX VII F

RISK AND CONTROL

1. At this point in time there are several problems that are surfacing with the Shuttle and its hardware. Problems with pumps and main engines are candidate examples. From these problems several questions arise. The most obvious of these is whether the problems would have been found if the Shuttle had continued to fly its ambitious schedule. If the answer to this question is yes, then the next question is whether the procedures to fix the problems are in place and what sort of impact would the procedures have on the schedule. If the answer to the question is no, then there could be several causes. One is that the problems are due to the stand down, i.e., they would not have occurred if the equipment had continued to be used in a regular fashion. The other cause is perhaps more severe. It may be that the testing procedure is inadequate to locate the problems during the intense activity surrounding flying. Another possibility is that the testing procedure may have found the problem but been to slow to react. There is no doubt that the people who are uncovering these areas are sensitive to the above comments. However the problem is that some important issues may fail to be surfaced or fail to be acted on. These considerations lead to the following recommendation.

RECOMMENDATION: A procedure needs to be developed that deals with these issues as they occur. This procedure should include a central control point through which all of these issues pass. At the control point each issue should be categorized into sets such as:

a) would not have occurred during regular flight
b) would have occurred but would have been found and resolved with no major impact on schedule
c) would have occurred and been found but would have a major impact on schedule
d) would have occurred but would not have been found.

This sorting of the issues could then be used to direct managerial attention to the correction of any significant problems.

2. There is concept which we will called "perceived danger" that affects systems when they have numerous dangerous components. This condition occurs when one of the elements of the system is perceived to be more dangerous or troublesome than the others. Attention is concentrated on the most dangerous element and controls are built to reduce or control the level of risk of this element. Then, as the system matures, another element malfunctions and a serious problem occurs. As an example of this concept, are the controls on the rest of the system as stringent as those on

the SSME's? Some attempt must be made in the system to level out the degree of protection for all elements of the system. This is normally done at the onset of system development, but as the system matures and the perceived most dangerous element begins to be identified there is a natural tendency to shift increasing attention to this dangerous element. The usual result is an unbalanced system with extreme protection and control being used on the dangerous element and other elements having less protection. These considerations lead to the following recommendation.

RECOMMENDATION: An evaluation needs to be done on the protection and control system of all parts of the system with the objective of evaluating whether the protection and risk control is of an equal level for all parts of the system. This evaluation should be done by an agent which has no emotional attachment to the outcome and which has no previous bias. The intent of this evaluation is not that the protection of minor items with virtually no impact should be the same as for major items with serious impact. The intent is that the protection for all items with equal impact are equally protected.

APPENDIX VII G

AN OPERATIONAL ARM FOR THE MANAGEMENT OF THE SPACE SHUTTLE

1.0 INTRODUCTION

The basic problem on which this paper concentrates is the determination of the organization and structure of the management of the Space Shuttle Program. This issue is not new to the National Space Transportation System (NSTS). Numerous papers and reports have been written on the subject and have been presented to NASA management. Two factors make this problem worth revisiting. One is that a significant amount of flight history has occurred. The second is the Challenger accident and the resulting world wide interest and concern with NASA and NASA management. In addition, major strategic changes, such as those considered in this paper, have a long lead time. This alone, makes this issue one which should be revisited periodically.

2.0 INTRODUCTION AND BACKGROUND

2.1 PROBLEM IDENTIFICATION

In order to deal with questions concerning management structure, the first step is to look at the mission of the organization. A basic consideration for NSTS is to fly the shuttle as often as necessary and to fly it safely. In this consideration the question arises as to the definition of "as often as necessary". To begin to answer this question it is necessary to analyze the formal objective of NSTS as of 15 August 86 which is:

> "to establish a national space transportation capability that will (i) substantially reduce the cost of space operations, and (ii) be designed to support a wide range of scientific, applications, defense, commercial and international uses." [Vol 1 07700 series, Level II Program Definitions and Requirements]

As with many formal organizational objectives, there is the strong possibility of confusion, ambiguity, and lack of commitment throughout the organization. This is particularly true when the objectives get transformed into operational strategies. For the shuttle, for example, is the strategy to realize short term gains and fly this generation of vehicles as often as possible as soon as possible? Or is the strategy to go to school on this generation of vehicles in order to identify problems which must be resolved before the next generation of vehicles can make space flight more routine? Or is perhaps the strategy some combination of the two?

Regardless of the current strategy, in order to reduce costs and to provide broad access to space, at some point in time the shuttle operation must become more routine and more standardized. In other words it must become more operational in nature. Here operations is defined as routine timely performance with emphasis on cost control. It is in light of this reasoning that the possible management structures are analyzed. This is done with the full realization that these considerations are long lead time items and the question of who will manage the operational era is the prime concern. This question will not go away; in fact, it will reappear with the space station. For these and other reasons, strategic decisions should be made as early as possible in order to support the program in the out years when the operation becomes more routine.

2.2 COMPLICATING FACTORS

There are numerous problems complicating the choice of management structure for NSTS. While the alternatives for the management of the space shuttle program are discussed starting with section four, the factors complicating this choice must first be understood. These factors are summarized in Table 1 and discussed below.

Variability in processing: There is a large amount of variability in processing the shuttle. The Committee Of Science And Technology pointed this out when it stated that each shuttle flight is unique, and requires unique preparations (22, p. 122). This is evident on even a casual reading of Figure 1 which shows the turn around or processing times for the shuttle in the 3 major facilities: the orbiter

COMPLICATING FACTORS FOR CONSIDERATION OF MANAGEMENT STRUCTURE

* VARIABILITY IN PROCESSING
* NOT DESIGNED FOR PRODUCTION
* UNIQUENESS OF THE VEHICLE AND THE PROGRAM
* SPACE STATION AND SPACE SHUTTLE
* DOWNSTREAM CHANGES
* PROJECT VS. PROCESS MANAGEMENT
* LACK OF OPERATIONAL EXPERTISE
* DEMOGRAPHICS
* NATIONAL INTERESTS

TABLE 1

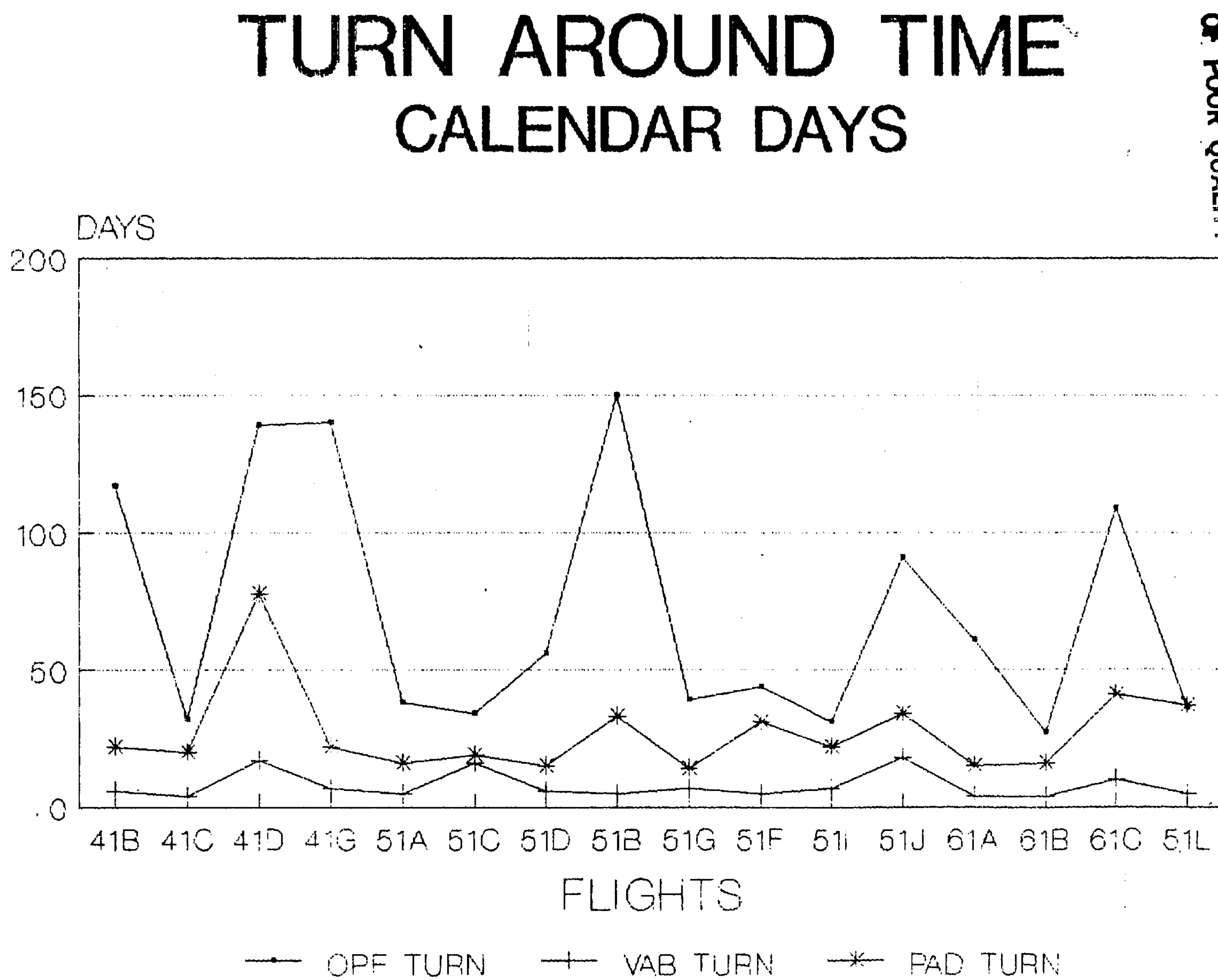


FIGURE 1

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processing facility (OPF), the vehicle assembly building (VAB), and the launch pad (PAD). Over the 16 flights listed in this figure, the shuttle averaged 71.5 days in the OPF, 7.9 days in the VAB, and 27.2 days on the PAD. The total of these times is shown in Figure 2. In both figures the times have high variability, making it difficult to come up with reasonable estimates for the future missions.

There is of course some chance that this variability is controllable. Figures 3 and 4 seem to disprove this assumption. In Figure 3 the planned versus the actual workdays at Kennedy Space Center (KSC) where the shuttle is processed is presented. In the 18 flights listed, the plan was only achieved once. There are 6 flights with a variation of approximately 50% or better of the delta to the plan. Of these one was 99% and one was 212%. Figure 4 shows much the same data with a listing of the amount of months of launch slip. The conclusion to be drawn from these first 4 figures is that there is a large amount of variability in the processing times for the shuttle and that this processing time is hard to control.

Not designed for production: Neither the shuttle or the processing facilities at KSC were designed for production. In the shuttle fleet, each vehicle is different from the next. This makes it difficult to develop routine processes which apply to all vehicles. During the time that the shuttle was designed there was little experience with routine

TOTAL TURN TIME
CALENDAR DAYS

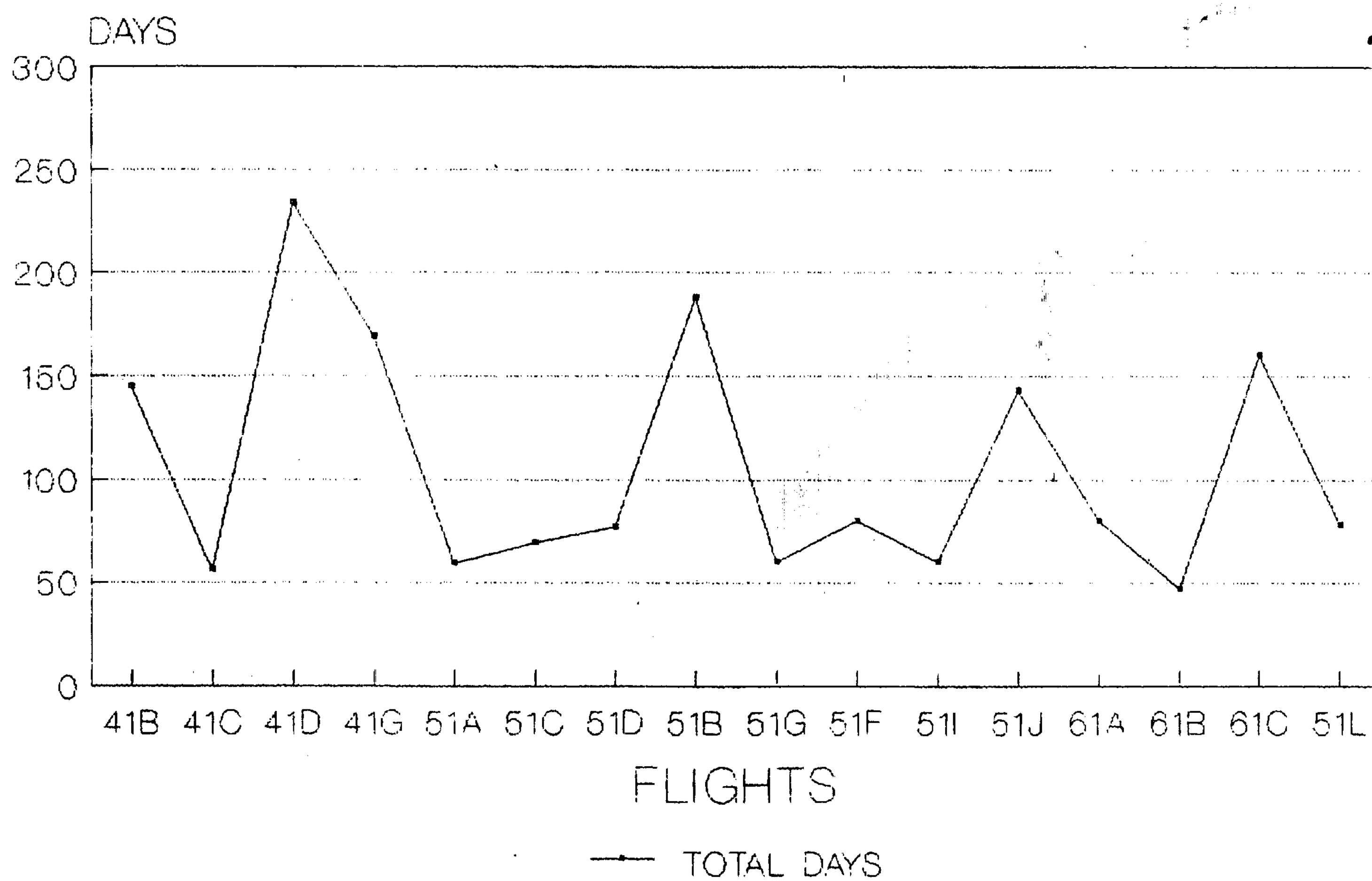

FIGURE 2

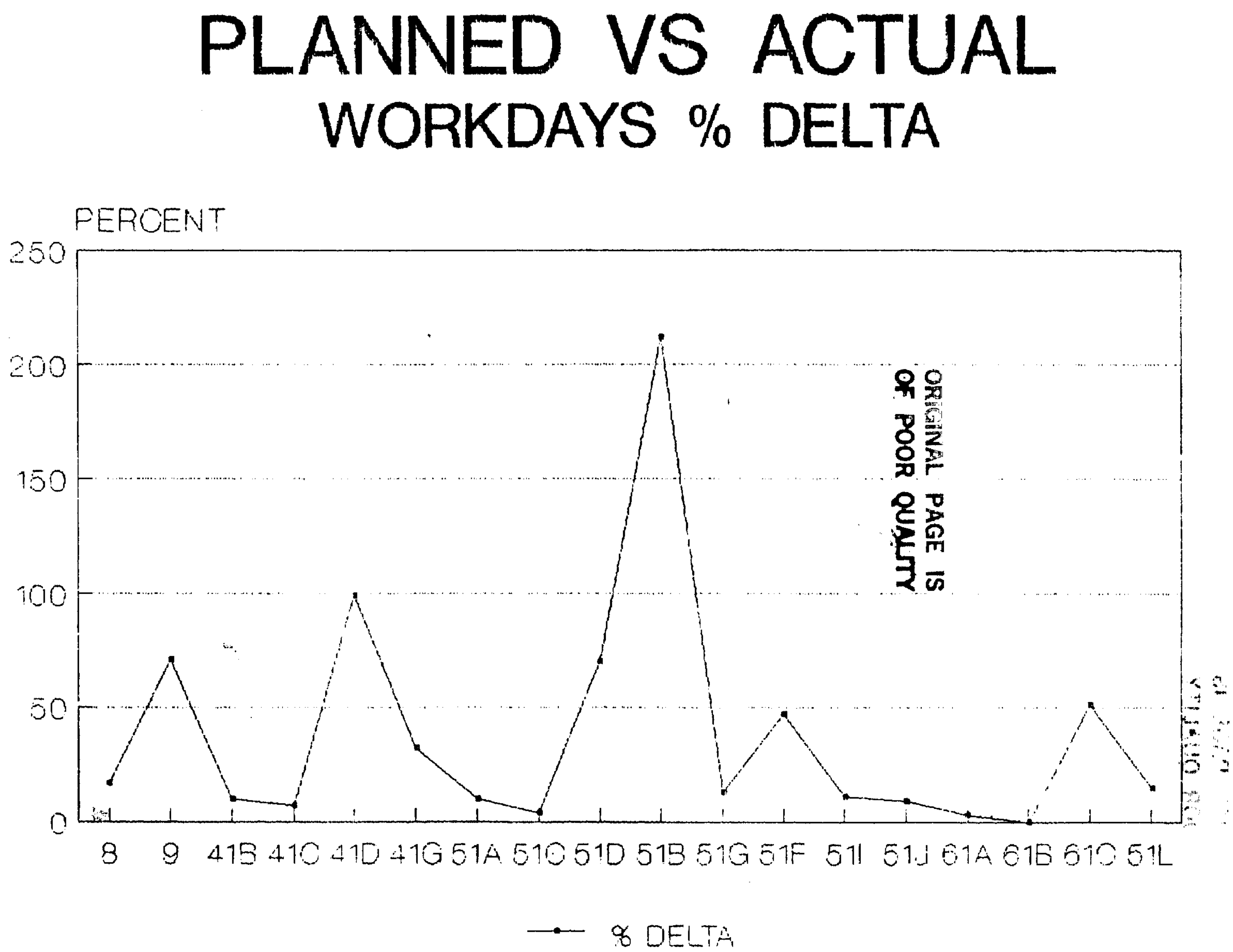
PLANNED VS ACTUAL
WORKDAYS % DELTA
PERCENT
250
200
150
100
50
0
8
9
41B
41C
41D
41G
51A
51C
51D
51B
51G
51F
51I
51J
61A
61B
61C
51L
% DELTA
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FIGURE 3

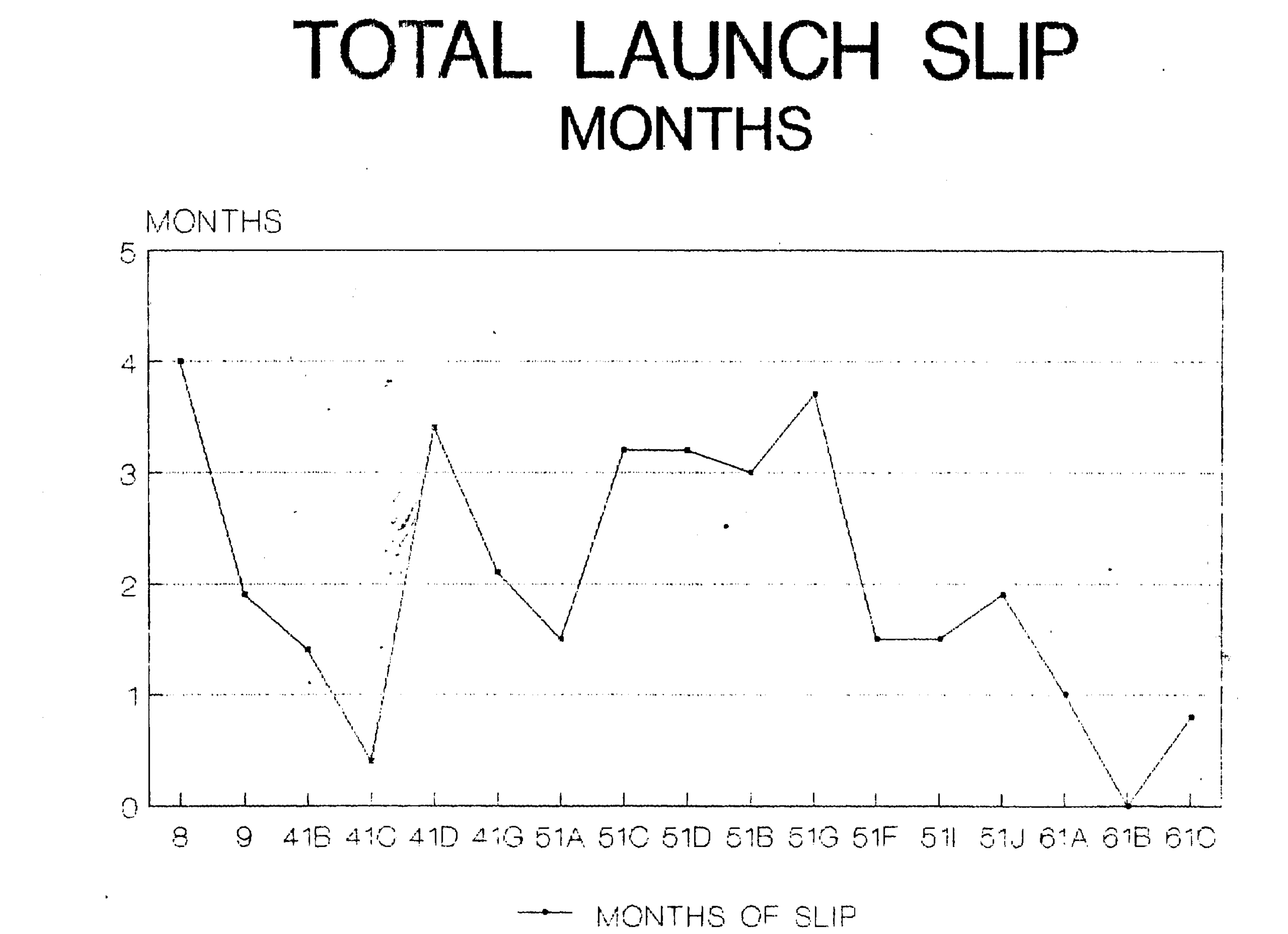
TOTAL LAUNCH SLIP
MONTHS
MONTHS
5
4
3
2
1
0
8
9
41B
41C
41D
41G
51A
51C
51D
51B
51G
51F
51I
51J
61A
61B
61C
MONTHS OF SLIP

FIGURE 4

space flight. This of course made it difficult to predict how to design for production. This is illustrated by the sensitivity of the Solid Rocket Motor joint design to processing (13).

At KSC the process flow lines are relatively long with many of the moves being difficult and complex. As an example, the shuttle on the Mobile Launch Platform takes a full day to travel from the VAB to the pad. Another example involves the mating of the external tank to the orbiter in the VAB. This move requires an external tank to be lifted over 100 feet in the air in order to clear a sill in the VAB. This moves takes at least a shift to accomplish. If there is an orbiter stored in the VAB then it must be moved out of the way in order to lift the tank. This of course adds more time. Much of the processing assembly structure at KSC was inherited from earlier days when time was not as severe as a constraint. Much of the material handling equipment at KSC is unique. The Mobile Launch Platform mentioned earlier is one example. Another deals with the Solid Rocket Motors. Once these are flown they are retrieved from the sea and cleaned at KSC. Then they are loaded on special railroad cars and carried to Utah where the propellant is added. From here they are shipped back to KSC again on the same special railroad cars. Needless to say the railroad cars are unique and the scheduling is complex due to the small number of the cars. These are just a few of the problems illustrating that the processing facility was not designed for routine processing.

Uniqueness of the vehicle and the program: There are only 3 orbiters in existence capable of flying, with a fourth in production. There is a hanger queen which will never fly again still around and of course the Challenger was a flying vehicle. There is a strong probability that these will be the only vehicles of this type which will be built. As time passes these will more than likely be replaced with different designs, even though this will be some time in the future. This generation of vehicles was the first of their type in that part of the vehicle is returned and flown again. Both the orbiter and the Solid Rocket Boosters are returned to fly again. This is a new concept and like most new programs still has many problems to be resolved. As a specific example of the uniqueness of the vehicle, the Solid Rocket Boosters are the largest solid propellant motors ever developed and the first to be used on a manned craft (22, p. 42).

The program is likewise unique. Indeed, few products have the complexity, cost, visibility, and potential for impact on the reputation of the United States as does the space shuttle (13). Dealing with hardware reflight issues is new. While manned flight is not new, it is young. Also, the shuttle has new issues in manned flight such as space repair of satellites and controlled landings. Adding to these issues is the increased volume of space cargoes intended for flight. Then there is of course the Strategic Defense Initiative which ties space closer to the defense of the Country. Other countries such as Russia and the European Space Agency have programs with the same concerns. However, due to national interests, there is at best limited access to the knowledge that these programs may possess.

There is some tendency to equate shuttle operations to airline flight or military operations. This is a gross oversimiplification of the issues involved and in fact this similarity is disclaimed in National Research Council (NRC), (23, p. 29).

All of these factors combine to illustrate that there is no large base of knowledge dealing with programs such as the shuttle.

<u>R/D nature of the product and of the program:</u> The product in this discussion is defined to be the basic vehicle with all its components along with the missions into space with all their components. Since the product is relatively new, it is unreasonable to suppose that major significant changes will not continue to occur in the product. In fact, the shuttle is not out of the development stage (23, p. 33; 25, p. 194). Furthermore, the shuttle is too complex to ever be considered operational (26, p. 14). Specifically figure 5 shows the number of major changes to the vehicle throughout one of the latter years of the shuttle's history. It is worth noting that there were a significant number of planned changes and

SHUTTLE VEHICLE CHANGES
AUG 84 THROUGH JULY 85

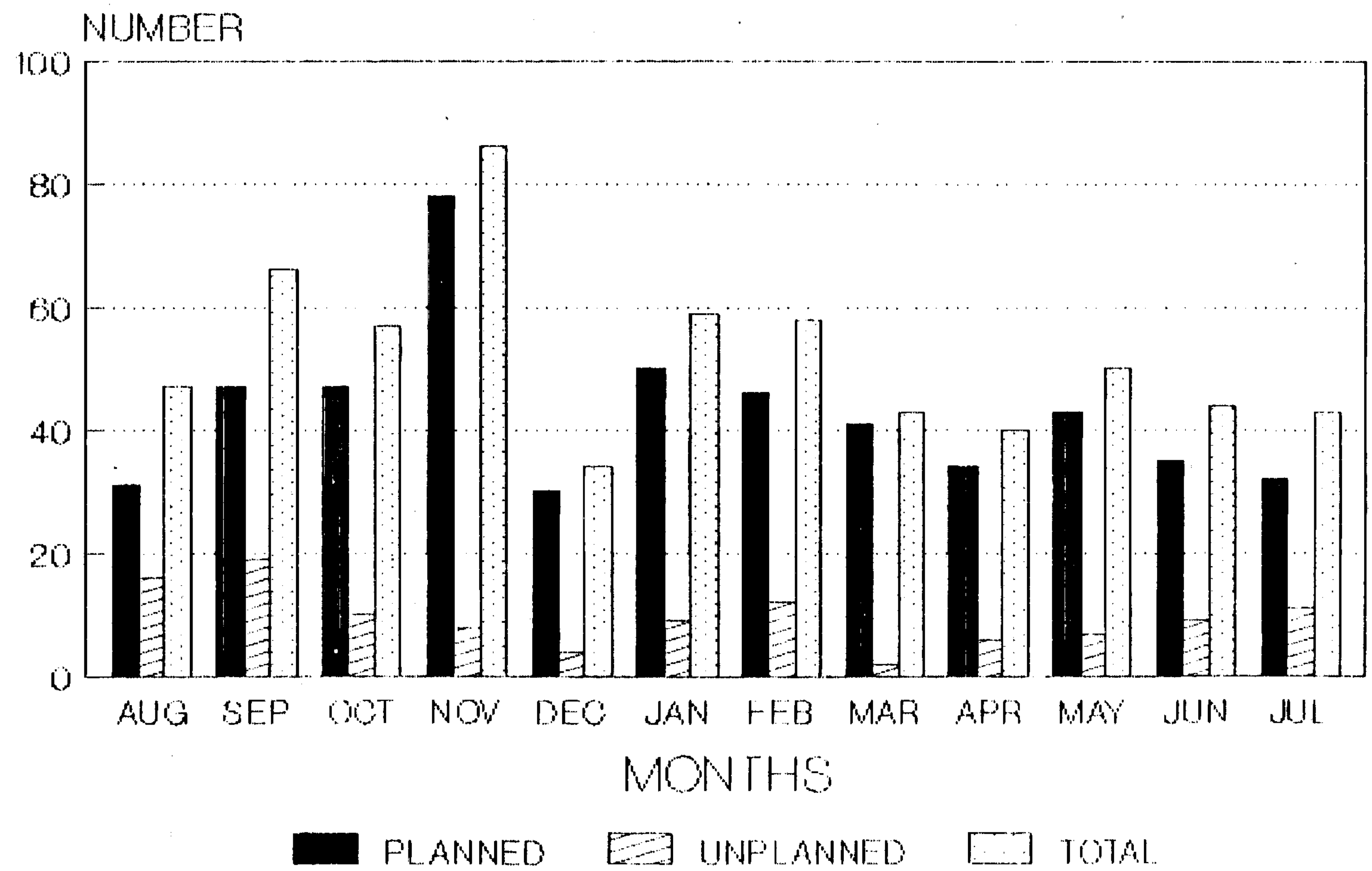

FIGURE 5

that the number of unplanned changes is non-trivial. This is of course to be expected with any developmental vehicle. While it is hoped that the number of changes reduces with time, it would be folly to assume that they will reduce to near zero. In other words, the shuttle has a strong R/D nature now and will more than likely continue to have a large amount of development throughout its history as the business of flying in space matures and the shuttle changes to accommodate new knowledge. On page 14 of the Lessons Learned Report, it is pointed out that the shuttle is too complex to ever be considered operational. Figure 6, showing anomalies by flight, adds credibility to this argument.

In a similar vein, space missions have changed significantly in the last several years. New satellites are being developed with new requirements. Several years ago, few people would have guessed at the success of the shuttle in its repair role with malfunctioning satellites. The space station along with SDI may also change mission concepts. Even a causal reading of the report of the National Commission on Space (24) illustrates that the role, scope, and shape of missions in space is going to be continually changing.

<u>Space Station and Space Shuttle:</u> These two programs are interrelated. Much of the use of the shuttle will be towards supporting the space station. This support must be provided in a routine regular fashion. In addition the interface

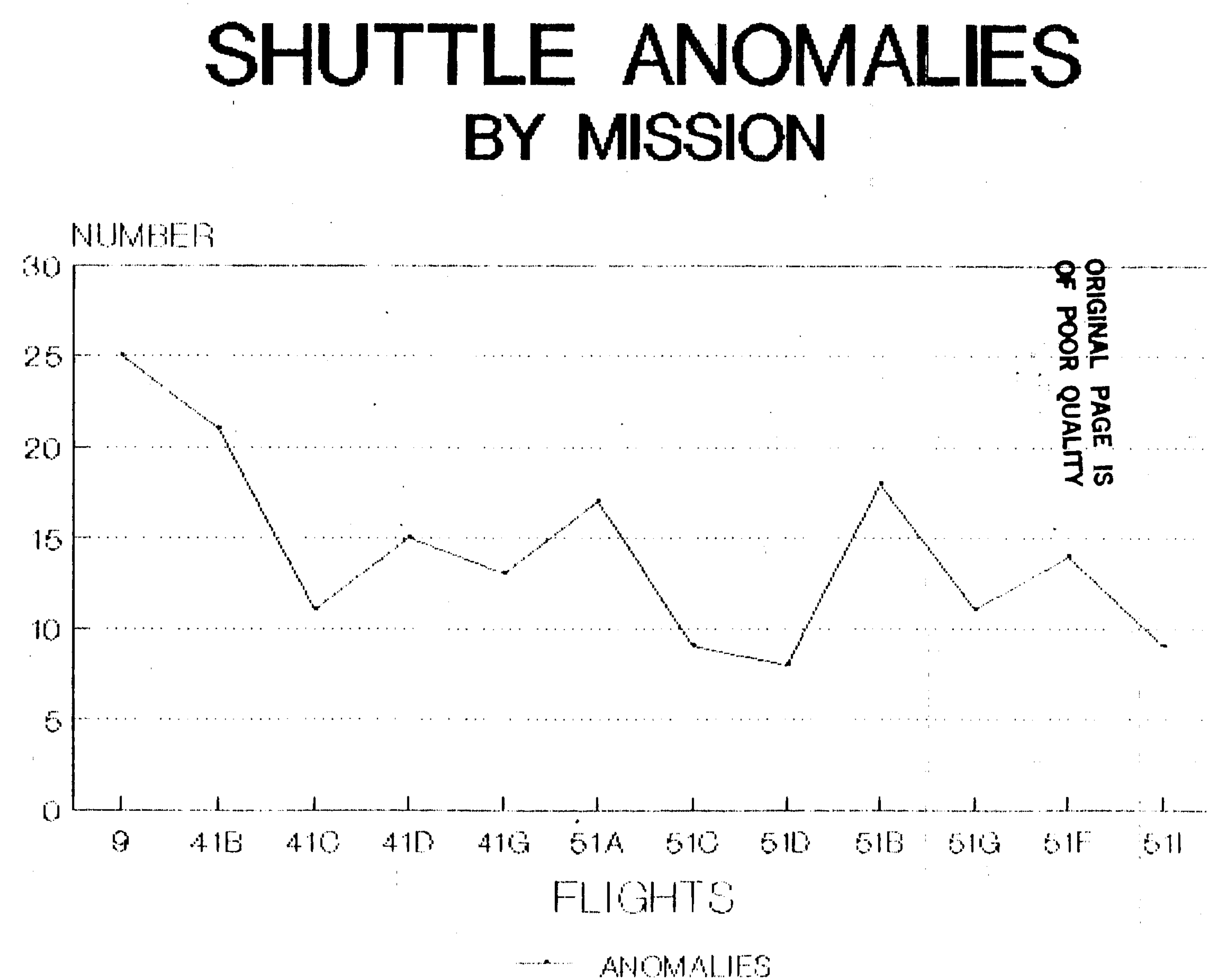
SHUTTLE ANOMALIES
BY MISSION
NUMBER
30
25
20
15
10
5
0
9
41B
41C
41D
41G
51A
51C
51D
51B
51G
51F
51I
FLIGHTS
ANOMALIES

FIGURE 6

between them must be constructed so as to provide for routine interaction. In fact the tie between them appears to be so strong that it is difficult to imagine an effective management structure which separates these two programs very far. The assumption here is that the operation of the shuttle and the space station must be tied closely together. The NRC report (23, p. 16), lends weight to this argument when it points out that the heaviest launch demand on the shuttle will be the space station. This demand is so strong that it could not be supported by 3 orbiters. Also, unless the shuttle fleet is maintained during the 1990's at approximately the realistic flight rates in the NRC report, the necessary foundations for the space station, SDI, etc., will not exist (23, p. 47).

Downstream changes: The product of NSTS is complex and one of the major contributing factors to this complexity is the issue of manifesting missions. The product cycle for missions is relatively long and begins in earnest at Launch minus 15 months (L-15) when cargo mixes are established and baselined in the Flight Definition And Requirements Directive. This product cycle is being shortened but as of 1985, at approximately L-10.9 there is a dry run on the cargo integration review (CIRD) which baselines the authorized requirements and objectives for a specific mission. This review provides the authorization to begin the preparation of the final engineering and flight design to determine mission feasibility. At approximately L-7.7 the CIR (Cargo Integration Review) is held which approves the baseline and approves the engineering data for release. Then at L-5 the final Flight Planning and Stowage Review is held. Around 1/2 month prior to launch the final engineering data is provided to the launch site and to the customer.

Given the complexity of this process, downstream changes have a significant impact on workload and on budget. Even easy changes put demands on the system (25, p. 171-173), and a small delay ripples through the system, causing an enormous amount of problems and unplanned work (13). In addition the later in the cycle that a change occurs then the more impact that is felt. In addition, change have a trickle effect in that a change to one mission, late in the cycle, will at the very least, steal time from later missions. At the worst, a late change may cause a later mission to be delayed or even canceled. As the flight rate increases this problem has the potential to become more severe.

The history of NSTS has been one of late changes to the manifest. In figure 7, changes to the cargo bay and to the mid deck are presented for flights 41-G through 51-L. This chart shows the changes that occurred between significant milestones. As an example, 25 changes occurred in the cargo bay between L-15 and the CIRD. Around 40% of the changes to the cargo bay occurred after the CIR and about 1/2 of these after L-5. Even though the mid deck changes do not have as significant an impact on the over all work load as the cargo

MANIFEST CHANGES
Flights 41G-51L

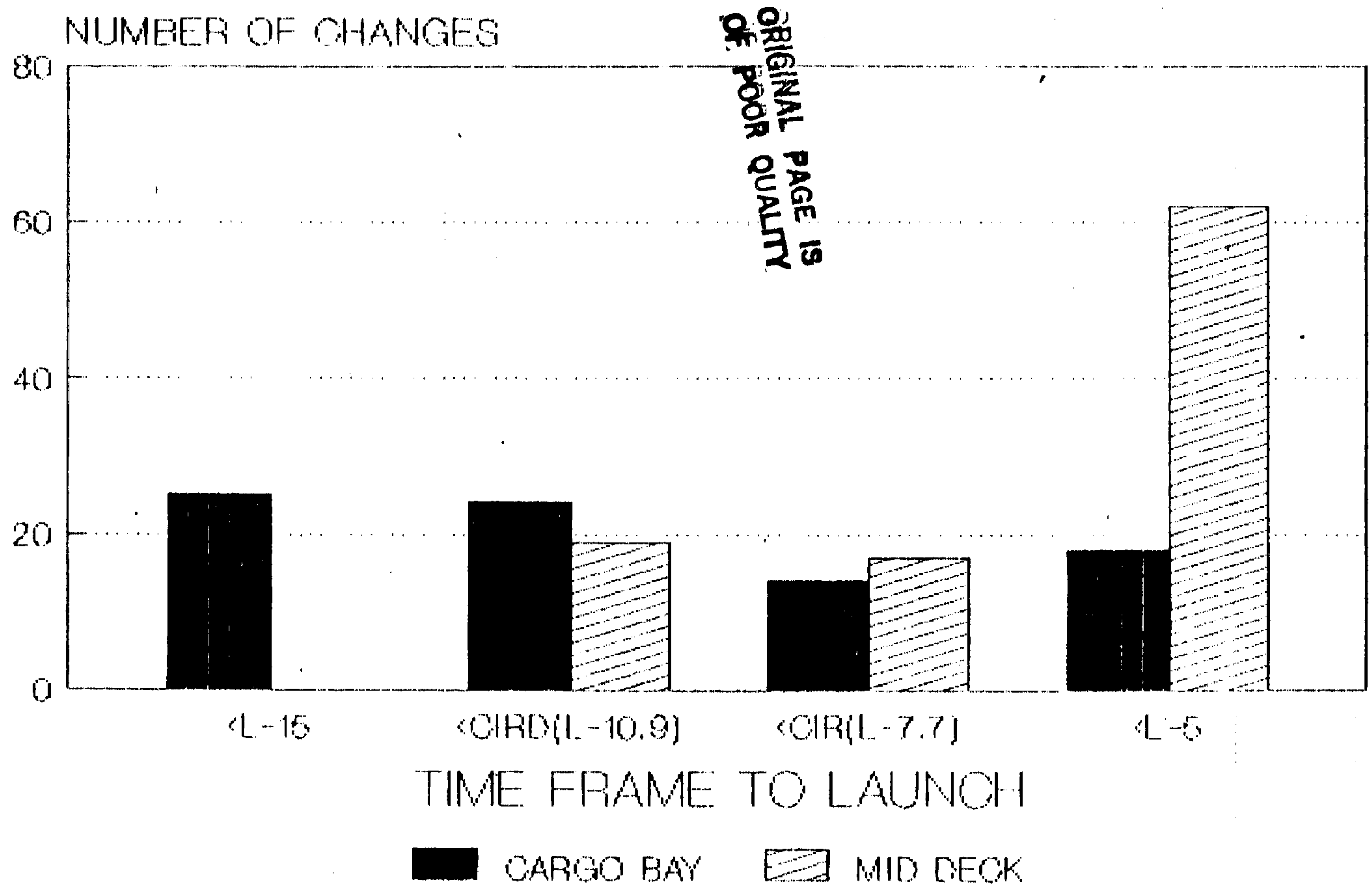

FIGURE 7

bay changes, they do distract from the main business of the flight contained in the cargo bay. In the mid deck changes after L-5, 41 of the 62 changes occurred after L-3 further impacting the time spent on the up-coming launch.

In summary, the process of manifesting is complex with a long lead time. In its history, NSTS has experienced a significant number of manifest changes late in the process cycle which have had a non-trivial impact on workload and budget. Thus, rigid manifesting criteria need to be established and enforced to reduce perturbations, remanifesting, and variability (26, p. 38).

Project as opposed to process management: Throughout its history, NSTS has been managed in a quasi-matrix structure. The managerial process is project like in nature as is somewhat typical with an R/D organization. Everything is done on a flight by flight basis, and the increased flight rate has made this problem even more severe (13). If work does not get done then the project completion date, the launch, is rolled back. In other words, NASA has not yet been able to leave "project" management and engage in "process" management (13). Historically this has not led to too many problems. However, as the launch rate increases in response to the increased need for flights, these roll backs will have an impact which becomes increasingly severe. At some point in time, it may be necessary to leave the project structure and manage processes as opposed to projects.

Lack of operational expertise: Most of NASA's programs have been sunset in nature. They had a definite start and a definite end. As opposed to this the shuttle has a product life baselined at 100 flight per vehicle. Even with considerable error in this estimate this yields a program life of the order of magnitude of 20 years. This is a type of program with which NASA has little experience. NASA has been a world leader in the R/D arena throughout its history and it is in that arena that its expertise lies.

Demographics: When the demographics of the Johnson Space Center (JSC) are analyzed then it is found that the average age of the technical employees is around 43 years, most of the employees are engineers, 27% have a masters degree or better, most are GS 13's or above, the average service with NASA is 16.4 years, and the average start age with NASA was in the late 20's. In other words this is an educated experienced workforce which is in its middle age and whose significant employment has been with NASA. This is a workforce whose primary experience has been with R/D programs and with those programs they have been quite successful.

However, during the last decade, NASA has had significant decreases in manpower. A disproportionate reduction may have occurred in the safety, reliability, and quality assurance staff at NASA headquarters and at the Marshall Space Flight Center. Additionally, during the period preceding the Challenger accident, the Office of Space Flight also suffered a decline in staff (22, p. 154). NASA technical expertise is further reduced by the departure of highly skilled employees. During fiscal year 1985, approximately 1500 employees left the agency, over one-half of these (784) were engineers, technicians, and scientists. If present trends continue, NASA can expect to lose between 7500 and 9000 technical and scientific employees over the next ten years. While fifty percent of these personnel losses are formally attributed to retirement, NASA officials "know ... that many retirees leave NASA for higher paying jobs in industry". Additionally, seventeen percent of the departing employees acknowledge that they are leaving NASA for more financially rewarding jobs (22, pp. 155-156). The workforce reduction is also due to hiring freezes and transfers to other programs (13).

<u>National interests:</u> The pride of this nation is tied to the success of the shuttle program. Anything which adversely impacts NSTS affects our world esteem. This relationship between the shuttle and national self esteem must be considered in dealing with issues concerning managerial structure.

The shuttle is a very expensive National asset. The costs of orbiters, launch sites, and missions runs into the billions of dollars. However, loss of orbiters without replacement ones would deal manned spaceflight a serious blow

(23, p. 48).

The shuttle is also tied to National security. The Congress and the Executive Branch jointly developed the policy that the space shuttle should, in a reliable fashion, and at an internationally competitive cost, provide for most of the Free World's space launch needs (22, p. 119). Needless to say, DOD is one of the major customers of the shuttle. In fact, according to NRC (23, p. 47) maintaining the fleet at the flight rates shown in the report is imperative to build the foundation of SDI. Even without SDI many of the surveillance satellites will most probably be flown on the shuttle.

2.3. SUMMARY

The problem of determining the correct structure to manage the shuttle program is a difficult one. There are numerous complicating factors which impact the decision. This problem of effective management will continue to grow in size and complexity as the flight rate increases and as the demand for launches goes up.

As a partial summary of the complexity of the issues involved, the following statement from the Committee on Science and Technology is offered (23, p. 22):

> "The Space Shuttle has not yet reached a level of maturity which could be called operational as that term is used in either the airline industry or the military.

Each Shuttle flight is fundamentally unique, and requires unique preparations. Therefore, small changes in a mission can cause significant perturbations of mission planning and crew training."

3.0 CRITERIA FOR THE COMPARISON OF ALTERNATIVES

In order to make a choice between alternatives, the criteria for selection needs to be formally stated and well understood by the decision making body. To give the discussion a logical basis, the following criteria are presented. This list is, of course, only a partial list and its use must be integrated with an understanding of the complicating factors presented earlier. However, it offers a starting point to begin to compare alternatives in light of the complicating factors already discussed. These items are presented in summary in table 2 and discussed below.

3.1 ORGANIZATIONAL FEASIBILITY

Feasibility must be considered from at least 3 different aspects: technical, political, and cultural. In simple terms, any organization can be thought to be made up of these 3 components. The technical aspect refers to the level of technology within an organization necessary to satisfy goals and objectives and covers items such as computer processing, information systems, education, processing equipment, etc. The political aspect deals with items such as the internal

CRITERIA FOR COMPARISON

ORGANIZATIONAL FEASIBILITY

ECONOMIC VIABILITY

IMPLICATIONS ON NATIONAL SECURITY

IMPACT ON FUTURE SPACE DEVELOPMENT

EXPANSION OF THE USE OF TECHNOLOGY

CUSTOMER SUPPORT

SUPPORT OF ORGANIZATIONAL OBJECTIVES

TABLE 2

political structure within the organization and political pressure from outside. Within the organization, questions such as the location and possession of power become important. Outside the organization, in the question of shuttle management, the political aspect includes the normal activities of politics in the national arena. The cultural aspect of the issue deals with the cultural make-up of both the work force and the organization and includes beliefs, value systems, historical values, and social norms to name a few. The question here is how successful will the organization be in accepting, adapting to, and using an imposed managerial structure.

3.2 ECONOMIC VIABILITY

Will NASA and the United States both be able and willing to accept the cost of an imposed management system? Will this acceptance be manifested in congressional approval of funding? Is a given alternative a good use of the funds? Is it cost effective? Both long term and short term considerations of funding levels and cost control must be considered.

3.3 IMPLICATIONS ON NATIONAL SECURITY

Even though this was listed as a complicating factor it is also a criterion for selection. Any imposed management system must meet the needs of the Nation regarding security.

3.4 IMPACT OF THE MANAGEMENT SYSTEM ON FUTURE SPACE DEVELOPMENT

The question here is how will a given management system affect future space operations and development. Does a management system lend itself to the expansion of the shuttle program into other areas and provide for a smooth transition? Does a given choice hinder, aid, or not affect future space R/D programs?

3.5 EXPANSION OF THE USE OF TECHNOLOGY

Here the issue is the degree to which a management system allows for the expansion of technology and the related dissemination of the new information. The influx of new technology into our society is, of course, one of the reasons our space program is so valuable to the American people.

3.6 CUSTOMER SUPPORT

Any management system must be able to support the users of the product. In the case at hand, the customers of NSTS consist of NASA itself, DOD, and commercial payloads. These customers will, at the least, be concerned with timely missions, reliability, ease of use, and good cost control.

3.7 SUPPORT OF ORGANIZATIONAL OBJECTIVES

Perhaps this goes with out saying. However, it is included for the sake of completeness. Whatever the objectives of the organization may be, any system must be chosen with the intent of supporting these objectives both as they currently stand and as they may be predicted to change.

4.0 ALTERNATIVES FOR THE MANAGEMENT OF NSTS

There are as many different options to manage the shuttle as there are people to come up with ideas. The main alternatives are listed in Table 3 with the pros and cons being summarized in Table 4. The following discussion is an expansion of these tables. The idea here is to take the alternatives which have been considered in earlier works and evaluate them by use of the criteria in section 3. In doing this process, while the complicating factors of section 2.2 may not explicitly appear, they certainly will have an implicit impact on the evaluation.

4.1 DOD AS THE PRIMARY MANAGER

The Department of Defense (DOD) is one of the major customers of the space shuttle program. Consequently, there are several advantages to DOD running the shuttle program. From a national security standpoint it is hard to imagine a more secure form of management. With the growing emphasis on the Strategic Defense Initiative, this form of management would certainly provide for a close relationship. DOD has some experience with flying in space with its space command and with its close relationship with NASA. This last

ALTERNATIVES FOR THE MANAGEMENT OF NSTS

* DEPARTMENT OF DEFENSE
* OTHER EXISTING AGENCY
* A NEW GOVERNMENT AGENCY
* PRIVATE SECTOR MANAGEMENT
* NASA DOING BUSINESS AS USUAL
* NASA BUILDS A NEW OPERATIONAL ARM

TABLE 3

Table 4 - Criteria For Management Structure Comparison

Criteria	Dept. Of Defense	Other Govt. Agency	New Govt. Agency	Private Sector	Business As Usual	Operational Arm
Technical Feasibility	1	-2	0	1	1	2
Political Feasibility	-2	-1	0	-2	1	2
Cultural Feasibility	-2	-2	-2	0	1	2
Economic Viability	0	-1	-2	-2	1	2
National Security	2	0	1	-2	1	2
Space Development	-2	-2	-1	-1	1	2
Use Of Technology	-1	-1	0	2	2	2
Customer Support	-1	-2	-1	2	1	2
Org. Objectives Support	-1	-2	2	1	2	1
OVERALL SCORE	-6	-13	-3	-1	11	17

Ranking Scale:

-2 = Major Negative Implications
-1 = Minor Negative Implications
0 = Neutral
+1 = Minor Positive Implications
+2 = Major Positive Implications

relationship has also given them some insight into the shuttle and its related problems. In addition, DOD has had a large amount of experience with operational systems and moving R/D projects to an operational status.

Economically, DOD management of the shuttle seems to be almost neutral. In the short term, this would increase the budget of DOD significantly but would not seem to be too large an increment in the overall picture. In the long term, DOD management would not seem to be conducive to allowing the shuttle program to develop areas of economic return.

As has been pointed out earlier, the shuttle has and will continue to have a large R/D component. For DOD to manage the shuttle program would require a larger degree of R/D expertise than DOD currently has with space hardware. In this same vein, even though there is some degree of nebulousness about the exact statement of the missions of the two organizations, one thing is clear, there is a large difference between them. To use DOD to manage the shuttle would be a bad mix of these objectives and a would provide a dilution of mission for both organizations. This would also make for a competition for resources for space development.

There is a large probability that there would be considerable political pressure against DOD managing the shuttle. The US has taken a public posture on the use of space for peaceful means. This political pressure could come from both the people of the US and from foreign countries.

There is no reason to suppose that DOD would be terrible concerned with customer needs outside of DOD, thereby slowing the commercialization of space. In addition, the dissemination of space technology to the American public might also conceivably suffer.

As a final point, DOD management would not allow for a fertile ground for future space development due to their necessary narrow focus on national security. This not only includes the integration of the shuttle with the space station but other activities as well.

4.2 OTHER EXISTING GOVERNMENT AGENCY

There are a few advantages to having another existing government agency such as the Department of Transportation taking over the management of the Shuttle. Perhaps the most viable of these is that the agency would have to build a new organization which would correspondingly have no in-bred bias or preconceived notions. This would allow structure to be built which would meet the specific needs of a space transportation system. As an example, a new organization could be structured to take a very aggressive market position to help allay costs of launches. Since the structure would be new, there would no cultural difficulties with the mission of the new organization.

Most of the disadvantages of DOD management apply to any other government agency. These include dilution of mission and a bad mix of organizational objectives along with future space development problems and a competition for resources for space development. Added to these considerations are the fact that this would be an expensive option due to the need for new structure to be built. In addition, another agency would have little if any technical ability or experience with space and no experience with the shuttle. Realistically, the technical ability will come from existing NASA/contractor personnel and would bring along all the biases, culture, and preconceived notions that already exist in NASA.

4.3 A NEW GOVERNMENT AGENCY

In addition to the advantages listed above for an existing government agency, building a new agency to manage the shuttle would show a strong national commitment to space transportation. The disadvantages are likewise similar with one notable exception. Of all the options considered this would perhaps be the single most expensive. A new administrative structure would have to be built as well as the operating structure. In addition, it is not clear that building a new government agency would be politically acceptable.

4.4 PRIVATE SECTOR MANAGEMENT

The advantages of this management structure would include those of any new organization built to manage the shuttle. Included in these are the establishment of a culture which would be supportive of the operational space environment and taking an aggressive market position. This type of structure has the potential to be very supportive of the customer since private industry is, as a rule, used to thinking in this vein.

Some technical expertise certainly exists in the private aerospace community as well as operating experience although it is not clear that any one company would have the amount of expertise necessary to operate over the long term.

Politically, this system might be difficult to implement for numerous reasons. The size of the contract would bring "pork barrel" considerations to bear as well as perhaps be damaging to free enterprise in the space realm.

This management style would be bad for the future development of space since it is not clear that private enterprise can be far-seeing enough to meet future needs. Specifically, the interface of the shuttle with the station might suffer in the short term. As another major disadvantage national security problems would abound with this style of management.

Perhaps the major disadvantage to this style of management is economic. There is so much variability in the shuttle and its processing that it would be extremely difficult for private industry to control costs. This problem is compounded by the fact that in all likelyhood the shuttle will never be cost effective in that flights will pay for themselves.

4.5 NASA DOING BUSINESS AS USUAL

Because NASA has done a good job with national security and the expansion of technology, this style is strong regarding these two factors. It is not quite as strong for the future development of space since operational concerns will distract the R/D side of the house and will compete for resources. Due to the visibility of flying this competition for resources might be more favorable for operations than for R/D. Technically, NASA has the expertise to fly but it is not clear that they have the expertise to maintain an operational program. The political question is a mixed bag with the strong support NASA has had in the past having to be tempered with the influx of various governmental committees investigating NASA as a result of the Challenger accident. In the short term, this is perhaps the least costly of the alternatives. On the other hand, this may be a very costly option in the long haul if the shuttle program does not meet the needs of the nation.

Culturally, the present employees at NASA are not geared to run an operational system over a long period of time. The comments under the previous demographic section apply very strongly here as do the arguments in section five. In addition to this disadvantage, the operational objectives compete with and do not mix well with the overall objectives of NASA. As a last disadvantage, NASA seems to have had difficulties in dealing with customers in the past. If anything they have been overly responsive to customers causing late manifest changes and lack of standardization of cargo.

4.6 NASA BUILDS A NEW OPERATIONAL ARM

This structure seems to be the best of the alternatives for the long term management of the shuttle. Politically this leaves the management of space with NASA, an option which seems to be well met by the American people. Technically, this would allow for strong ties with the R/D community which designed the shuttle as well as allow for the infusion of operational technical expertise. A culture could be built in a new organization which was supportive of the space operational environment. It would be at least as good for national security, the future development of space, and technology expansion as the business as usual option since many if not all of these functions would be carried over to the new operational arm. In fact, the operation of the space station should be simplified. It could be structured to exhibit more control and service for the customer service area. It would also help to alleviate the problems associated with the dilution of the organizational objectives problem which business as usual would experience.

The major disadvantage to this option would be the fact that it would be slightly more expensive than the business as usual option in the short term due to the creation of a new sub-administrative system for an operational arm. However, this disadvantage should not be too severe since most of this structure would have to be created under the business as usual option anyway. In the long haul, this should have economic advantages over the business as usual option in that it would allow for a closer control of operational costs and a cleaner separation of these costs from those of R/D.

To sum up the arguments presented, only two options are in essence viable: business as usual and the operational arm. The operational arm provides the best of both worlds in that it carries with it the technical R/D expertise of NASA while allowing for a cleaner operational environment. However, it is fully expected that many will have trouble appreciating the need to separate the operational realm from the R/D realm. It is for this reason that the following section is presented.

5.0 WHY SEPARATE R/D FROM OPERATIONS?

A simplistic answer to this question is because the two management systems follow entirely different sequences and neither can function smoothly inside the other. They are inherently different because of the diversity of the management structure, political system, and cultural philosophy. The organizational ethos, motivational stimuli and communication system are different (12). The functions of one performed under the structure of the other is liable to produce sub-optimal results. The desired operational functions for the smooth operation and the future direction of the space shuttle program cannot be completely fulfilled under the present R/D structure at NASA. When the objective of smooth performance cannot be reached under the present structure, then a change is necessary.

At this point, the problem has been identified and a tentative solution has been proposed. The next step in the argument is to gain a better understanding of the two management systems. This understanding, while clarifying some of the aspects, should substantially both motivate and ease the planning and implementation process. Furthermore, while implementing the change, although it will be necessary to study everything in detail as the plan proceeds, it often helps to gain a macro perspective of the environment before the start of the actual planning. Sections 5.1 and 5.2 provide a macro view of R/D and operations management. A pair wise comparison of different organizational elements of the two management systems (taken from referance 4) is presented in Table 5. These thirteen elements will further help in understanding the system of before and after the change. The diversity of the two management systems is apparent from the table, which suggests a careful planning phase for the planned transition. Section 6 provides guidelines for adapting the proper mechanism of transition and ends with some suggestions for facilitating the process.

TABLE 5. CHARACTERISTICS CHART OF R&D vs. OPERATIONAL MANAGEMEN

ELEMENTS OF ORGANIZATION	R&D MANAGEMENT	OPERATIONAL MANAGEMENT
1. OBJECTIVES AND TARGETS	* Discovering and furthering knowledge under corporate planning. * Provide technical services to functional departments. * Objectives are generally defined as opposed to means. * Looking for significant breakthroughs.	* Fullfilment of well defined purpose which are reason for its creation and existance. * Achievement of the economic balance between demand and resources. * Looking for minor changes in incremental fashion. * Concerned about stability of the system.
2. ORGANIZ-ATIONAL STRUCTURE	* Fragmented: Divisional, Functional, and Flexible. * Allows easy transfer of info-rmation and personnel (10).	* Hierarchical. * Specialized, and clearly defined tasks.
3. SYSTEM HIERARCH-IES	* Authority is based upon the technical expertise (7). * Commitment to the task is negotiated.	* Authority is based upon the organizational position (7). * Responsibilities are mostly accepted.
4. LEADERSHIP BEHAVIOR	* Responsible to provide input to the strategic planning on a proactive basis, and not solely reactively (6). * Provide proper career development programs for scientists and researchers. * Provide behavioral and tech-nical support at all levels.	* Provide motivation and the targets for achievement. * Unity of command. * Provide technical guidance on how and what is to be performed.
5. SYSTEM MANAGEMENT	* Easy access to resources. * No short term work pressures. * Corporate strategy must be driven without long formal process. * Self directed and mostly responsible for own work. * Open discussions. * Friendly competition. * Decentralized power base.	* Defined/restricted access to resources. * Institutional organizational channels. * R&D and ventures must be tied-in with other growth oriented activities. * Worker is a part of the whole; guidelines are there-fore necessary for coordinat-ing activities. * More focused power base.
6. PERFOR-MANCE CRITERIA	* Long-term, risk / reward oriented on new businesses. * Encourages the strategic innovation.	* Short-term, result oriented on existing businesses. * Short-term evaluation programs are used where external factors are easily predictable.

TABLE 5 (CONTINUED).

ELEMENTS OF ORGANIZATION	R&D MANAGEMENT	OPERATIONAL MANAGEMENT
7.REWARD SYSTEM	* Recognition, status, and more complex assignments(10).	* Financial and hierarchical progression (10).
8.COMMUNICATION SYSTEM	* Across the major operating Units (10). * Mostly informal networks of communication. * Communication at low level.	* Within major operating unit. * Lateral communication is too specialized and at high levels. * Formal communication network.
9.INFORMATION SYSTEM	* Forward and outward oriented towards future needs. * Large amounts of the data received and processed.	* Highly structured towards the need of existing businesses (10). * Minimum amount of information is handled.
10.FLEXIBILITY	* Long-term commitment to the projects. * Flexible control of people. * Mostly undirected activity. * Room for creativity.	* Short-term schedule of the changes. * Structured job discription. * Limited undirected activity. * Flexibility to allow room for productivity.
11.WORK ENVIRONMENT	* Friendly, with respect for peers. * Working with, instead of working for. * Intellectual freedom. * Flexibility to some extend in organizational rules.	* Competitive and target oriented. * Structured work schedules. * Conformance to organizational rules. * Formal work environment.
12.CULTURAL CLIMATE	* Motivation by peer recognition and job satisfaction(18). * Internalized standards, as a result of extensive training. * Collegial approval sought; often based upon long run quality (7).	* Competitive and financially oriented. * Motivated by rewards, job satisfaction, recognition of of work and authority. * Established norms for the overall organizational rationality; often based on short term efficiency. * High work pressure.
13.POLITICAL CLIMATE	* Loyal to profession and organization; seek collegial approval and external recognition; identify with goals, values and incentives of profession (9). * Referent, information and expertise is the source of power for people with high maturity.	* Loyal to organization; seek super-ordinate approval and recognition; identify with goals, values and incentives of organization. * Organizational participants are in contest for resources and their control.

5.1 WHAT IS R/D MANAGEMENT?

The key to a successful research and development organization is the very presence of the atmosphere of creativity (3). The approaches taken and followed by the management have a tremendous potential to increase the morale and productivity of the organization. Perhaps the most important consideration for effective R/D management is the judicious balancing of the behavioral and technoeconomic factors. R/D requires a collaborative, rather than competitive work environment and flexibility in the operating procedures. The management job, while maintaining the economic viability of the organization, is to provide the following features for establishing a creative climate (15):

- o Autonomy and challenge to the individuals and groups;
- o Responsiveness to individual ideas:
- o Nurturing of puzzlement and wonderment;
- o Tolerance of differences of ideas; and
- o Inter and intra organizational communication.

The extent to which these features are to be provided or made available to a research group depends upon the type of work involved. For example, the creativity of an undirected research group following an offensive/defensive strategy should itself be "undirected", since ideally its desired output is a continued but unspecified flow of novel inventive ideas (15,19). Much of the work in this category involves conceptualization and theoretical investigation (5). This intellectually demanding activity performed mostly by highly mature scientists demands low bureaucratic activity and a more supportive work environment. Whereas, the success of the company following an applications engineering strategy is dependent upon the continued ability of its development engineers to provide creative solutions to particular user problems in a timely manner (19). These two examples, in a way, are the two extremes of an R/D environment. Most situations require a mixture of complete autonomy on some subjects and considerable control on the others. Whatever may be the situation, it is important to realize that the very survival of an R/D organization is dependent upon its ability to be creative and innovative, and this objective must not be sacrificed for any short term goals.

Effective Research and Development: The function of an effective R/D management is not only that of the usual short term planning for the control of uncertainties and daily routines, but is also that of planning for the future growth and direction of the organization (16). A representative R/D organization may have one or more of the following primary objectives along with some secondary objectives as well (6,19):

- o Discovering and expanding knowledge;
- o Developing new products;

- Improving existing products;
- Finding new uses for the existing products;
- Improving production processes;
- Finding potential uses for by-products or waste products
- generated by the present production system;
- Providing technical services to the functional departments in the organization;
- Analyzing and studying competitors.

How these functions and objectives are realized is the responsibility of the R/D management. Quite often it is possible that objectives may have conflicting requirements. Under such circumstances, it is again the responsibility of management to find a compromise formula which does not sacrifice organizational interests. An important aspect while making such decisions is to remember that the very survival of the R/D organization is dependent upon the ability of its members to foster innovation. Any organizational policy which curbs the innovative environment will eventually result in substandard performance by the organization. Indeed the organizational attributes do not produce creativity, but are aimed at motivating the individuals to be creative (21).

Besides the proper environment, the organization requires the right kind of people to do the job (11). R/D demands people like Newton who can work independently and come up with innovative ideas for undirected research. When the research is of a directed nature, then the hiring of people like Archimedes who have the capability of working under pressure is warranted. In simple terms, the R/D organization requires people who can perform the work expected of them. Furthermore, a forum must be created that allows the top researchers in the organization to effectively communicate with each other and with the management of the organization. The proper interface will help provide for a better utilization of the resources and a closer conformation to the corporate management strategy (11).

The next issue is that of behavioral and technoeconomic considerations for the highly motivated researchers. R/D people are educated and mature. Inherently they require a collaborative environment in which the decision making process is shared. The day-to-day decision making is also mostly delegated, and operating procedures are flexible to support and encourage the ingenuity of the researchers. The interaction between superiors and subordinates being informal, is usually at a low key. One common trait of R/D people is their desire for perfection. At times the cost of perfection goes beyond the limits of the control system. In such situations, a compromise solution is necessary which does not discourage the researchers.

<u>Operational Characteristics of R/D Management:</u> Difficulties arise on the economic side of the R/D picture. While it is mandatory for management to provide the right kind of

environment to foster innovation, unfortunately, there is a cost associated with the provision of this environment. One problem is that everyone is not an Einstein and every organization does not need one either. What every organization does require is economic viability. Moreover, the lack of historical data to evaluate alternatives makes the problem of economic analysis difficult, and the presence of so many intangibles further complicates planning. Any activity directed toward control could actually be curbing innovation and should therefore be cautiously planned and enforced. The question arises as to the solution of maintaining such a delicate environment. The one phrase answer to the situation is "balancing of behavioral and technoeconomic considerations" (19). The responsibility of R/D management is to perform that function without hindering creativity.

5.2 WHAT IS OPERATIONS MANAGEMENT?

The function of operations management is to provide goods and services to satisfy the anticipated demand. Due to the quantitative nature of the function, this performance can be evaluated on the basis of physical and economic considerations (8,17). The criteria of physical performance are those related to the quantity and the quality of the work produced. Whereas those related to the economic considerations are the measures of how effectively the resources were utilized to gain the overall objectives of the organization. The economic considerations include timing and location of the production, along with the equipment, material, energy and labor utilization. All of these considerations must be converted to common economic terms in order to evaluate the contribution of the resources toward the overall objectives of the organization.

The objectives of operations are well defined and quantifiable, which simplifies their evaluation. Similarly, performance is also measurable in terms of how well management handles the conversion process that transforms the inputs into the desired outputs. This implies that the working model and performance criteria of operations management are well established. Moreover, because the structure which forms the basis of management control is well established, the working philosophy of the operations management is relatively easy to implement.

Effective Operations Management: An important factor in the smooth functioning of an operations management is the presence of a well structured organization. The leadership of the organization is instrumental in providing this function. It is also responsible for the setting up of operational objectives and smooth work flow. A major function of the leadership of operations management is maintaining the future direction for the economic growth of the organization. In other words, it is responsible for what the organization must do to remain economically viable. How this goal is to be accomplished should preferably be in a participative environment in order to gain the support and commitment of the employees. In addition, the effective operations management requires:

- o Healthy and competitive work environment;
- o Judicious reward and incentive system;
- o Independence in decision making in congruence with the organizational guidelines;
- o Formality in the procedures;
- o Flexibility to change.

Characteristics of Operations Management: The evaluation of operations management is much easier than that of R/D management. Most of the variables in operations management are quantitative and therefore can be measured and appraised. The leadership function of planning, as in any other management situation, is very important in the operations environment. Unlike R/D, where most of the future direction of the organization is prescribed by the scientists and researchers working within the corporate philosophy, the operations management has the primary responsibility for this function. However, the planning function of "what has to be done", performed by top management should not be interpreted to imply non-participation by the employees. The employee participation is very important in determining "how it could be done", primarily because they have the expertise and definite interests in the area. The absence of participation in the latter situation can very likely result in low morale, lack of commitment to the work, and eventually lower productivity. The other requirement, as discussed before, in the smooth functioning of operations is the presence of a well defined structure. These two requirements may seem to be at odds with each other, and indeed there is a delicate relationship between them. There is a definite need to have established operating units with defined functional boundaries. Within the boundaries there is tremendous room for employee participation which will enhance the smooth working of the operating unit. Further, there is a need for cooperation and participation between operating units. Such linkages are important from a macro perspective and they reduce the need for a strict control system, thereby improving the productivity. The organizational structure must provide for such defined channels to insure that cooperation can be achieved.

6.0 BUILDING AN OPERATIONAL ARM FOR THE SHUTTLE PROGRAM

As is apparent from the presentation of R/D and operations management the two organizational structures follow a different course of action. The diversity of the two systems shows how difficult it is to manage the space shuttle program under the present R/D management umbrella. NASA has the people who have been performing the function of running the shuttle program. For the kind of work involved, they may have been working under what appears to be a sub-optimal organizational structure. They are experts in an area which is functionally different from the kind of work they will be expected to perform in the long haul. The need under such circumstances is that of changing not only the structure, but also the technical, political, and cultural systems of the program.

The first step in satisfying this need is that of identifying the problem. The second step is finding a solution to the problem, followed by a way to implement the solution. Finally, the last step is that of implementing the solution.

When NASA is convinced that it needs to change the present framework of the shuttle program to an operational arm, it needs to go through an organizational transition to reach the desired state of operation. The authors have developed a "Transition Life Cycle Model" for organizational changes (12). The problem of building an operational arm for the space shuttle program is a candidate example for the application of this theory. The characteristics chart of Table 6 (taken from referance 12) presents the role of five major elements of the organization during the four phases of the transition management. The first phase of the above model, called the creativity phase, requires a deliberation process by all involved in the change process (4,12). The requirement is that of establishing the uncertainty levels of

TABLE 6. CHARACTERISTICS CHART OF TRANSITION MANAGEMENT LIFE CYCLE

LEMENTS OF RGANIZATION	CREATIVITY PHASE	CONTROL PHASE	INTEGRATION PHASE	STABILIZATION PHASE
.OBJECTIVES AND TARGETS	* Create awareness for the change. * Study the problem. * define objectives. * Weigh alternatives. * formulate a mechanism for change. * Gather support for the change.	* Implement change process developed as a result of deliberation activity. * Monitor the cost, performance, and time frame for the change.	* Critically review the change process. * Plan and implement necessary changes in the transition strategy.	* Study the stable organization and hypothesize if the desired change has been made. * Disintegrate transition management team. * Effectively utilize human and non-human resources in the new system.
.ORGANIZATIONAL STRUCTURE	* Informal organization structure. The group maintain its advisory capacity.	* Matrix with major focus of control towards transition management group.	* Matrix with focus towards evaluating and replanning the strategic plan.	* Reorganization to the desired state of operation.
.LEADERSHIP BEHAVIOR	* Full commitment to change by the top management. * Provide input to strategic planning. * Provide behavioral and technical support at all levels.	* Unity of command. * Provide motivation and targets for achievement. * Delegation of responsibility. * Emphasize on pattern breaking.	* Delegation of authority. * Reward the people responsible for bringing change.	* Stabilize the system hierarchies. * Provide motivation for the people in new environment.
SYSTEM MANAGEMENT	* Decentralized power base of transition management. * Easy access to the resources. * Open discussions during the planning process for change. * Participation in decision making.	* Defined/restricted access to the resources. * Restricted changes to strategic plan. * Instutionalized organizational channels for work. * Focused power base.	* Delegation of work and responsibily in the redesigned system. * Re-evaluation of the strategic plan. * Instutionizing the communication channels of the new environment.	* Plan and implement the proper needs of the new system. * Effectively utilize the employees in the new positions.
PERFORMANCE CRITERIA	* Encourage strategic innovation.	* Conformance to the Strategic plan.	* Conformance to the strategic plan.	* Performance in the new system.

the technical, political, and cultural aspects of the space shuttle program. The choices available from the literature range from the Dissipative Change Model (2) to Logical Incrementalism (18). In fact, both of these extreme situations are rather infeasible in the case under study. The experience obtained by several years of flying in space has shown to a large degree that incremental change is far too unresponsive to meet the rapidly changing needs of the program. Similarly, because of the complexity of the technical process, cultural diversity of the management systems, and public exposure as a result of the space shuttle Challenger accident, it would be difficult to implement the change in an instantaneous manner. A realistic choice is a parallel track management model. The research oriented cultural atmosphere prevalent at NASA as well as their past history lends weight to this choice. For a more in-depth discussion of possible structures see reference (14).

In the parallel track model, the two management structures function simultaneously in the transition state: one conducts the organizational business as usual while the other manages the transition (1). It is not uncommon for the managers to function simultaneously in both structures. During the change process, the rate of organizational change is determined by the transition management team's analysis of feedback from the environment, operational managers and employees (14). The parallel track model provides a structured direction for transforming the present set-up into a new framework in which the management of the shuttle takes place under an operational arm.

7.0 SUMMARY

The main conclusion of this report is nothing new. It has been reached in most of the preceding studies considering this question. Perhaps what is new is the logic leading to the conclusion. If nothing else, it is of importance that this conclusion was reached after both a significant amount of flight experience and the Challenger accident.

The report can be thought of as consisting of three separate parts: the first presents complicating factors and criterion for evaluation, the second is the evaluation of the alternatives leading to the operational arm conclusion, and the third is the rationale for separating R/D and operations and the methodology for transition. It is fully expected that NASA management will for the most part agree with the first part of this report. They will also agree that the only two viable alternatives are the business as usual option and the operational arm. However, it is at this junction that the authors and NASA may diverge. For this reason, the separation argument was presented in detail. Some may feel with the separation of the shuttle program into a separate office that an operations arm is already in place. This is yet another reason for the presentation of the separation argument.

What does seem to be true is that the existance of the shuttle program as a separate entity is the beginning of the establishment of a parallel track system to create an operational arm. If this is the case, then there needs to be a creation of vision and strategic goals which clearly points out the direction of the agency. However, these two vital elements seem to be currently missing from the agency, which shows an ultra-conservative management process. This is truly amazing for an organization that is so bold in its conquest of space.

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CHAPTER VIII

RECOMMENDATIONS AND CONCLUSIONS

1.0 INTRODUCTION - ASSUMPTION AND GOALS

2.0 EVALUATE THE RISK MANAGEMENT SYSTEM

3.0 EDUCATE NASA ON THE DIFFERENCES BETWEEN R/D AND OPERATIONS

4.0 DESIGN FOR PRODUCTION AND QUALITY

5.0 EVALUATE AND INITIATE VALID RECOMMENDATIONS FROM LAST YEAR

6.0 EVALUATE AND INITIATE OPERATIONAL STRATEGIES

VIII. RECOMMENDATIONS AND CONCLUSIONS

1.0 INTRODUCTION-ASSUMPTIONS AND GOALS

1.1 ASSUMPTIONS

The following assumptions and opinions are built into the rest of this chapter and are stated here for completeness and in aid of following the rationale of the arguments presented.

The Years of 1987 and 1988 Will be Years of Turmoil, Uncertainty and Instability for NSTS: It will take at least two years for the program to settle down as a result of the aftermath of the Challenger accident and the resultant investigations.

NASA is Currently in a Response Mode of Management: Much of the effort of NSTS is being spent supporting and responding to the various commissions investigating the agency as a result of Challenger.

Currently There is No Integrated, Coordinated Plan For Transition: If such a plan exists then it has not been well communicated throughout the agency. Certaintly there is no participative system dedicated towards developing such a plan.

There is Some Degree of Confusion About the Strategic Goals of the Shuttle Program: A recent survey of Dr. Mark Markly of the University of Houston-Clear Lake brought this point home when he found a significant population at JSC which did not seem to understand the strategic goals of the agency.

The Demographics of NASA are Currently in Poor Shape to Manage an Operational Era: This assumption is unchanged from the last annual report. Further explanation lies in the demographics chapter of this report. Conversely, the demographics are in good shape to begin the management of the transition period.

There is No Real Pressure on NSTS to Transition to an Operational Mode in the Near Future: In fact, Challenger may have created just the reverse pressure. If any real resource is committed to this problem it is yet to surface in a visiable manner.

1.2 GOALS

In order for the NSTS to transition the following two goals are essential:

- NSTS MUST BEGIN INTEGRATED AND LONG RANGE PLANNING FOR TRANSITION. THIS INCLUDES THE ESTABLISHMENT AND COMMUNICATION OF STRATEGIC GOALS.

o NSTS MUST SEEK NEW METHODS OF DOING BUSINESS AND ACCOMPLISHING THE STRATEGIC GOALS FOR THE OPERATIONAL ERA.

These two goals are interrelated. Without a plan, a smooth transition will not occur. Without communication of the plan to the workforce, unified support of the plan is not possible. Once strategic goals are established, then new methods, in the sense of different from the old or usual ones, must be found to accomplish these goals. One of the recurring themes of this report is that the old methods will have difficulty accomplishing operational goals.

1.3 INTRODUCTORY COMMENTS

The rest of this chapter is devoted to specific recommendations and their related reasons. While the shuttle is on a stand down basis the pressure on management should be reduced to the point where there is time to concentrate on strategic questions. It is equally as important to lay a good foundation for an operational era as it is to get back to flying. Strategic considerations have a long lead time. Now is the time to begin the transition process in earnest. These recommendations are aimed at beginning the process.

It is a firm belief of this research team that NASA must solve its own problems. The only value of an outside influence such as this team is that of stimulating the thought and problem solving process at NASA. It is in this light that the recommendations are presented.

2.0 EVALUATE THE RISK MANAGEMENT SYSTEM

A task force needs to be formed to evaluate the risk management system in light of Appendix VII F. The purpose of this task force would be to determine if the risk management system would have identified the problems found since the stand down in a timely manner and whether the program would have been able to react to such findings if the flight rate was as predicted.

3.0 EDUCATE NASA ON THE DIFFERENCES BETWEEN R/D AND OPERATIONS

Until this is done, many at NASA will believe in the work harder, faster argument. Efforts need to be expended to insure that all elements of the shuttle program understand how their environment will be changed when the shuttle enters the operational era. Without this understanding, it will be impossible to insure a smooth transition.

4.0 DESIGN FOR PRODUCTION AND QUALITY

A new orbiter is being built. Programs and structures are being changed. Now is a good time to emphasize that quality should be built in from the bottom up. This issue needs some leadership in the form of committment from upper level management.

Production issues such as standardization and the shortening of transportation lines need to be addressed. In addition, it is important to cross train to ensure that the interface between design and production is smoothed. Directions for operational viability need to be determined.

5.0 EVALUATE AND INITIATE VALID RECOMMENDATIONS FROM LAST YEAR

The recommendations from last year need to be evaluated by upper level management. The valid ones of these need to be initiated. These recommendations (see "An Investigation of Transitional Management Problems for the NSTS at NASA, annual report, 15 Jan 85-15 Jan 86, cont no. 9-bc4-19-4-lp) are listed below. The original report should be read for an in-depth discussion.

- o Begin the planning.
- o Begin to build the structure.
- o Increase employee's awareness of operational concepts and of transition.
- o Begin to model the demographics.
- o Start to build monitoring systems to track transition.

6.0 EVALUATE AND INTITIATE OPERATIONAL STRATEGIES

A committee such as the recent Phillip's committee needs to be appointed by the administrator to evaluate the operational arm concept. Then operational strategic goals need to be determined and communicated to the work force. If an operational arm is the objective then plans to obtain that objective must also be established and communicated. A process to accomplish this action is included in last year's recommendation to begin the planning.