AN ABSTRACT OF THE THESIS OF

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Title: Cockpit Task Management Errors : An ASRS Incident Report Study

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Kenneth H. Funk II

The flightcrew of a modern airliner operates in a multi-tasking environment with several tasks competing for the same attentional resources at the same time. Too many tasks vying for the crew's attention concurrently imposes a heavy workload on the flightcrew. This results in the satisfactory execution of some tasks at the expense of others. Consequently, flightcrews must manage cockpit tasks - a process we call Cockpit Task Management (CTM). Funk (1991) defines cockpit task management (CTM) as the process flightcrews use to prioritize cockpit tasks, allocate required resources, initiate and terminate multiple concurrent tasks.

Despite improvements in aircraft reliability and advancements in aircraft cockpit automation, "pilot error" is cited as the main reason (over 60% of all aircraft accidents) for planes still falling out of the skies. One of the objectives of this research was to determine the significance of CTM errors in "pilot errors". Having established its significance, the next step was to refine the existing error taxonomy of Chou & Funk (1991). A structured error classification methodology was also developed for classifying CTM errors and validated using 470 Aviation safety Reporting System (ASRS) airline incident reports.

This study identified CTM errors as a significant component of "pilot errors" accounting for 231 of the 470 incidents analyzed (49.2%). While Task Initiation errors

accounted for the largest of the *general* error categories (41.5%), it was the Task Prioritization errors (35% of *general* and *specific* error categories) that unlocked the door that led to error committals in the other error categories. Task Prioritization errors led to Resource allocation errors which, in turn, resulted in several kinds of errors being committed in the other categories.

The findings had implications that were largely training-based. In particular, the importance of pilot education which CTM provides (as opposed to crew training that CRM provides) is emphasized. The incorporation of formal CTM concept into existing CRM training programs was advocated. In addition, a staggered scheduling mechanism in crew training agenda involving CTM, CRM, Line-Oriented-Flight-Training (LOFT) and simulator sessions was suggested. A recommendation was made for a comprehensive Cockpit Task Management System (CTMS) to be installed in the cockpit to help crews to prioritize tasks and remind them of the need to initiate, terminate or re-prioritize tasks as necessary. The inclusion of Air Traffic Control personnel in flightcrew training sessions was also recommended.

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An ASRS Incident Report Study

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1. INTRODUCTION

More and more, flight safety is being emphasized by regulatory bodies as well as the airlines themselves. Despite the fact that the number of aircraft accidents, over the last ten years, have continued to decline, the *rate* of improvement in air safety has slowed somewhat in the same period. As a matter of interest, 1992 appears to have been the worst year for airline accidents for the last decade. Various agencies besides aircraft manufacturers have compiled airline accident statistics over the last several decades and, with slight discrepancies, there appears to be strong agreement as to their primary cause. One such source listed causal factors for air carrier accidents as shown in Table 1.

Table 1 Causal factors for air carrier accidents, 1959-1990 with 1981-1990 data in parenthesis.

Probable Cause	% of Total Accidents
Pilot Error	65.2 (60.4)
Airplane	16.4 (15.0)
Maintenance	2.8 (3.4)
Weather	4.5 (4.3)
Airport/ATC	4.9 (5.8)
Misc.	6.2 (11.1)

Source: Statistical Summary of Commercial Jet Aircraft Accidents, Worldwide Operations 1959-1990. Boeing Commercial Airplane Group. p. 14.

Rouse & Rouse (1983), Chambers & Nagel (1983) and O'Hare & Roscoe (1990) give estimates of accidents due to pilot error varying from 60 % to 90 % of all accidents. Advances in aviation technology have made the aircraft a very reliable machine, with well over half the total accidents being caused by the human element. The problem of 'pilot error' is fairly complex in nature and, as yet, no comprehensive model of 'pilot error' exists. There are several reasons for this. First, research into human behavior is not quite as advanced as the physical phenomena (Nagel, 1988). Second, aircraft accidents are usually catastrophic in nature, resulting in insufficient evidence, during accident investigation, to draw a complete picture of the *cause(s)* of the errors (as distinct from the causes of the *accident*). Third, the threat of litigation and punishment associated with accident investigation makes it difficult for the parties involved to be honest in their testimonies. This means that the reports received from the flight crew after the accident (were they to survive it) are sometimes not reliable. Since the cockpit crew is the one involved in getting the airplane from departure to arrival, eventual blame is laid squarely at their door.

Flying a modern airliner is no longer a tedious task requiring a multitude of crew-members with special expertise in diverse fields. In the industry's dauntless quest to automate almost every aspect of flying and controlling the aircraft, progress in automation has reached a point that relegates the pilots to the role of *monitors*, at best, a tedious function to which people are ill suited. Even the presently touted new technology, such as the glass cockpit and fly-by-wire designs bring along associated new problems. Impaired by boredom, a monotonous environment and coupled with fatigue, the effects of lengthy monitoring duties finally reveal themselves as in-flight incidents and, in extreme cases, as accidents.

Airplanes operate in a complex systems environment. On the flight deck of a modern airliner, the flight crew has an array of instruments giving vital information on the aircraft's ever-changing state. All of this information has to be assimilated and integrated in a coherent way such that safe execution of maneuvers can be accomplished. The flight crew must be seen as *system integrators* working within a larger system, comprising ground control and national airspace control. However, the principal responsibility for integrating all this information and execution of subsequent actions rests with the captain, who functions as a *systems manager* on the flight deck of this *multi-tasking and dynamic* environment.

There are a number of problems associated with the proper assimilation of all the relayed information and their translation into correct and timely responses. Part of the problem may be attributed to the "one-box-at-a-time" (Wiener, 1987) device installation in cockpits. The make and models of the various instruments and their display techniques vary by the manufacturers. This leaves the crew with the job of decoding and integrating all the different instrument displays, which detracts from their primary task of flying the aircraft. This "one-box-at-a-time" problem is now being addressed by the concept of the "fully integrated cockpit" where avionics manufacturers are doing the integrating and providing the flight-crew with only the necessary information in normal flight or to take-over automation, with varying levels of control, during an emergency.

Assimilation and translation of all the information displays are carried out by several of the processing modes in humans. Failure of *one* of the several *information processing modes* (comprising visual, tactile, auditory and sensory modes) on the part of the flight crew, even for a momentary period, may cause a sudden overloading of the other modes to create a critical condition for errors to be committed. Nearly a third of all airline accidents in the past several decades has been due to procedural errors i.e. non-compliance with standard operating procedures by the flight crews (Nagel, 1988). These non-standard operating procedures reveal themselves as incidents or, where the results are more serious, as accidents. Complete elimination of these errors would be difficult to achieve within a short time; a more realistic near-term goal would be a substantial reduction of these procedural errors (Nagel, 1988). Indeed, the focus of accident investigative reports and recommendations should be on making flight-crews aware of the many failure modes that are possible (and which result in incidents and accidents) such that they become aware of the phenomena and will be better equipped to deal with them when they arise.

Several categories of aircraft accidents involving operational and human factors are subsets of populations of incidents that contain the same elements (Billings & Reynard, 1984). Since procedural errors account for over one-third of all the accidents (Sears, 1986), it is therefore important to gain an understanding of the tasks involved in the cockpit environment and thereby understand the process that led up to the reasons for the deviations and, ultimately, errors being committed. Sears (1986) compiled airline accident statistics over a twenty-four year period, from 1959 to 1983, comprising 93 major accidents (Table 1.1).

Table 1.1 Significant Accident Causes and Percentage Present in 93 Major Accidents (1959-1983)

Cause of Accident	Presence (%)
Pilot deviated from basic operational procedures	33
Inadequate cross-check by second crew member	26
Design Faults	13
Maintenance & inspection deficiencies	12
Absence of approach guidance	10
Captain ignored crew inputs	10
Air Traffic Control failures	9
Improper crew response during abnormal conditions	9
Insufficient or incorrect weather information	8
Runway hazards	7
Air Traffic Control/crew communication deficiencies	6
Improper decision to land	6

Source: Human Factors in Aviation. Academic Press 1988. David Nagel & Earl Wiener

The most recent data on aircraft accidents that resulted from controlled flight into terrain, or CFIT's, is depicted in Figure 1.1. This shows that in 1992, 706 people were killed in 21 CFIT's - the second highest total in the last ten years. CFIT accidents are the most avoidable of all regular categories of accidents describing a particular type of aircraft collision with the ground. CFIT accidents were not related to aircraft types but to two major causes - weather and crew distraction. The use of the term "controlled" in CFIT accidents is unfortunate because it could be interpreted to imply pilot intent. What it really means is that the aircraft had no technical problems which would have caused the accident anyway and that the pilot was in full control of the airplane at the time of impact with the ground. The term implies that the pilot was unaware of the impending impact or realized too late to prevent it.

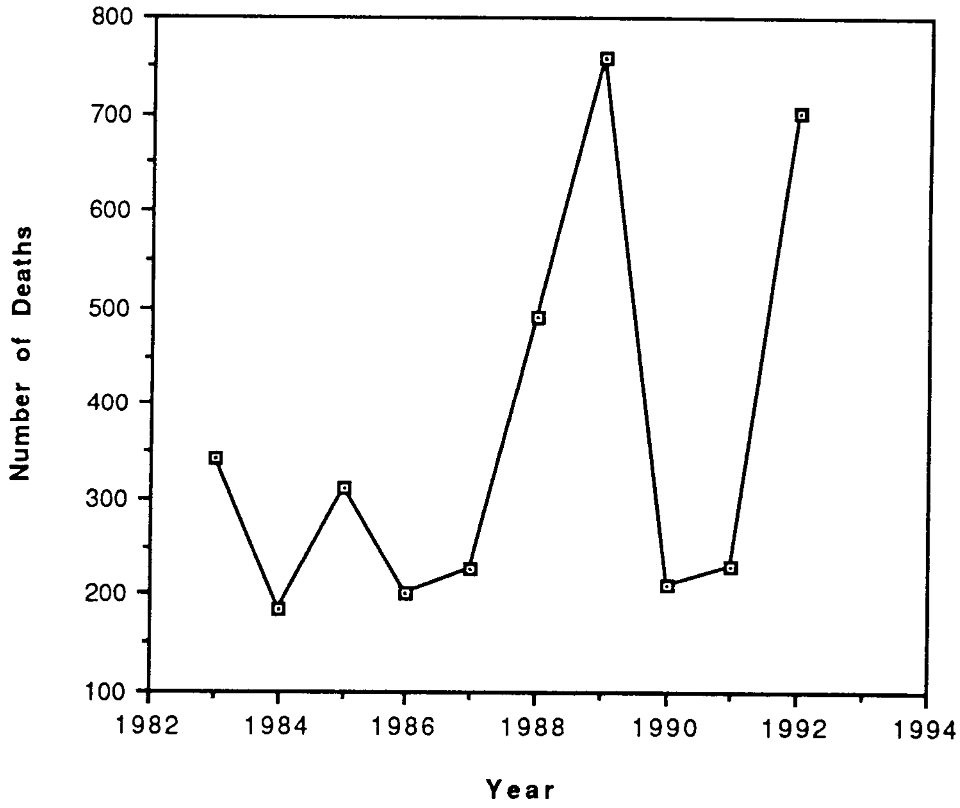

Figure 1.1 Number of Controlled Flight Into Terrain (CFIT) accidents resulting in fatalities during the last ten years. Source: Flight International, Jan. 27 1993.

Figure 1.2 depicts the part, in the flight phase (by percentage of accidents), where most of the accidents had occurred. Almost half of the accidents took place in the latter stages of the flight, beginning with the approach (to land) phase. Despite accounting for almost fifty per cent of all accidents, this flight phase accounted for only 4% of the entire flight duration.

Clearly, there was a need for a model to classify these errors in order to trace the origins of these errors that led up to the accidents. Classification of errors itself, while being useful in gaining an overall perspective, did not reveal why crews failed to follow standard operating procedures.

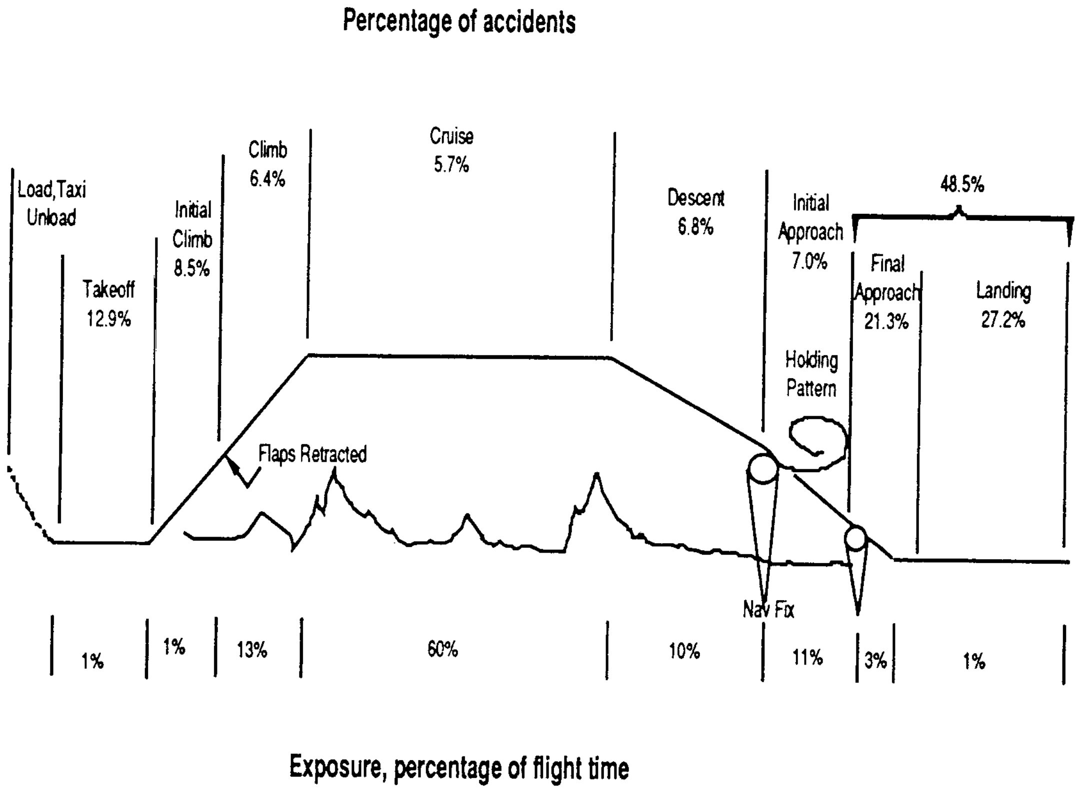

Fig. 1.2 Percentage of Accidents by flight-phase based on an average flight duration of 1.6 hours. Source: Statistical Summary of Commercial Jet Aircraft Accidents, Worldwide Operations 1959-1990. Boeing Commercial Airplane Group. p. 13.

It is also appropriate to talk of causal factors of an accident rather than *the* cause, since accidents and incidents were normally the result of a chain of events with a *probable* *cause* (primary) supported by *causal factors* (contributory)[1] . Nevertheless, one thing is clear: errors (especially procedural errors) that lead to accidents are neither random nor mysterious. It has been said that there are no new types of aircraft accidents, only people with short memories. In many of these cases, the incidents and accidents were foreshadowed by clear evidence that the problems existed long before (Barlay, 1990). An operational incident, once incurred, would signal the possibility of an impending accident; with a repeat of the same incident, the *possibility* would then become a *probability*. Sheer repetitions of the same mistakes should have drawn attention to themselves and revealed their causes such that preventive measures could have been taken (Barlay, 1990). However, public attention is generally focused on airline safety issues only when accidents happen.

1.1 Cockpit Task Management (CTM)

Much has been done in the field of optimizing available resources in the cockpit. Cockpit Resource Management is a concept that is widely accepted by most major airlines and focuses on crew resource optimization on the flight deck of an aircraft; resources that include both equipment and the physical resources of the crew. The drawback of CRM is that its focus is on very broad issues relate chiefly to the sociological aspects of crew behavior. It includes personality, crew compatibility, coordination and communication and other aspects of team building issues. What is lacking is a focus on the tasks that the crews engage in on a continual basis and whose execution results in errors that lead to incidents and accidents. Cockpit Task Management (CTM) is a term used to describe the process that crews use to prioritize, allocate resources, initiate and terminate multiple concurrent tasks (Funk, 1991). CTM focuses specifically on cockpit tasks and their management by the

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[1] The Canadian Air Safety Board (CASB) reports accidents in this manner, with a *probable cause* which was later changed to *'cause related findings'* and *'related findings'*. The German system reports accidents as *'findings'* and *'list of chain events'* which leaves it to the reader to interpret as desired. The U.S. system sticks to demanding a *'probable cause'* (and naming it if possible) and getting the report out *inside twelve months*.

crew. CTM offers a way to analyze incidents (and accidents) using an error taxonomy that categorizes specific task errors such that root causes for the error committal can be identified. It must be noted, however, that CTM offers one (of several) perspectives of looking at task management errors.

1.2 Research Objectives

The principal objective of this thesis was to determine the significance of CTM errors with respect to flight safety and to develop a structured method of error classification to account for all the task management errors committed in the cockpit of a modern airliner.

The basis for the research came from earlier work on CTM errors (Chou, 1991) and a collection of ASRS incident reports. While the work of Chou dealt primarily with NTSB accident data (with a little ASRS incident analysis), the bulk of this thesis was based on ASRS incident reports dated between 1987 and 1993. In particular, the original error taxonomy of Chou and Funk (1990)was revised extensively and a method of classifying the errors, more rigorously, is presented. By adding structure to the methodology of classifying these errors, I hope to enable other researchers studying the same incident reports to arrive at the same error classification. The attempt was to have a coherent system that could be applied to every incident report to obtain consistent results. It must be noted however, that the methodology was not validated by any other researcher or individual.

Having thus determined the significance of CTM errors and having classified them, some recommendations were developed for the design of procedures and equipment that would contribute to mitigating those task management errors and thereby improving flight safety.

1.3 Overview

An overview of this study and the organization of the investigation is as follows. Chapter 2 gives some background information on human error studies methodology and discusses the relative strengths and weaknesses of each approach. There is also a discussion on both earlier and more recent research into human error models by several leading investigators in this area. An introduction to the concepts of Cockpit Resource Management (CRM) and Cockpit Task Management (CTM) is also given in this chapter which is discussed further in Chapter 3. An introduction to the earlier CTM error taxonomy is given. The research objectives are also outlined. Chapter 2 also introduces the fundamentals in a task transition process and its relation to CTM errors. Chapter 3 discusses error classification schemes in general and, in particular, discusses the error classification methodology used. The original error taxonomy was modified in the light of the research into the 470 ASRS incident reports. The error classification methodology is discussed with definitions and supported by four examples of reported incidents in each classified error category. Chapter 4 deals primarily with the results of the report analyses. The results of the analyses were tabulated and summarized. Chapter 5 is a discussion of the results of the research. Specific error categories are discussed with respect to the actual task management errors committed in each of those specific categories. In Chapter 6 an attempt was made to link some of the specific task management errors to certain human cognitive failures. Chapter 7 provides some conclusions and recommendations to mitigate these errors.

2. BACKGROUND

2.1 Introduction

There are a number of ways in which human error studies have been conducted. Nagel (1988) identified four different methods. First, there is direct *observation*, where the observer watched the flight crew perform their duties on the flight deck and noted his observations. There were a couple of drawbacks to this approach. The main one was that the presence of the observer could alter the behavior of the observed. The second was that the observer himself could make observation errors; this implied that the observer should be very familiar with the pilots' duties. Curry (1985) and Wiener (1985), both pilots and human factors professionals, had applied this method very successfully in their studies of flight crew performance.

The second approach is to study *accident data*. The drawback here is that although the probable cause of the accidents could be identified, the reasons for the errors leading to the accident could be difficult to establish since the leading witnesses, in most cases, perish in the accidents.

The third method involves the study of aircraft *incident reports*. In the U.S., the Aviation Safety Reporting System (ASRS) represents a collection of self-reports (provided by aircraft flight crew and Air Traffic Control personnel) on aircraft incidents. One important aspect of the system is that the reporters are given some degree of confidentiality and immunity from prosecution. The drawback however, is that these reports are not random; often, safety-minded people report more often or some recent incidence of accidents or legislation may prompt more reports to be submitted. However, the added advantage (from a human factors perspective) is that it is possible to perform a call-back interview with the reporter to find out what caused the error to happen and the circumstances under which it was committed. Data from the ASRS database caused hundreds of "alert bulletins" to be issued to appropriate agencies that resulted in a variety of actions that have themselves had measurable effects on aviation safety in the United States (Nagel, 1988). Table 2.1 shows the percentage of ASRS incident reports that reflect pilot and controller error.

Table 2.1 Frequency Distribution of ASRS reports by Problem Origin

Problem Origin	% of reports received
Air Traffic Control	40
Flight Crew	41
Aircraft/subsystem	3
Airport/subsystem	4
Publications/procedures	2
Other	10
	100

Source: Human Factors in Aviation. Academic Press 1988. David Nagel & Earl Wiener

The fourth method of error studies is to study errors in laboratories and simulators. This is a relatively simple method of error study since a number of the complex conditions (that would be present in the real environment) can be filtered out so as not to obfuscate the research. The drawback, of course, is that this clinical approach does not accurately represent real-world conditions. Ruffel Smith (1971), however, showed that accurate reproduction of operational conditions via a *full mission flight simulation* could be a valid model using this methodology.

For this research, the third method - study of incident data - was utilized. Incidents are really accidents that did not occur and the reports provided ample evidence of repeated task management errors made by flight crew. Incident analyses, as it became apparent, revealed the specific areas of the flight regime where errors were committed with more frequency than others, including the actual task management error committed by the flight crew. It was possible, at the end of the research, to see very obvious areas of task management problems and provide recommendations for mitigating them. Another advantage of the incident review technique is that it provides the basis to devise a structured call-back questionnaire i.e. asking the right questions (of the reporter) to provide an accurate historical record of events preceding the error committal. One of the drawbacks with the current callback technique used by ASRS, was that the callback review did not go back far enough to give a better historical record of preceding events that eventually led up to the incident.

2.2 Human Error Analysis Models

Investigative studies and formal research into the subject of human error is not new. The fact that human errors are the principal cause of aircraft accidents served to initiate early research into human error studies. A brief overview of existing models on human error by leading researchers in this field is given as background information.

Human behavior is a complex subject - more so if the human is a captain at the controls of a modern airliner. With a multitude of tasks (each demanding some measure of his attention at some time or another) and a flight crew and Air Traffic Control to manage, an accurate portrayal of his behavior under such workload would be difficult to simulate.

As such, no model of pilot error exists that satisfactorily and comprehensively accounts for all errors committed on the flight deck. A number of theories based on a general approach to error classification (Rouse & Rouse, 1983) and single-task human performance (Rouse, 1981) have been adduced. Other models based on behavior-oriented schemes that emphasize basic human information processing capabilities have been adduced, notably the models of Norman (1981) and Rasmussen (1983). Parasuraman (1987), who studied user interaction with automated monitoring systems where information is displayed at rapid rates and dynamically updated, concludes that human monitoring performance can be sub-optimal as a result of lowered vigilance. At the other extreme, Taylor (1981), who studied car drivers, argues that safety is hard to improve beyond a certain limit. He stated that drivers tend to keep their arousal at a desired, constant level, and consequently if conditions become too undemanding, will go faster to generate more arousing incidents (Taylor 1981). It appears, if Taylor is right, that the reason for accidents may be an intention to take risks. In fact Taylor (1981) criticizes the "mechanistic" accident investigation of *causes* rather than the *reasons*. Reasons are seen as conditioning elements (prior to error commitment) while causes relate to a course of events (after error is committed). In aviation, each plays a role simultaneously and it would be pointless trying to distinguish between the two.

Models of dual task performance of humans, using Multiple Resource Theory (Wickens & Flach, 1988), extended to cover multiple task environments have also been investigated. The information-processing model of human performance (Card, Moran & Newell, 1983) is an information-decision-action model that asserts that cockpit behavior is a three-stage process. The acquisition, exchange and processing of information is the key activity in the first stage; decision-making with specific intents and plans to act marks the second stage while implementation marks the final stage. The Billings and Reynard model (1984) also has categories that reflect information transfer problems in aircraft.

2.3 Cockpit Resource Management (CRM)

Almost all of the error models discussed above started out as general error models or single-task and dual-task performance models that were extended and applied to the multi-tasking cockpit environment. These generalized models, while they provide a better understanding of the kinds of errors committed on the flight deck, do not focus on the specific tasks involved in the various phases of flight. This is somewhat akin to a student going for an examination with a head full of general answers looking for question categories to fit them into. This generalization, in part, has resulted in the concept of cockpit resource management (CRM). The subject of cockpit resource management, showing a close relationship between pilot workload and errors in vigilance and decisions, has been documented in simulator studies (Ruffel Smith, 1979). Lauber (1986) defines CRM as *"..the effective utilization of all available resources-hardware, software and liveware...to achieve safe, efficient flight operations"*. This is a catch-all concept that includes all possible combinations of human factors as well as theoretical and applied psychological aspects of human behavior. What is needed then, is a model that accurately characterizes the specific tasks the crews engage in, such that the establishment of measures and standards (a problem with CRM) are facilitated.

2.4 Cockpit Task Management (CTM)

Much of the focus in crew training of the major airlines is on flight crew performance as a team in the cockpit environment. Issues such as crew coordination, team-building, and other such issues on social dynamics are being emphasized. In all of these efforts, there was very little attempt to focus on the specific tasks that crews engaged in and the techniques employed for their successful execution. In particular, the subject of how crews went about prioritizing tasks, allocating the necessary mental and physical resources required for the task execution had hardly been addressed at all. What was unusual was that, when the ASRS incident reports were analyzed, there were numerous situations where the flight crew committed un-forced errors in carrying out routine tasks - tasks for which there were specific guidelines in their Standard Operating Procedures (SOP) handbook for managing them. The traditional approach to dealing with task management errors by focusing on the social aspects of crew interaction and their coordination appeared to be missing the point. The approach adopted in this study could be termed a "bottoms-up" approach where errors were looked at and projected backwards to uncover the trigger events that led up to the error committal and then ways to mitigate those errors were sought. This study focused specifically on cockpit tasks - their management (or mis-management) by the crews and aimed, as a first step, at developing a structured method of classifying these errors.

Cockpit Task Management (CTM) is a concept used to describe the process that flight crews use to prioritize, initiate, execute and terminate multiple concurrent tasks (Funk, 1991). It is a multi-step procedure that consists of mission goals, a series of tasks to achieve those goals, a method of prioritizing those tasks and sequencing their execution, a method of allocating resources to those prioritized activities, a method of revising and continually updating the sequence and priority level of those tasks and a method of terminating those tasks.

Since goal fulfillment is the basis of all cockpit tasks, it offers a starting point for understanding CTM concepts. A goal for a system is defined by a set of desired behaviors and if any one of the behaviors is exhibited by the system, the goal is achieved (Funk, 1991). The use of the term goal is generic and actually covers higher level goals (super-goals), mid-level goals (goals) and lower-level goals (sub-goals). Funk's partial flight agenda (Fig. 2.4) shows the various elements of the hierarchy. An example of a supergoal would be the safe arrival at the destination airport.

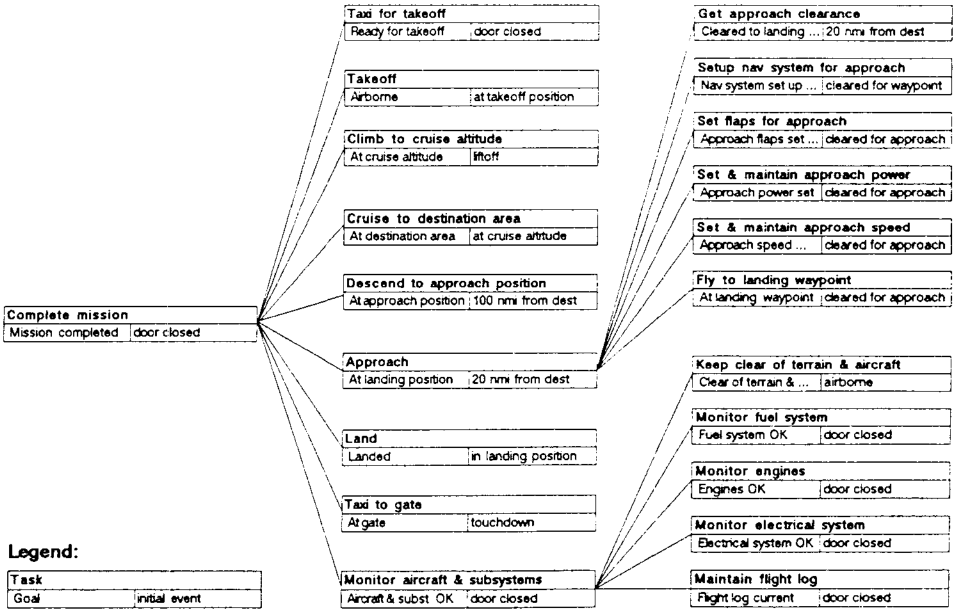

Figure 2.4 A Partial Flight Agenda (Funk, 1991)

In CTM, a task is defined as a process that is completed to cause a system to achieve a goal (Funk). Funk further identifies an *initial event* (trigger event) that defines the conditions under which the goal becomes relevant and a *terminal* event that signals the end of that goal pursuit. For an aircraft starting its descent phase, the initial event is the distance to airfield (100 nm in Fig. 1.3). This trigger also signifies the terminal event for the cruise phase (the preceding goal). Hence, there are numerous sub-goals in most of the preceding goals. Taxiing for take-off (*initial* event - doors locked) is one of the several tasks carried out to satisfy the next goal - ready for take-off.

2.5 Task Transition Process

A task, under normal circumstances, could be seen to be in one of the several states as depicted in Figure 2.5. Initially, a task is seen to be pending until an initial event occurs. For example, just prior to being established on the approach phase (task pending), the initial event, 20 nm from the field is reached (task active) until a terminal event (the Outer Marker, say) is reached.

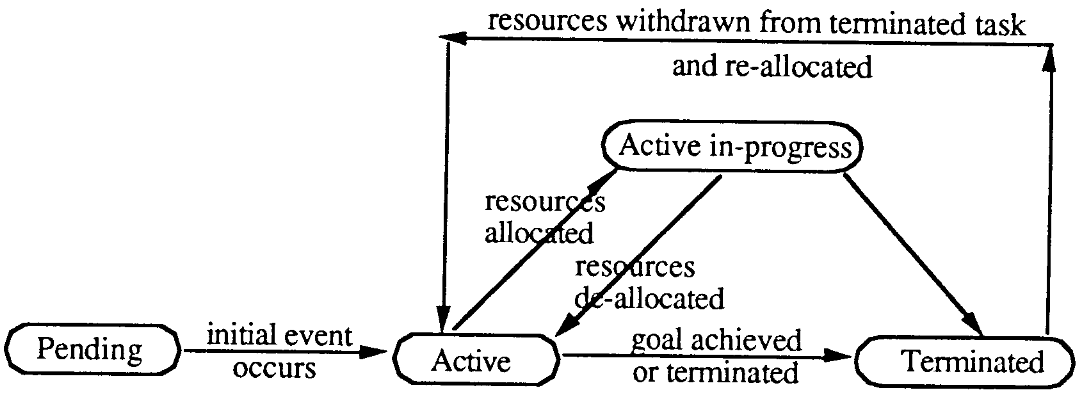

Figure 2.5 Transition stages of tasks

Pending tasks become active, in time, which means that they are no longer dormant but will be acted upon at short notice. Active in-progress tasks are distinguished from active tasks in that, the former will have mental resources allocated to them and are being acted upon (attention, actions or decisions taken) by one or more crew members. In addition, active tasks have a greater degree of immediacy attached to them which implies that they will be made active-in-progress in a very brief time period. An aircraft on short finals will have a number of active in-progress tasks going on concurrently. An example of an active task here is the instrument scan. The crew switches their attention for a sweep of the instruments from time to time to make this task active in-progress (very briefly) and it (the scan) returns to the active state, time and again (much the same way as a motorist switches his view from the road ahead to the rear-view mirror from time to time). In the case of multiple tasks, as is the case during an approach, the most immediate task (already prioritized before-hand) is attended to first and, as time goes on, resources withdrawn from it (terminal event reached) and re-allocated (to next, immediate task) relative to the degree of its goal fulfillment (goal fulfilled, re-prioritized or aborted). Additionally, any of the transitions may be reversed or re-ordered at any point in time.

The task transition process can be better understood if it is applied to an actual scenario involving a particular flight phase. Figure 2.6 depicts the case of an aircraft on short finals and identifies some of the tasks that are pending, active and terminated at the various phases of the approach.

Note that there is another category of a task stage (latent) that does not generally appear on the agenda but is always present in the background that can be transitioned to, at a moment's notice.

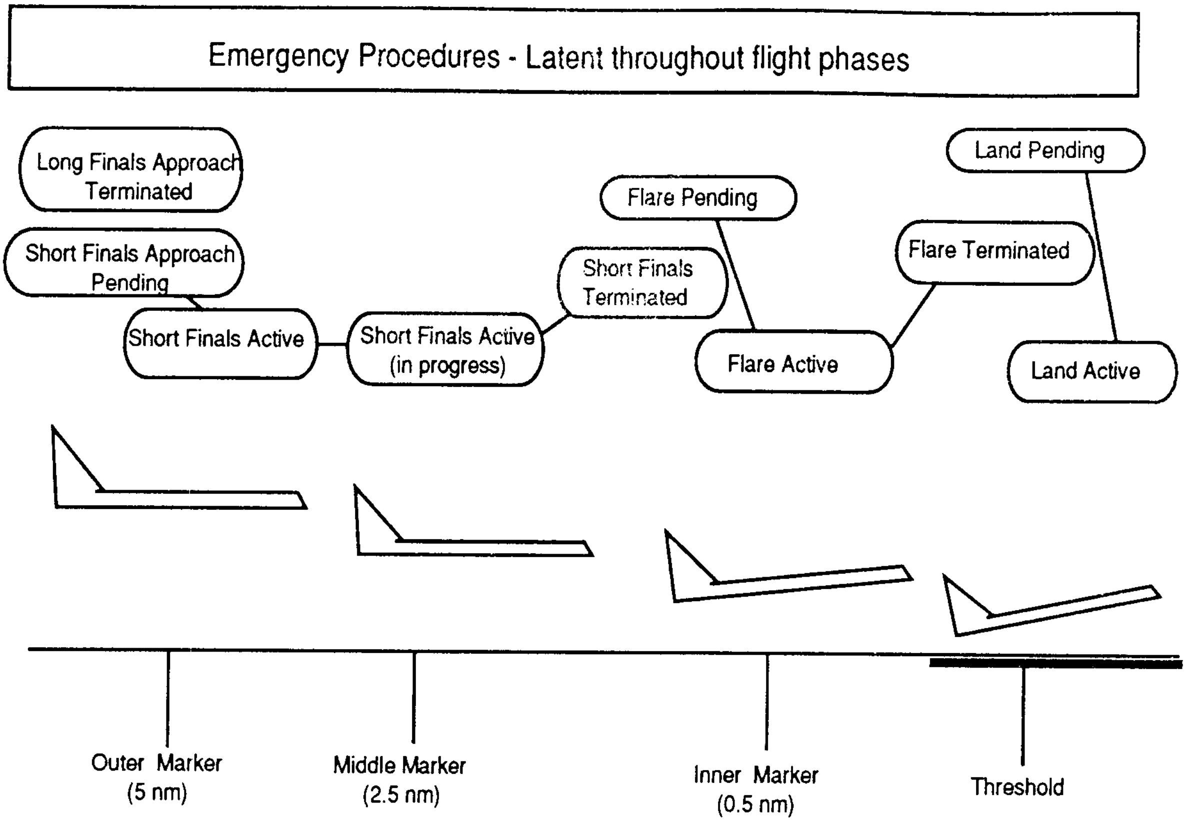

Figure 2.6 Task transitions in the approach phase

This is the latent stage and it comprises all the non-routine procedures (not included in the flight plan), such as for fires or explosions on board, equipment malfunctions, lightning strikes or bird strikes, weather and other such non-planned changes to the flight plan. While being non-routine, these are all tasks that the crew is equipped to handle (and can be evoked- made active and active in-progress) at any stage of the flight.

The final approach itself, in the earlier example, could be broken up to a more detailed analysis to reflect the actual case with more sub-goals. In this case the approach could be categorized into long finals, short finals, flare and land. The aircraft is deemed to be on short finals as soon as it captures the localizer and/or glide slope (initial event) in an Instrument Landing System (ILS) approach. Approach is continued until each of the markers, comprising the outer and middle markers, is crossed (Figure 2.7). The aircraft has specific height clearances it has to maintain at each of these markers and a continuous check is made of aircraft attitude, height, speed, throttle settings and trim adjustments until the inner marker is reached (terminal event - approach phase and initiating event- land phase) when the aircraft is leveled and gradually flared for manual landing. As the flight progresses, there may be several transitions going on between the different stages (for each of the several tasks) as sub-goals are fulfilled and tasks are re-prioritized. It is also important to remember that there may be, at any one time, several tasks that are pending which may (or may not yet) have been prioritized and resources re-allocated.

In all the task related activities (prioritizing, allocating and de-allocating resources, initiating and terminating) discussed above, one thing stands out as a common denominator - satisfactory task performance is limited by resource availability. When there are several tasks competing for the same resource (example, on finals tracking the ILS, watching for traffic and ATC communication to manage) the tendency to commit more resources than necessary to one task (both crew members looking out for traffic, say) might result in the poor or non-performance of another task (ATC communication, say). This happened on numerous occasions in the incident reports.

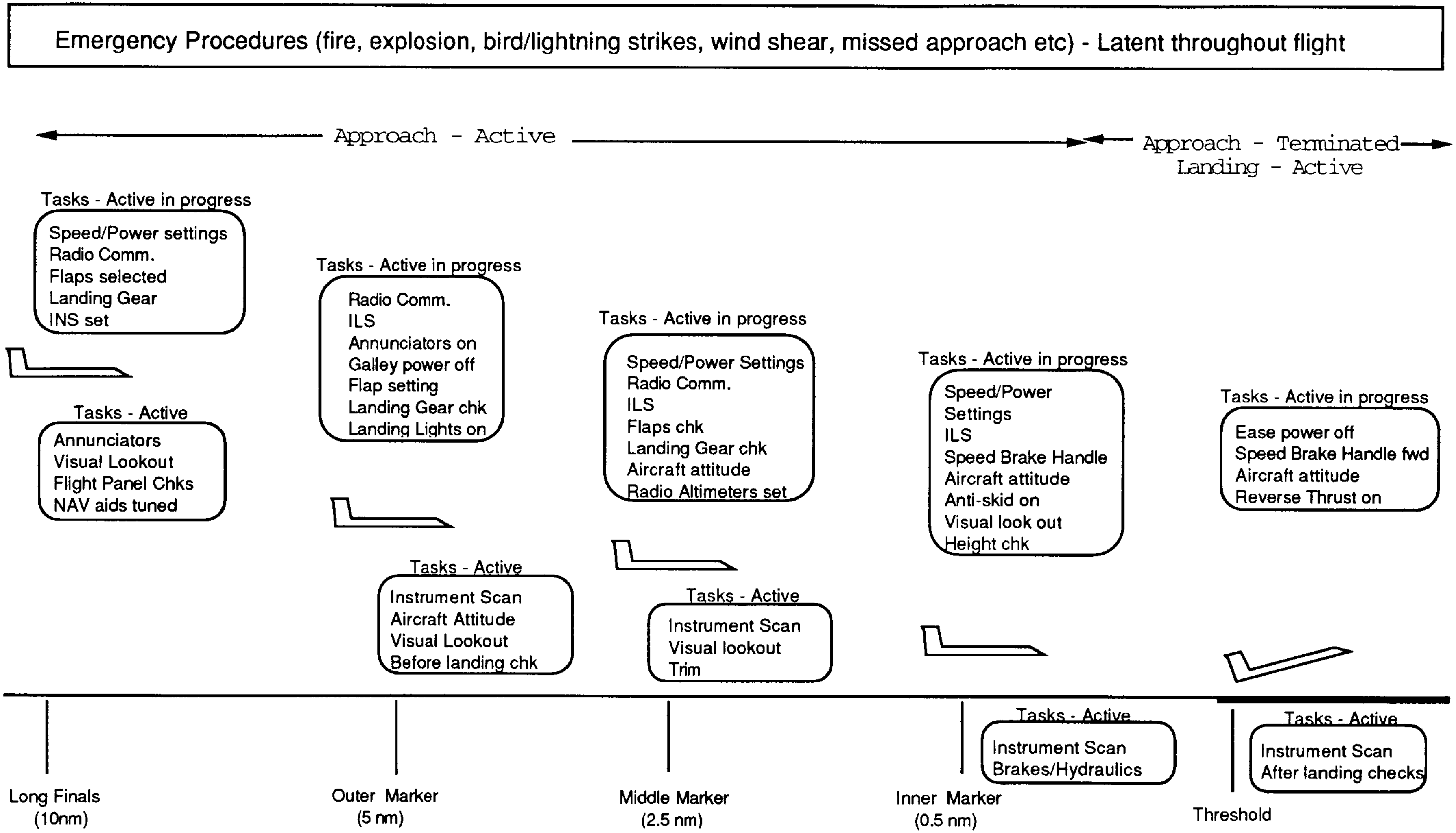

Figure 2.7 Task transitions during a normal "final approach"

2.6 CTM Errors

The flight deck of the airliner is a very regimented one where almost every task, pertinent to the safe flight of the aircraft, is carried out in accordance with Standard Operating Procedures (SOP's) or in accordance to specific instructions from Air Traffic Control (ATC). In spite of this, errors can (and do) occur at any point in the task transition process. The flight crew has to maintain a dynamic mental record of each of the transition stages and the associated tasks that go with each phase as the aircraft makes rapid progress towards the threshold. These transitions are very rapid and the crew may be engaged in several task prioritization, resource allocation and de-allocation, task initiation and task termination activities. The need for greatest crew concentration appears to be at the approach phase where, besides all the internal activities that keep the plane in the air until touchdown, there is a need to maintain ATC communication and also to maintain a traffic watch outside the cockpit. In the research of the ASRS incident reports, there were numerous cases of pilots forgetting to operate certain controls at the designated points in the approach, either because they were all concentrating on the traffic outside or trying to maintain straight-and-level flight in bad weather. This was more obvious at busy airports, airports with more than one active runway and at locations with two airfields located close to one another. In a number of incidents, the crews were overwhelmed by the sheer workload at these airports and forgot to obtain landing clearances, resulting in un-authorized landings.

While behavioral psychologists tend to approach human performance (and hence account for their errors) in terms of behavioral models, Rasmussen (1985), pointed out that human performance could not be studied independent of task characteristics. In other words, human reliability and performance depended on a model of successful or normal task performance and not on a model of human behavior. This appeared to be valid, since error frequencies from incident reports would be dependent upon task characteristics and the opportunity for operators to detect and correct the errors immediately. Further, as

Rasmussen pointed out, human reliability prediction follows the format of industrial technical reliability analysis where the system components are broken down and data analyzed for the individual components; operator activities are decomposed into elementary task units and reliability data obtained in terms of error rates. This followed the Tayloristic tradition of studies based only on observable categories of operator activities. Given the strictly procedural environment of the modern airline cockpit, where each phase of the flight plan consists of specific sets of activities, it becomes possible to analyze flight crew performance for the entire flight by decomposing the many tasks into corresponding error categories.

As opposed to most normal operating environments, the flight deck of a modern airliner is a regimented one. Every action and reaction of the flight crew is in strict accordance with standard operating procedures (SOP). The majority vote does not determine headings to be flown, radio frequencies to be selected, altitudes to cruise or holding patterns to be deployed. Each stage of the flight has its own pre-determined course of actions. Even emergencies were handled procedurally. Despite the procedural nature of the operating environment, task management errors are routinely committed by experienced flight crews. The problem is that there are usually *multiple, concurrent* tasks to be performed. These require some strategies, on the part of the crew, by which to evaluate tasks, sequence them in order of priority, execute and/or terminate them.

This regimented environment therefore, provides a basis to perform an error analysis specific to cockpit tasks only. The concept of Cockpit Task Management (CTM) was first adduced by Funk (1991) and was an attempt to "..formalize the process that flight crews use to initiate, monitor, prioritize, execute, and terminate multiple, concurrent tasks". The emphasis in CTM, therefore, is on the crew's ability to manage *multiple, concurrent* tasks with *limited resources.*

The most significant difference between CRM and CTM is that, in CRM the cockpit (layout and displays) is considered as a constant and modifications are made to crew behavior to find an optimal fit into the cockpit (Funk, 1991). In CTM, the cockpit is not considered as a given i.e. the cockpit is also a variable that lends itself to modification.

Lauber's definition implies that CRM is rather broad in scope and deals mostly with social interaction between flight-deck members, their activity coordination and general cockpit management. CTM is more focused and refers only to tasks in the cockpit - their assessment, prioritization, execution and monitoring.

Yet another difference between CRM and CTM, is that the origins of CTM and CRM are different (Funk, 1991). CRM had its origins in the principles of organizational psychology and business management whereas CTM emerged from concepts of systems theory and cognitive psychology, specifically time-sharing and workload.

Despite these differences however, it must be noted that CTM is an integral subset of CRM but significant enough for it to be addressed distinctively rather than glossed over, as is the current practice.

2.7 Earlier CTM Research

One of the objectives of original CTM studies was to classify cockpit tasks and identify CTM errors in the environment of a modern airliner. The two main sources of information for this research were National Transportation Safety Board (NTSB) accident reports (forming the bulk of the analyses) and, to a lesser extent, Aviation Safety Reporting System (ASRS) incident reports. Funk (1990, 1991), Chou and Funk (1990) and Chou (1991) were responsible for the development of the first error classification taxonomy specifically to address cockpit task management errors. Their model is summarized in Table 2.7.

Table 2.7 CTM Error Taxonomy (Chou and Funk, 1990)

General Level	Specific Level
Task Initiation	Early Late Incorrect Lack
Task Monitoring	Lack Excessive
Task Prioritization	High Low
Resource Allocation	High Low
Task Interruption	Incorrect
Task Resumption	Early Late
Task Termination	Early Late Incorrect Lack

2.8 Research Objectives

Chou's 1991 study of CTM errors had a couple of limitations. First, the taxonomy was used primarily to deal with NTSB accident reports. These reports were readily available and there was also an attempt to classify some ASRS incident reports. The Industrial Engineering department had in its possession some ASRS reports and Chou did some preliminary analyses on these reports. The primary focus however was on NTSB accident reports.

Second, the error taxonomy itself was not fully addressed. In particular, the error classification methodology and justifications for the various error categories were not discussed in detail.

This research built on the earlier work of Chou and Funk (1990, 1991) and, in particular, established Cockpit Task Management (CTM) as a concept that was significant enough to justify treatment as an important component of Cockpit Resource Management (CRM). It was based upon the normative CTM error taxonomy developed by Funk (1990, 1991) and Chou (1991) and was applied to a much larger and more complete collection of ASRS airline incident reports.

One of the primary objectives of this research, with a significantly larger database of incident reports to analyze, was to determine the significance of CTM errors in reported airline incidents using the original CTM taxonomy. Having thus determined their significance, the next objective was to develop a structured methodology of classifying the CTM errors such that it could be applied to any incident to yield consistent results. The taxonomy itself was to be validated by the incident reports and refinements made to it in the light of the research. In addition, an attempt was made to relate the specific CTM errors to human cognitive limitations.

The overall objective of this research then, was to determine the significance of CTM errors with respect to flight safety, arrive at a consistent error classification methodology, and develop recommendations for the design of procedures and equipment that would contribute to flight safety by facilitating CTM.

3. METHODOLOGY: ERROR CLASSIFICATION SCHEME

3.1 Introduction

The research methodology was structured in three parts. First, the CTM error taxonomy (Chou, 1991) itself was studied and necessary changes made to it, based on a detailed analysis of the available ASRS incident reports. In particular, a structured approach to error classification, such that specific errors made in task management were clearly identified by their salient characteristics, was attempted. This would enable any researcher to repeat the method and arrive at the same error classification. In other words, an attempt was made to standardize the method of classification of these errors so that they could be applied consistently to every incident or accident report. For each error category classification, actual incident reports (containing these error categories) were reproduced, verbatim, to illustrate better the specific task errors committed.

Second, 470 Aviation Safety and Reporting System (ASRS)[2] incidents were identified and categorized using the revised error taxonomy. The focus was on the descent and landing phase of the flight regime. Appendix I provides a summary of these incident reports from the ASRS database and summarizes the error categories identified in the revised error taxonomy. ASRS classified these reports under several headings, comprising, "In Flight Engine Emergencies" (99 reports), "Controlled Flight Toward Terrain (CFTT)" (206 reports), "Cockpit Co-ordination Incidents" (100 reports), "Cockpit Resource Management" (43 reports) and "Flight Crew Distraction Incidents" (100 reports). These reports spanned several years from 1987 to 1993. They are by no means an exhaustive list, since ASRS had other incident categories and they receive these kinds of reports on a continual basis. The overriding evidence in all these reports, however, points to a repetitive pattern of errors, further substantiating the belief that new kinds of errors are

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[2] ASRS is a voluntary, anonymous reporting system (for pilots to call in and report incidents) developed and operated (since 1976) by NASA for the FAA. **A glossary of aviation terms used in this study is given in Appendix II.**

rare events. The original error taxonomy, therefore, was modified to reflect a more accurate representation of the kinds of Cockpit Task Management errors committed.

Finally, while not forming the thrust of this thesis, an attempt was made to identify and assign the associated human cognitive failure (secondary) that may have caused the error to take place. CTM errors may be traced to associated failings in the human cognitive process. In particular, attention (processing limitations), workload (time-sharing), judgment and decision-making in a multiple-task environment are major cognitive categories for each of these CTM errors. These secondary cognitive failures could be further traced to more fundamental failures that have their origins in human memory limitations, in particular, short-term memory limitations. It is hoped that another researcher will be able to pick the thread up from here and explore this connection in some detail.

While flying an aircraft is a complex activity that embodies concepts entrenched in both theoretical and applied research, the approach used here was from a human factors perspective with emphasis on applied research findings.

3.2 A Revised Error Taxonomy

The original CTM error taxonomy (Chou & Funk, 1990) drew upon some elements of an earlier work by Rouse & Rouse (1983) and showed seven CTM functions at the general level and, for each function, an error at the specific level (Table 2.6). Categorizing cockpit task errors in this manner offered the opportunity to design specific countermeasures for the associated errors.

A critical analysis (using formal definitions of the categories and also applying them to a greater collection of incident reports) of the Chou & Funk error taxonomy revealed that several of the error categories could either be eliminated completely (due to redundancy) or streamlined for greater clarity. Central to the theme of going beyond 'pilot error' as a causal factor for error committal was the utilization of the 'Five Whys Deep' concept

(Crouch, 1992). This concept, entrenched in Total Quality Management (TQM) principles, asks the question "why?", five times (with each why following an answer to the previous why) as a means of getting down to the root cause of the problem. The reasoning behind this being that, the root cause of a problem is often buried under several layers of sub-problems. The following is a hypothetical example of this technique.

1. Question: Why did the plane crash?

   Answer: Due to 'pilot error'.

2. Question: Why did the pilot make the error?

   Answer: He was trying to correct a maneuver on his approach but over-corrected.

3. Question: Why was he correcting the maneuver?

   Answer: He was late configuring.

4. Question: Why was he late configuring?

   Answer: He was caught high at the Outer Marker

5. Question: Why was he high at the Outer Marker?

   Answer: He was distracted by a cabin crew member and forgot to tune in his final Navaid frequency and hence lost his bearings.

Applying this simple technique, led to the elimination of superfluous categories and resulted in a simpler error taxonomy. Often, the sub categories were defined after going only two or three "whys deep". Hence, the Task Monitoring Lack category was eliminated altogether since it was an answer at a superficial level (e.g. Question: Why did the plane crash? Answer: Due to an inattentive crew - this does not reveal why the crew was inattentive). The other error categories, on the other hand, appeared at a much deeper level - after going several whys deep. Indeed, Task Monitoring Lack was a consequence of some other task management error - usually found in a Task Prioritization Incorrect error leading to the allocation of little or no resources to the monitoring of a specific task. Crew concentration, on a normal flight, was usually higher during the approach and take-off phases of flight. It was easier to infer a condition of an inattentive crew than it was to infer a task monitoring excessive condition (over-attentive crew?). The reason for the inattention was further traced to a mental resource allocation error which in turn was almost always the result of a task prioritization error. As a consequence, the Task Monitoring Excessive category was also deleted. Task Interruption no longer appeared as an error category simply because it was one of the transition stages of a task. Any task that was on-going or pending could be interrupted; the interruption could be an emergency, such as an explosion, a bird strike, a fire or even an overshoot due to patchy fog, say. If the active, in-progress task was the final approach and a fire broke out (task interrupted), the task could be terminated and emergency procedures made to become the active in-progress tasks while a go-around was initiated. However, the crew could have continued with the approach if they believed that they could land the aircraft - task interrupted and emergency procedures made active in-progress but initial task (landing not terminated) still active . Similarly, Task Resumption (which was consequential to Task Interruption) was omitted, as this would reveal itself in either Task Initiation or Task Termination categories. Note that the components of Task Initiation had their complement in the Task Termination categories. For example, for an aircraft nearing its destination, a late configuration of the aircraft to land (Task Initiation Late) had its complement in the failure to terminate cruise phase (Task Termination Late). The previous Resource Allocation error category was eliminated completely because the preceding category, Task Prioritization Incorrect would have already determined where the resources would be allocated in accordance to task prioritization. In other words, Resource Allocation high/low was a redundant category. This was replaced by the Task Prioritization Incorrect error category. The Task Termination Incorrect category was also eliminated since it proved almost impossible to find an instance of a crew member incorrectly terminating a task in the 470 incidents analyzed.

In addition, every task management error had an initiating event (also called a trigger event) which could be hard to discern at times. The triggering event, in the hypothetical plane crash example, was the pilot allowing himself to be interrupted by a cabin crew member (a low priority task) on approach, which led to his omission of the non-directional beacon (NDB) tuning and hence his disorientation and, quite possibly, a lot of over-corrections leading to the "crash". Sometimes the triggering event was a little more subtle. Consider the example of a flight at the Outer Marker, fully configured and approaching the runway. Midway through the procedure, ATC decided to change the runway designation and issued new landing clearance. The Captain accepted the clearance and tried to make it in, re-configuring for the new runway and did a hard landing. The triggering event for the hard landing was not that the crew was late (or omitted some steps) at performing the several tasks preceding the landing. The captain's acceptance of a difficult clearance (in the short time frame) requiring an unreasonable amount of effort from the flight crew, was the triggering event. This happened in several of the incident reports where 'last-minute ATC changes' and other ATC maneuvers (chiefly, the notorious 'slam-dunk' approach - bringing the aircraft in high and issuing landing clearances that required the shedding of a considerable heights in a short time-frame) were deemed unnecessary and mostly ascribed to controllers' convenience. In some instances, the captains admitted that they should not have accepted the clearances and that they should have initiated a go-around if the revised clearances were for genuine reasons. These errors were not tabulated in the error taxonomy since they were deemed to be judgmental errors.

Also, in classifying the errors committed, if a specific error was committed twice (or three times in some cases) in the same incident, it was still counted as a single occurrence. For example, if the pilot flying forgot to tune in the correct NDB frequency (task initiation lack) and later forgot to ask for landing clearance (task initiation lack, again) it was still counted as one occurrence in the same incident report. However, if an error was committed in a specific category (descending too early, say - task initiation early error) which occurred as a result of the pilot being pre-occupied in a conversation with a flight attendant, say (task prioritization incorrect error), then the errors were logged in both categories. This was inevitable since the method of classifying the errors relied on exact erroneous actions of the crew, not implied ones. In the example of the pilot talking to a flight attendant, both the errors were specifically observable. However, some of the errors involving task prioritization were more subtle.

There were also several cases (77 incidents) of errors due crew members mis-dialing the altitude alerter, tuning in the wrong radio frequencies, landing at the wrong airfields, refusing to abort dangerous approaches and the like. While these were filtered out of this research, since they did not fall under the CTM error categories as defined currently, they deserve at least a passing mention due to their significance. These errors could be categorized under three distinct groups:

Mistakes - where the intention itself, in the task execution, was incorrect. This may have been due to a lack of knowledge of systems, aircraft position or attitude, etc. An example of a mistake would be the entering of the wrong coordinates (of a way point) into the flight director. Yet another example would be to turn on (or off) the wrong switch on the control panel. In all these examples, the pilot was conscious of his/her actions, believing them to be correct actions and therefore executed correctly with respect to his/her intentions. Similarly, misreading altimeter settings of 29.01 as 29.10 were classified as mistakes as were mis-interpretations of altitude clearances.

Slips - where the intention was correct but the resulting action, with respect to the intention, was incorrect. Reason (1987) referred to slips as the failure of actions to go as intended (execution failures). Slips may be viewed as an automatic mode of behavior in which conscious attention is diverted elsewhere (O'Hare & Roscoe, 1990). An example of a slip would be the mis-entering of the coordinates of a way point into the flight director which could be due to the slip of a finger. Shutting down a good engine when the intention was to shut the problematic one is also a slip. There was an another instance of a slip in the report analyses, where a pilot copied down the correct minimum altitude to be set in the altitude alerter and subsequently dialed another altitude, with his note pad directly in front for reference.

Violations - where the intention was to deviate, knowingly, from procedures. The decisions by the captain (or co-pilot) to deviate from procedures despite the better judgment (based on SOP's or ATC instructions) of the other crew members were also termed violations. There were several violations recorded in the report analyses. Most of them related to instances where the captains refused to listen to fellow crew members' inputs about landing below minimum weather conditions. In all of these cases, the captains landed the aircraft despite alerts by other crew members to abort the landing.

Judgmental Errors - where the decisions made were not optimal. These errors were admitted to by the pilots in the report narratives. Pilots decided to accept a change in ATC clearance while on finals (fully configured) and then discovered that they could not make it admitted to having made poor decisions.

There may be a case for including this category of errors as a sub-set under the CTM umbrella since they all relate to specific tasks and their remedies parallel those for the CTM errors. A total of 470 ASRS incidents were thus analyzed in detail and a revised error taxonomy that reflected a more accurate assessment of task errors committed in the cockpit environment was constructed (Table 3.2).

Table 3.2 Revised Error Taxonomy (Madhavan & Funk, 1993)

General Level	Specific Level
Task Initiation	Early Late Lack
Task Prioritization	Incorrect
Task Termination	Early Late Lack

3.3 CTM Error Category Definitions

The net result of the streamlining was a simple error classification scheme for Cockpit Task Management errors. Before any further discussion is possible it would be pertinent to give some formal definitions of the various error categories and their salient characteristics.

Error Category: **Task Initiation Early**

Definition

Beginning a task before its initiating event window (before its assigned schedule in the flight plan).

Notes

The problem here was to determine when a particular task should have been started by the flight crew. For the majority of the descent and landing incidents reviewed here, Air Traffic Control (ATC) determined the 'schedule'. For example, ATC issued approach and descent clearances which, when received by the cockpit crew, resulted in a planned approach with specific actions to be carried out at each stage of the approach - when to tune specific navaids, when to change communication frequencies, when to configure, lower flaps etc. There were exceptions to the degree of control the flight crew had over the assignment of the 'schedule' which depended on the type of approach that the aircraft would be executing. For CAT III (auto land) approaches and certain CAT II (vectored) approaches, ATC decided on courses and altitudes to be flown, and turns to be taken at each stage until touchdown. The management of the actual tasks, however, including the methods utilized to execute any maneuver (configuring, decision point assignment, flaring etc.) or deploy any control surface on the aircraft, was determined by the flight crew which in turn relied on the airline's standard operating procedure (SOP) for each specific task.

Some examples of **Task Initiation Early** errors were:

- the beginning of the descent phase prematurely.

- carrying out corrective actions before confirming the problem (especially in emergencies).

-calling waypoints and altitudes (unconsciously) to ATC before arrival at that point. Conscious, false callouts (there were some of these made by the crew attempting to 'make it in' regardless of weather or traffic conditions) were classified as violations.

How were these inferred from the incident reports?

To a large extent, the report narratives themselves identified these **Task Initiation Early** errors. Four examples of actual ASRS report narratives that involved this type of error are given below. They were reproduced *verbatim* except for some comments included for clarification purposes in parentheses.

ASRS Report # 209614

"...I started a R turn. At aprox. 1500 ft. MSL [mean sea level] the R fire light and bell sounded. As I looked at the glowing fire handle, the Cpt. reached up, without saying anything to me, and pulled the R fire handle, shutting down the R engine **[Task Initiation Early]** ....and could not believe that the engine #2 was winding down. The R hand fire light went out as Cpt. said, "Ah! I screwed up"!

Here, the Cpt. responded almost instinctively to the alarm without confirming visually - as per SOP, whether it was a real fire or, as it turned out to be in this case, a false alarm.

ASRS Report # 209868

"..cleared to 3000 ft. on a downwind. For some unexplained reason, 1000 ft. was set in the alt. alert window. I sensed we were descending and turned my attention back to the cockpit and saw we were descending [**Task Initiation Early**]. I told F/O to stop descent at 2500 ft....."

Here, the aircraft was cleared to 3000 ft. by ATC and then (implied) to await further instructions. The F/O, perhaps focusing more on the alt. alerter to advise him to stop descending rather than listening to ATC instructions, descended out of 3000 ft. prematurely. If we took this error one more level down i.e. ask the question 'why?' again, we may find that the error was probably due to the mistake of mis-dialing the altitude alerter (root cause).

Note that the latter diagnosis, mis-dialing the altitude alerter, was largely an inferred one and was offered as a 'contributory cause'. It may turn out to have been the 'root cause'. However, since it was not clear what the F/O was thinking at the time of the error commission, his error was ruled on the basis of what was known for certain - that he descended too early.

ASRS Report # 194905

"Upon arriving at ARA the wx was marginal VFR and the Capt recd a verbal apch brief from the ctrlr. ..our initial alt. was 1600' to the FAF [Final Approach Fix] and the MDA [Minimum Descent Altitude] was 420'. The FAF was 4.4 mi from the arpt. Aprox 4 mi before the FAF Capt instructed me to dsnd to MDA . .... noting some agitation in his voice and having visual contact with the ground I began to dsnd" [**Task Initiation Early**]

The co-pilot complied with the captain's erroneous decision to descend early. The co-pilot did voice his concern but decided to follow orders because he had full visual contact with the ground and, presumably, could have taken corrective action if necessary. It appeared that the F/O may not have complied if they had no visual contact with the ground. However, these are speculations. If the decision to descend early was a conscious decision this would be termed a violation.

ASRS Report # 211425

"..vectored for final ....told to maintain 5000 ft and rpt field in sight. ATC supvr called and said..he showed us at 4000 ft. We previously had leveled off at 5000 ft... I looked at the altimeters and they displayed approx. 4000 ft....the Capt had spun the alt selector to 0000 and begun a gradual dscnt without telling me [**Task Initiation Early**]....Just then we got a TCAS II RA of "clb, clb now".

The Captain assumed that the co-pilot had called airport in sight and begun a slow descent without informing his co-pilot. This was a busy airport and the co-pilot was busy with a traffic watch. Several other errors were committed as a consequence of this initial error.

<u>Error Category:</u> **Task Initiation Late**

<u>Definition</u>

Beginning a task after its initiating event window (after its assigned schedule in the flight plan)

<u>Notes</u>

Again, ATC and SOP's are the benchmark from which we infer deviations. Some examples of <u>task initiation late</u> errors were:

- late in configuring the aircraft (for final approach and landing)

- late altitude callouts or warnings by cockpit crew members
- late reactions to ATC instructions

The following were some examples of incident reports that had this element.

ASRS Report # 192660

"We were vectored to start the apch. over the Marker. At the Marker, as we turned to intercept the GS [Glide Slope] and start the descent, the F/O was slow to correct back to the course [**Task Initiation Late**], but I'm afraid we had a momentary full scale deflection to the left (on the GS)".

This report is more explicit (as opposed to the inferred ones above) and blames the First Officer, who was lagging behind the aircraft, for the error.

ASRS Report # 200203

"On an autoland (CAT III) aprch into O'Hare, I began final dscnt cklist. The Capt. realized we weren't down quick enough with the autopilot and dis-engaged it as we finished our final configuration. .....I became concerned with our being high and fast on the GS. Factors that led to the incident...staying with the planned coupled aprch too long [**Task Initiation Late**] causing us to be higher and faster than planned".

The First Officer admitted that they hung onto the planned coupled approach (usually a mandatory requirement for CAT III landings by most airlines) longer than necessary, which resulted in a late full-configuration.

ASRS Report # 202129

"The TCAS II's RA [Resolution Alert] temporarily diverted our attn of our [sic] alignment for the turn to final for rwy 24R. Turn was started just prior to rwy. ctrline [**Task Initiation Late**]. Bank angle was increased to 45 ^{0} to minimize overshoot".

Here, the error was alluded to in the narrative. With both pilots' attention drawn by the traffic alert, they were late turning on to finals which left them with a steep angle of bank to correct very rapidly.

ASRS Report # 202390

"..first approach resulted in a GAR [go around] at 500 ft. above ground when we had not caught GS (Glide Slope). ... Inexperienced Capt. slow and late executing procs and preparing (configuring) aircraft" [**Task Initiation Late**].

The error here was also identified when the Captain was caught lagging behind the aircraft. In addition, the root cause (Captain's inexperience) was also stated very clearly in the conclusion of the report by the First Officer.

Error Category: **Task Initiation Lack**

Definition

The omission of a particular task or the omission of a task in a sequence of tasks.

Notes

ATC instructions and SOP's were again used as benchmarks from which deviations were inferred. Phrases in the narratives such as, "..should have done..", "..hadn't selected..", "..did not..", "..omitted..", etc., all pointed to some specific task omission. In some cases the error had to be inferred [e.g. when the pilot not flying (PNF) did not check the pilot flying's (PF) instruments to verify that they were set correctly on approach.].

The following were some examples of incident reports exhibiting these kinds of error.

ASRS Report # 197423

"..we were concentrating on the apch and missed the call to TWR [**Task Initiation Lack**]".

Here, the pilot readily admitted that the crew was too engrossed on the approach that they forgot to call TWR for the landing clearance which resulted in an unauthorized landing. In actual fact, this was a **Task Prioritization Incorrect** error, where all available resources were focused on the approach with no residual for other tasks, which led to the **Task Initiation Lack** error.

ASRS Report # 203313

"..Improper instr procs - not checking alt while passing marker [**Task Initiation Lack**] and pre-occupation with maintaining visual contact with preceding aircraft...".

This was similar to the preceding report, where all resources were consumed by the traffic watch **Task Prioritization Incorrect**, which resulted in the omission of an altitude check on approach.

ASRS Report # 201848

"....After starting our apch (following problem with the operation of our slats), the F/O noticed that the hydraulic pumps were not in the HI pos [necessary for normal slat operation - **Task Initiation Lack**]. After selecting HI pump pos, the slats operated normally."

The engineer forgot to set the required position on the pump selector which resulted in the emergency. The error was detected a little later by the F/O but not before an emergency was declared and preparations made for an emergency landing

Error Category: **Task Prioritization Incorrect**

Definition

An error resulting from the allocation of crew resources to a task of less immediate importance over one that required more immediate attention.

Notes

This category of errors was, to a large extent, inferred from the narratives. By far, it was the largest category in the taxonomy. This was not surprising because a significant number of errors that fell into the other categories were as a consequence of the misprioritization of tasks before-hand.

The following narratives involved some aspects of task mis-prioritization.

ASRS Report # 20223

"...we were fully focused [**Task Prioritization Incorrect**] on the CAT III apch [auto-land] - a first for both of us and forgot [**Task Initiation Lack**] to give the flt attendants the three bell signal for imminent lndg....and two, of the four attendants, were standing [in the aisle] at touchdown."

Total attention was given to this novel approach (i.e. all available resources were allocated on this new approach) that the pilots forgot their routine task of giving the timely landing warning.

In another similar incident, the crew was engrossed in a traffic watch and also omitted the landing warning with the result that they landed with a few food trolleys in the aisle.

ASRS Report # 201415

"..Capt. was distracted for a few mins by the flt. attend. who came up to the cockpit to ask a question [**Task Prioritization Incorrect**]....and he missed the alt. x'ing restriction."[**Task Termination Lack**]

The captain committed the error of placing greater importance to acknowledging the flight attendant rather than ATC approach instructions. He was also in violation of the 'sterile cockpit' rules - rules that forbid cabin crew members from going into the cockpit at certain times of the flight, such as during take-offs, landings and emergencies.

ASRS Report # 197777

"..looking for tfc [traffic] outside after TCAS II showed close tfc. Went thro' 9000 ft by 270 ft. and immdtly [sic] climbed back up. .....always stabilize the aircraft before both heads are outside" [**Task Prioritization Incorrect**].

During the descent, the crew was so engrossed in the traffic watch, following a TCAS II alert, that they forgot to level off after arriving at the cleared altitude. This error also gave rise to yet another (consequential) error - **Task Termination Late** (i.e. the crew forgot, momentarily, to terminate the descent after reaching the intermediate goal of 9000 ft.)

ASRS Report # 210234

".. we had both failed to note the turn to the N at TWIK intxn....All preoccupied by a cockpit distraction - Capt. pushed the Flt. Attnd. call button to p/u [pick up] meal tray. No one responded and tray fell onto floor. Capt. picked up the mess and took it back to the galley [**Task Prioritization Incorrect**] and...I got real busy with several radio calls and alt. chges..."

Here, the captain attended to a lower priority task (clearing the meal tray) and left the cockpit to the F/O at a very busy time.

Error Category: **Task Termination Early**

Definition

The disengagement of a particular task, too early (before its goal is met) in the sequence of tasks.

Examples included:

- the early termination of a radio tracking procedure.
- the early termination of an altitude hold feature.
- the early termination of the auto-pilot.

Notes

SOP's and, to a certain extent, ATC instructions served as benchmarks from which deviations were inferred. In some cases the pilots admitted to the specific error committed.

Note that when a pilot overshot a descent altitude and the action was corrected (by the aircrew or ATC), it was not termed a **Task Termination Lack** error; rather, it was termed a **Task Termination Late** error. When ATC instructed an aircraft to descend and hold at 4000 ft. say, and the pilot descended to 3000 ft before it was noticed (and corrected) by ATC radar or a fellow crew member, the error was termed a **Task Termination Late** error. If the aircrew (or ATC) did not catch the error and no correction was made, then it would be termed a **Task Termination Lack** error.

Some examples of report narratives involving **Task Termination Early** errors were:

ASRS Report # 210716

"...while awaiting GS [Glide Slope] capture, we were sent to tower. Tower advised us that RVR [Runway Visual Range] was below our mins......In the meantime [at 10 DME] the FO had released alt hold **[Task Termination Early]** and descended below GS intercept alt and has [sic] fallen below GS too! We were already 400' low when I looked up".

Here, the First Officer (FO) terminated the altitude hold feature too soon and descended below the GS capture altitude by 400 feet.

ASRS Report # 216617

"...we were approaching LAX ..at 7000 ft. Apch ctlr ..cleared us out of 7000 ft for 6000 ft. our TCAS II [Traffic/Terrain Collision Avoidance System] began giving us a TA [Traffic Alert] for the acft apching rwys 25. Distracted by the aural TCAS II warning, I failed to note that the autoplt's level-off alt of 6000 ft had become disarmed". **[Task Termination Early]**".

The captain noticed the early disengagement of the altitude level-off feature only after the aircraft had descended to 5700 ft.-a loss of 300 ft. The captain, in his extended report, attributes this error (a slip perhaps?) to the relative inexperience of his co-pilot.

ASRS Report # 196736

"...The PNF (Capt) was in the process of completing the apch chklist when clrnc for the bay apch was given. The chklist was interrupted **[Task Termination Early]** leaving an incorrect inbound course set in the ILS front course window. On this acft this will result in an improper capture of the loc [localizer] which occurred in this case."

While the termination of the final approach checklist was categorized as a **Task Termination Early** error (actual error), it was also a **Task Prioritization Incorrect** error (implied error) that led the crew to place greater emphasis on the clearance than the checklist items - one of which was the ILS frequency check.

ASRS Report # 98235

"...weather was IMC..radar showed the strongest returns ahead and to the left with turbs increasing to mod. We were now in the middle of the red area and the turbs were quite strong. It took the autopilot a few secs to start the turn due to the turb. The capt. didn't like the way the autopilot was starting the turn and quickly turned it off [**Task Termination Early**]. At the same time the strongest of the turbs hit and the capt started over controlling".

Here, the early termination of the autopilot in thunderstorms caused the crew to lose control of the aircraft for several minutes. The auto pilot was engaged again as soon as the plane was straight and level.

Error Category: **Task Termination Late**

Definition

The disengagement of a particular task, too late (after its goal had been met) in the sequence of tasks.

Examples included:

- the late termination of initial approach phase resulting in a 'high arrival'.
- the late termination of circuit legs, e.g. downwind leg or base leg.
- the late termination of procedures, e.g. checklist items, coupled approaches etc.

Notes

Again, SOP's and ATC instructions served as benchmarks from which deviations were inferred. In some cases the pilots admitted to late termination of specific tasks. Phrases such as "..lagging behind the aircraft/ATC instructions", "..held onto the coupled approach for too long", "..overshot the base leg", "..stayed with the downwind leg for too long" etc., all pointed to a **Task Termination Late** error. Some examples of report narratives involving **Task Termination Late** errors were:

ASRS Report # 197423

"Both pilots set for the apch to 23L. We were cleared to 3000' for the intercept and then cleared for the approach. We were in and out of the bases of clouds. I then elected to start descent to 2500' ...noticed that the ADF [Automatic Direction Finder] needle did not coincide with the localizer course. I immediately stopped the descent at 2500' [**Task Termination Late**]..and the loc needles had deflected full to the right. Ctlr asked if we had the loc for rwy 28. It was at this moment I had realized we had set up for the wrong apch. He then informed us that we should be at 3000'...".

Here, both pilots set themselves up for the approach to the wrong runway. Despite the captain's reservations about the heading clearances (for runway 28), both pilots followed them while all the while assuming that they were heading for runway 23L. They overshot the 3000' clearance by 500' before they realized the error.

ASRS Report # 200203

"I began the final descent chklist. The capt realized we weren't getting down quick enough ...... I finished the final dscnt chklist inside the Final Approach Fix [**Task Termination Late**] and became concerned with our still being high and fast on the GS. We continued with the approach and landed long. However, by devoting so much attn to what the pilot flying was doing, I neglected my duties...... Factors that led to the incident:... staying with the coupled approach for too long [**Task Termination Late**]".

This incident had several error categories in it. Late configuration (**Task Initiation Late**), task sequencing (**Task Prioritization Incorrect**), omitting obtaining landing clearance (**Task Initiation Lack**) and hanging on to the coupled approach (**Task Termination Late**) all caused the aircraft to take almost the entire length of the runway to come to a stop. The First Officer was still doing his checklist well inside the Final Approach Fix.

ASRS Report # 132717

"The plt flying started a dscnt upon intercepting the localizer. the PNF spoke up about 150' below our proper alt and then at 300' below yelled , pull up you are too low. We need 1800'. The PF complied [**Task Termination Late**] but was still unaware of what he had done wrong. After establishing correct alt there was a short discussion on correct proc. Contributing factors were, possibly: the wx was poor at Sacramento. .... and much discussion about whether to do a CAT I or CAT II apch and who would be flying [**Task Prioritization Incorrect**]. I was tired and we had been flying for 5+ hrs and been on duty for 9hr and 45 min. Our crew meals had not been boarded on the acft".

This tired and hungry crew appeared to lack a single command authority. Not being able to decide on the type of approach and, more importantly, who should fly the approach led to a sloppy approach (**Task Prioritization Incorrect**) and it appeared that decisions were made by a committee of people on board rather than the captain.

ASRS Report # 126484

"Dsnding from 5000' to 3500', the ctrlr asked us to reduce spd to 180 kts. ..the capt asked for flaps and did not get slat extension...Ctrlr notified of problem and that the apch spd would be higher than normal. ... we were informed that we were high and told to "get it down" twice. The pilot did not have the GS indication and thought that he was high above the GS. The pilot tried to intercept the GS from above and get it down as requested by the ctrlr. We passed the OM below the published alt and a GAR was initiated (**Task Termination Late**). A few secs later the "whoop-whoop" signal sounded. Everything which occurred after the slats failed to extend was more rushed and pressured than it would have been. ..."

The crew decided to go around (GAR) just seconds before the terrain warning sounded. The controller was not aware that a flapless/slatless landing would be at a higher speed than a fully configured landing speed and demanded normal speed adherence. The captain, however, could have insisted on maintaining 180 kts. all the way to the threshold (which he did not) and some mention was made of the captain's "lack of authority". However, the crew should have decided on the GAR immediately after their failure to capture the GS and when they sensed that they were too high.

Error Category: **Task Termination Lack**

Definition

The failure to end a particular task (after its goal had been met or could not be met safely) in the sequence of tasks.

Some instances of these kinds of errors included:

- going ahead with the landing when the weather had deteriorated to 'below minimums'.
- going below cleared altitude (by ATC) and on to landing without clearance.

Notes

SOP's and ATC instructions served as benchmarks from which deviations were inferred. In some cases the pilots admitted to the omission of specific tasks. Key phrases (in the narratives) in this category included "..failed to perform ..", "..forgot to call ..", "..omitted ..", "..overlooked .." etc. Note that the error was committed *unintentionally*. If the intention was to omit the task then it would be termed a *violation*.

Some examples of report narratives involving **Task Termination Lack** errors were:

ASRS Report # 133889

"The MAP (Missed Approach Point) is 10000' MSL and 2mi. I could still see the apch lights and contd with apch. At 1/2mi the fog was shifting and momentarily obscured our view of the airport. We were well inside the MAP so I said to continue [**Task Termination Lack**]. I feel the situation developed too fast to see it early. The apch looked better in terms of wx(weather) at 4mi than it did at 2mi".

The pilot continued with the descent and landed despite the deteriorating weather conditions. There were several reports that exhibited a similar pattern of behavior by the crew. The tendency for crews to be optimistic (always hoping and, indeed, believing them to be good) in marginal weather conditions was not uncommon in the incidents analyzed.

ASRS Report # 216617

".. cleared us out of 7000' for 6000'. When I turned back I noticed the acft at 5800' and dsnding [**Task Termination Lack**]. I called out the descent to the F/O who was flying. The acft contd to dscnd....".

The captain was occupied with a traffic watch (another aircraft crossing his aircraft's path) and did not notice that his aircraft had overshot his descent altitude clearance of 5000 ft.

ASRS Report # 132100

"...what happened next was an unstable dsnt (steeper than normal) to get back on profile. When we got closer to the grnd the GPWS activated due to the steep dsnt. [**Task Termination Lack**]. The acft got on the PAPI system at 1/2 mi. final and the lndg was within touchdown zone and uneventful. Looking at hindsight, our course of action should have been missed apch with vectors back to try again"!

The pilots made a non-procedural turn to base leg (extended base leg) to shed more height and continued with a steep descent despite the GPWS (Ground Proximity Warning System) siren going off. The correct procedure, as the pilot admitted, would have been to terminate the landing and go around for a second attempt at landing.

ASRS Report # 222508

"Capt took airplane from me and said he was going to fly apch. WX was reported to be RVR at 2400. Ctrlr asked "RVR is 1600' do you need 2400"? Capt ignored call. .... at 100' capt executed missed apch [**Task Termination Late**] straight ahead to 4000'. Visibility dropped to below 2400' RVR [on second approach] and apch terminated with a firm lndg" [**Task Termination Lack**].

The captain may have violated minimum runway visual range (RVR) rules by landing the aircraft when the RVR dropped below 2400 ft. Whether it was done intentionally (a violation) was not clear in the narrative. The captain claimed that he could see 2400 feet ahead but the co-pilot (reporter) disagreed.

4. METHODOLOGY: ASRS REPORT ANALYSES

4.1 Analyses

Of the 540 ASRS incident reports received, 470 were deemed to be unique incidents. Thirty one incidents were recorded twice by ASRS and designated with unique report numbers, possibly as an oversight on its part. The remainder did not fall under any of the categories as currently defined. The revised error taxonomy was applied to the 470 ASRS incidents reviewed using the format described in the preceding chapter. Each of the incident narratives was read and its associated CTM errors identified, categorized and the totals tallied at the end. There were several incidents (4.5% of total reviewed) related to small aircraft (light single-engine planes to small twin-engine commuter aircraft) that displayed CTM errors. These were eliminated from the classification as the focus was on airline incidents. While the focus was on the descent and landing phases of the flight regime, there were a few reports (less than 5%) that dealt with the cruise phase as well as the take-off phase of flight. There were 231 CTM error related incidents out of the 470 reports analyzed (49.2%). Air Traffic Control (ATC) errors caused 33 of the incidents that were reported (these errors were caught by pilots). The special category of mistakes, violations, slips and judgmental errors accounted for 11 incident reports. There were 77 occurrences of this special category of errors that appeared (in one form or another) that did not result in CTM errors. Maintenance and faulty equipment related reports accounted for 9 incident reports but did not lead to any CTM errors being committed. Weather-induced incidents that resulted in correct recovery procedures by the flight crew accounted for eight of the reported incidents. Emergency related incidents (fire, explosion, passenger illness, landing gear problems, flame-outs etc.) that resulted in correct recovery procedures accounted for 33 reports. A breakdown of initial search of the 470 reports was tabulated as shown in Table 4.1 and depicted pictorially in Figure 4.1.

Table 4.1 Analysis of 470 ASRS incident reports reviewed

Problem Origin	Number of Incidents	Relative %
Classified CTM error categories	231	49.2
Other (CRM incidents)	124	26.4
Air Traffic control (ATC)	33	7.0
Emergencies	33	7.0
Small Aircraft	21	4.5
Violations, Mistakes, Slips, Judgment errors	11	2.3
Maintenance & Equipment	9	1.9
Weather	8	1.7
Total	470	100

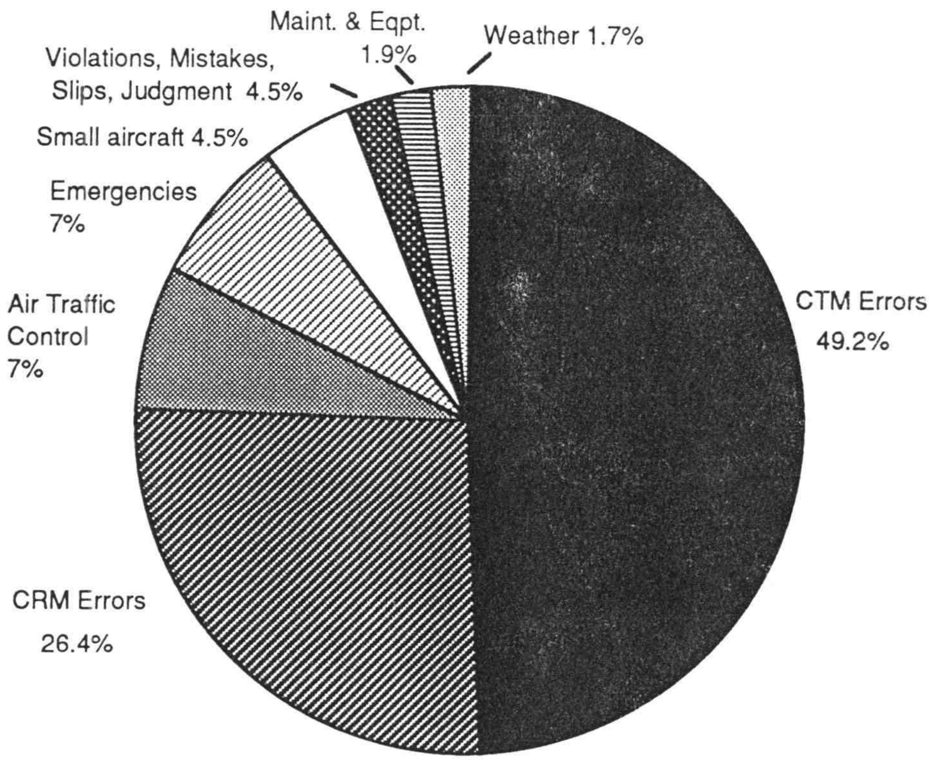

Figure 4.1 Analysis of 470 ASRS Incident Reports

In addition, there were in the report narratives, several references to high workload situations. Phrases such as "..I got real busy..", "..congested traffic ..", ".. complex approach pattern.", "overwhelmed by the multiple tasks.." etc. were all actual phrases used by pilots to indicate an overloading of their resources to effectively execute the required tasks. There were limits to the number of tasks pilots could handle concurrently and perform them all effectively. In studies of human ability to carry out two tasks simultaneously, accurate performance of one could only be maintained (under high workload situations), at the expense of poor performance in the other. Studies on multiple task performance and time sharing abilities under high workload situations have been conducted by several researchers notably by Wickens (1984, 1988), Parasuraman (1984), Ruffel Smith (1979) and Jennings (1977). Studies have shown that it is possible to perform certain non-conflicting tasks concurrently without performance decrement in either (Wickens, 1984, Parasuraman, 1984). Furthermore, the ability of pilots to perform multiple tasks had been shown to be related to the processing demands imposed by the individual tasks (Wickens et. al., 1984).

Workload was a difficult concept to define precisely although each of us would know and recognize it when it got uncomfortably high. This suggests that it is largely cognitive in character (O'Hare & Roscoe, 1990). In addition, pilots make an attempt to maintain performance through increased effort (since they know which flight phases are more demanding), in which case subjective measures of workload rating may be the most sensitive (Rehman et. al, 1983).

High mental workload appeared to be significant from the Descent-to-the-Outer-Marker phase onwards. Tracking the ILS, maintaining traffic watch, communication with ATC, operation of control surfaces (flaps, spoilers etc.) and tracking the runway center line were the specific tasks identified (by some pilots interviewed) as imposing more mental workload. The succeeding activities following the touch-down did not pose as much of a mental workload as during the immediate preceding phase.

5. RESULTS AND DISCUSSION

5.1 Results

There were three levels of segmentation of the CTM errors - at the general level, at the specific level and a detailed segmentation at the specific level. A summary of the CTM errors classified at the general level is given in Figure 5.1 below.

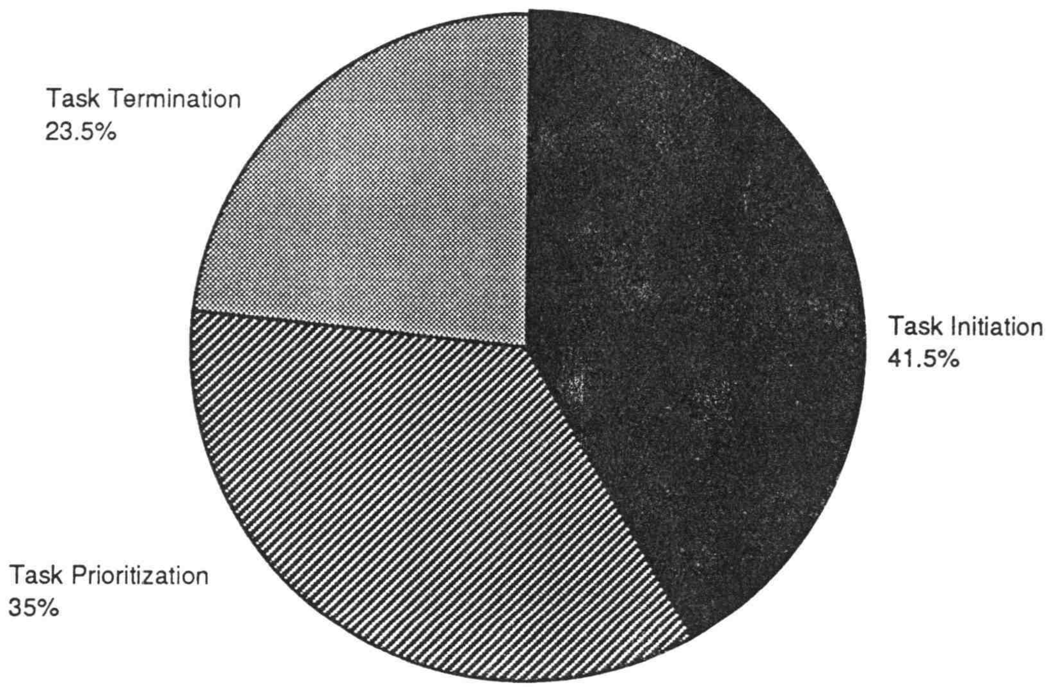

Figure 5.1 Percentage of CTM errors by General Error Categories

A detailed look at these 231 classified CTM error incidents to show the relative distribution of the specific errors is depicted in Table 5.1. Figure 5.2 is a pictorial display of the same results.

Table 5.1 Percentage of CTM errors by General Error Category in 231 ASRS incidents

General Error Category	Number of Errors	Relative Percentage	Specific Error	Number of Errors	Relative Percentage
Task Initiation	145	41.5	Early Late Lack	35 24 86	10 6.9 24.6
Task Prioritization	122	35	Incorrect	122	35
Task Termination	82	23.5	Early Late Lack	6 44 32	1.7 12.6 9.2
Total	349	100		349	100

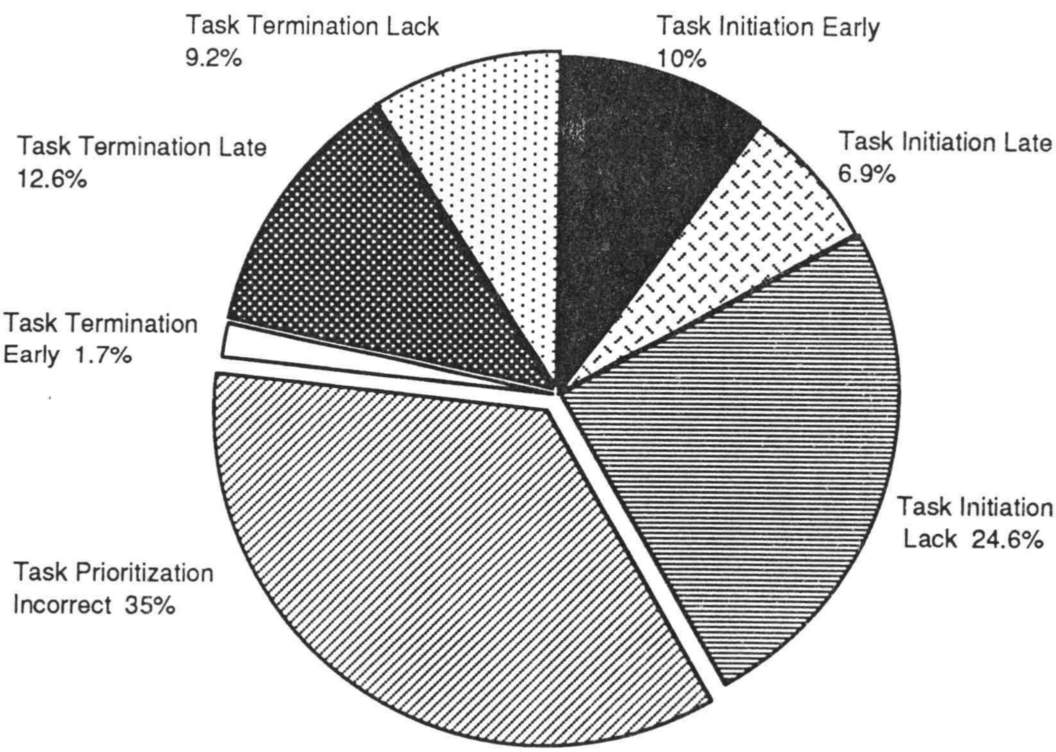

Figure 5.2 Percentage of CTM Errors by Specific Error Categories

A third level of segmentation of the specific error categories led to the classification of the actual types of errors committed. These errors were summarized in Table 5.2.

Table 5.2 Percentage of CTM errors by Specific Error Category in 231 ASRS incidents

General Error Category	Specific Error	Number of Errors	Specific Error	No. of Errors	Rel. %
Task Initiation	Early	35	Early Descent Early Chklist Other	28 2 5	8.0 0.6 1.4
	Late	24	Late Configuration Late Callouts Other	20 2 2	5.7 0.6 0.6
	Lack	86	Navaid tuning lack Non checking of PF Other	66 4 16	19.0 1.1 4.6
Task Prioritization	Incorrect	122	Traffic watch Weather watch Other	54 23 45	15.5 6.6 12.9
Task Termination	Early	6	Auto pilot off early Other	4 2	1.1 0.6
	Late	44	Altitude overshoot Other	39 5	11.1 1.4
	Lack	32	Didn't abort landing Descent alt. o/shoot Other	23 6 3	6.6 1.72 0.86
Total		349		349	100

The caveat concerning the use of the ASRS database for strict statistical analyses was discussed in chapter 2 (Section 2.1). To recapitulate, the main drawback with ASRS incident analyses is that these reports are not random; often, safety-minded people report more often or some recent incidence of accidents or legislation may prompt more reports to be submitted. In addition, I looked at incident reports that I expected would show a higher

5.2 Discussion of Error Categories

General - Task Initiation Errors

The *general* error category of task initiation accounted for 41.5% of the three possible *general* error categories - 145 out of 349 errors. The **Task Initiation Early** category accounted for 24% of task initiation errors while the **Task Initiation Late** category and **Task Initiation Lack** categories accounted for 17% and 59% respectively. It would appear therefore, that the task initiation error category was the main CTM error category. However, the true picture was not so readily evident as the following discussion of the *specific* error categories in this and the other major segments indicated.

Specific - Task Initiation Errors

Task Initiation Early

Almost all the errors in this category dealt with pilots descending out of specific altitude clearances. Pilots did not wait for specific waypoints to cross before descending or they just decided (for some unknown reason) to leave the specified altitude a little early. It was also noted that a few of these errors (9 out of 35 incidents - 26% of **Task Initiation Early** errors) occurred as a result of mitigating circumstances (such as emergencies, poor weather or very high workload). In these instances, tasks were wrongly prioritized and resources diverted to other tasks thus causing the crew to commit these **Task Initiation Early** errors. The second largest sub-category of errors (14% of **Task Initiation Early** errors) here was referred to as 'Other' and involved instances of early task initiation such as a hasty decision to shut down an engine (before confirming an initial diagnosis), early deployment of flaps and/or early deployment of an acute flap angle. Early checklist items (5.7% of **Task Initiation Early** errors) referred to instances where crew members started doing a particular check list item before arrival at that stage (e.g. doing a final landing check while on long finals).

Task Initiation Late

The overwhelming majority of errors in this category involved late configuration of the aircraft (83% of **Task Initiation Late** errors) by the crew. Most of these (14 of the 20 incidents - 70%) were caused by "high workload" situations where the crew members were trying to accomplish several goals in a very short time frame. All of them, however, were crew-induced errors caused by late termination of the initial descent phase resulting in a confused set of activities involving ATC communications, losing considerable height, maintaining traffic watch and communicating with cabin staff and passengers. In other words, due to the late termination of the initial descent phase, subsequent tasks were mis-prioritized (with the consequential mis-allocation of resources) resulting in late initiation of other tasks. Late callouts and "Other" (2 of the 24 incidents - 8.3% each) were the other remaining errors in this category. The "Other"' errors referred to such cases of late adherence to ATC instructions or late deployment of control surfaces.

Task Initiation Lack

This CTM error category accounted for 24.65% of all *specific* errors committed. The omission of tuning of navigational and communication aids (77% of **Task Initiation Lack** errors) was the specific error committed. Crew members omitted tuning the tower frequency (after having been on approach frequency) and invariably omitted getting landing clearance with the subsequent unauthorized landing in every instance. Each crew member assumed that the other had obtained landing clearance without realizing that they could not have obtained one without being on tower frequency. In some cases debates arose as to whether a landing clearance had been issued and the crew talked themselves into the belief that permission had been granted. No attempt was ever made (in all of these incidents) to confirm with tower on the landing clearance issue. Having filed the reports most pilots

adduced the error to 'late and delayed hand-offs' by ATC. Having been on approach frequency for a fair length of time the aircraft was usually cleared to contact tower at an assigned frequency *at a later point in time*. The hand-off was not immediate (i.e. the crew could not switch from approach to tower frequency immediately) and the crew had to remember, when they were at a particular point on finals, to switch to tower and obtain (or confirm) the landing clearance. Given the high workload situation just prior to landing, in all instances, this task was forgotten.
The other scenario described by the pilots was referred to as ATC's "slam-dunk" approach - to bring aircraft in high and then issue clearances to shed considerable height in a short time frame. Having accepted these difficult clearances, several tasks were omitted as the crew sought to configure (first priority) the aircraft. These clearances were described (by pilots) as "ploys" to make the controller's job of separating traffic easier. While there were instances of the acceptance of 'difficult' clearances (8 out of 86 incidents - 9%), it must be noted that the final decision to accept the clearance still rested with the captain. In four of these incidents the pilots did state that they would have initiated a go-around if they had to do it again. The "Other" *specific* error (18% of **Task Initiation Lack** errors) included such instances as the non-deployment of landing gear (on landing), flaps or other control equipment on board. The omission of checking duties i.e. pilot not flying (PNF) checking pilot flying (PF) (5% of **Task Initiation Lack** errors) was the remaining specific error in this category. PNF's in most of these instances did not cross reference or confirm that the PF's instruments (Navaids, Radios) were tuned to the correct frequencies resulting in missed execution of tasks.

<u>General - Task Prioritization Errors</u>

The *general* error category of task prioritization accounted for 35% of the three possible error categories - 122 out of 349 errors. This put it second to the task initiation error category as far as the *general* error category was concerned. If the *specific* error category were to be looked at, then task prioritization errors appeared to be the main CTM error category. As the *specific* error discussion below will reveal, task prioritization errors were not easy to discern.

Specific - Task Prioritization Errors

Task Prioritization Incorrect

This was the largest of CTM *specific* error categories (122 of 349 incidents - 35%) but the numbers themselves do not tell the whole story. As indicated in the earlier error categories, a large number of those specific errors were consequential to task prioritization errors. This was inferred from the narratives and duly recorded only in incidents where it was very obvious. In most instances **Task Prioritization Incorrect** errors were very subtle. The following scenario describes the complexity. If a specific error was committed (late aircraft configuration, say - **Task Initiation Late**) it would be possible to go sufficiently far back in time and say that error was due to a late termination of the initial descent phase which, in turn, was due to some distraction (further back in time) to which the crew diverted resources to (and hence did not monitor the approach). Hence, we could have hypothesized these situations and arrived at a **Task Prioritization Incorrect** error for most cases! However, since most of the narratives did not give a complete history of events leading to the commission of specific errors, most of these probable **Task Prioritization Incorrect** errors were not recorded. Perhaps a methodology to better capture these subtle task prioritization errors could be devised with the help of ASRS. Traffic watches proved to be a major distraction in causing crews to concentrate on the outside of the aircraft (54 of 122 Task Prioritization Incorrect errors - 44%). The "Other" category (45 of 122 **Task Prioritization Incorrect** errors - 37%) comprised GPWS II warnings, flight attendant entertainment and watching the other crew member. Being engrossed in weather watches (23 of 122 **Task Prioritization Incorrect** errors - 19%) also resulted in almost all available resources being diverted to tasks of lower priority.

General - Task Termination Errors

The *general* error category of task termination accounted for 23.5% of the three error categories - 82 out of 349 errors. Of this the **Task Termination Early** category accounted for 7% of task termination errors while the **Task Termination Late** category and **Task Termination Lack** category accounted for 54% and 39% respectively. The *specific* error categories for this segment and a brief discussion for each of the *specific* errors is given below.

Specific - Task Termination Errors

Task Termination Early

The **Task Termination Early** error category was the smallest of the *specific* error categories (6 out of 82 **Task Termination Early** errors - 7%). About 66% of these involved the early release of the auto-pilot feature. The remaining 34% involved the early termination of the check list (incomplete check list).

Task Termination Late

The **Task Termination Late** category (44 out of 82 **Task Termination Late** errors - 53%) was the third largest *specific* error category, after **Task Prioritization Incorrect** and **Task Initiation Lack** *specific* error categories. The majority of these errors involved pilots overshooting the specific altitude clearance given by ATC (39 out of 44 **Task Termination Late** errors - 88%). For example, an aircraft cleared to 7000 feet from 10,000 feet began the descent and continued descending past 7000 feet (initial goal) before corrective action (either by alert crew members or ATC radar) was taken. The

"Other" category (11% of **Task Termination Late** errors) included staying with coupled approaches for too long and cases of extended downwind and/or base legs.

Task Termination Lack

The **Task Termination Lack** category (32 out of 82 **Task Termination Lack** errors - 39%) involved mostly incidents of non-abortion of landings (23 out of 32 **Task Termination Lack** errors-72%). Almost all of these involved landings by pilots in poor weather conditions (below FAA and company minima). In almost every instance, the pilots admitted to the error and stated that they would have gone around (GAR) for a second approach if they were presented with the same situation again. These errors were so categorized after ascertaining that they were un-intentional i.e. the pilot flying (PF) was un-aware that he was in violation of minimum weather rules. There were some instances (5 occurrences in the 231 reports) of captains overriding their crew's warnings about weather minima and going ahead with the landing. These were not recorded as CTM errors but as violations (Reason, 1988). The other remaining error (6 out of 32 **Task Termination Lack** errors - 19%) contributing to the **Task Termination Lack** category involved pilots descending without arresting the descent at specified altitudes (by ATC) and then proceeded to land resulting in un-authorized landings.

6. CTM ERRORS AND HUMAN COGNITIVE LIMITATIONS

6.1 CTM Errors and Cognitive Limitations

While it is not the purpose of this thesis to go into detail on the cognitive aspects of human behavior, some reference to it is made here (as they relate to CTM errors) so that another researcher could explore the connection in some detail. In addition, an attempt was made to identify some specific human cognitive limitation categories for the 231 incidents.

A brief summary of the main cognitive limitation categories that occurred with greater frequency than the others (together with the specific phenomenon within the general category) is presented below interspersed with an example of the specific errors committed in these categories.

Signal Detection Signal detection is a wide field of study within the cognitive sciences and deals with the detection of some environmental event that is sensed and processed by the brain. Signal Detection Theory (SDT) attempts to distinguish between two discrete states of the world called signal and noise. One aspect of signal detection, which is very relevant to the study of pilot performance deals with *vigilance decrement* and *vigilance loss*. These effects resulted from prolonged periods of monitoring duties that pilots were often engaged in and occurred frequently during instances of high workload, usually around busy airports, in bad weather and during emergencies. The specific errors commonly encountered in the incident narratives are described below.

Vigilance decrement Crews exhibited several instances of vigilance decrement (losing track of headings, missing some ATC instructions, instrument scan breakdown etc.) due to various reasons ranging from momentarily high workload situations, weather and fatigue to even hunger.

Perception related problems in CTM incidents uncovered in this research related to one aspect of perceptual information processing - holistic processing. Information processing of incomplete "maps" of information (due to inattention or any of the other perceptual biases) resulted in sub-optimal outcomes. Some examples of these are given below.

Holistic processing This occurred on almost all the instances where the crews made the approaches to the wrong airfield. All the cases of "aiming the aircraft at the wrong airfield" occurred where the target airfield was in the vicinity of another with the net result that crews aimed for the wrong one. Compounding this was the tendency of crews to exhibit verisimilitude (Reason, 1988) where they sought cues that were useful in the past (if ATC clears for an approach via a certain intersection then this would result in a specific approach to a specific runway) and launched themselves on these specific approach patterns. Shutting down a good engine, in two incidents, involved this phenomenon where certain warnings (e.g. over-temp alert) were associated with engine shut-downs. In these cases the "whole picture" was missing in the minds of the crews.

Decision Making errors in the incidents reviewed arose out of several causes. Chief of these was a persistent tendency by some crew members not to consider all the information available relevant to the task before making a decision (*Ignoring sources of information).* In some cases crews made landing decisions in poor weather while discounting all inputs from fellow crew member and ATC. Some even arrived at airfields with a firm conviction of which runways were going to be assigned them. Landings at wrong airports were, largely, the result of crews ignoring all the relevant instruments (usually focusing on a couple of instruments) or ignoring inputs of other crew members. The main cognitive shortcomings in this category are identified below.

Ignoring sources of information
Equal weighting for all information sources
Overconfidence
Failure to consider all hypotheses
Confirmation bias

Poor decision making could be due to any one (or more) of the several sub-categories listed above. These were the main ones listed which occurred in more than one CTM incident. Of the 77 "other" category involving mistakes, slips, violations and judgment, 11 were errors arising out of poor decisions. Each of the 11 errors exhibited elements of several of the sub-categories identified above. The remaining 66 incidents did also reveal many instances of the slips, violations and mistakes arising out of specific errors in this category. In fact, there was not a single instance, other than in slips, in the remaining 66 incidents where the error committed (mistake or violation) was not due to one or several of the specific categories identified above. The tendency of captains (especially if they were flying with co-pilots much junior or less experienced than themselves) to exhibit overconfidence, to fail to consider all hypotheses, exhibit bias against disconfirming evidence (dis-confirming their initial diagnosis), to dismiss other sources of information were readily evident in the 11 cases. The reports were specific in identifying the captain's decision-making actions. Confirmation bias errors appeared several times when crews homed in on specific decisions and sought cues to justify those decisions to the exclusion of other dis-confirmatory evidence. One pilot set his altimeter wrongly and arrived high while disputing with his co-pilot (until very late in the maneuver) that the instruments "sometimes play up" and were unreliable in that particular vicinity and that the approach was fine!

Memory limitations in the incidents reviewed relate mainly to short-term or working memory limitations. Working memory is an attention-demanding, temporary store that we use to retain new information until it is learned and stored in long-term memory. Deficiencies specific to this area are discussed below.

Working memory persistence
Working memory capacity

Errors arising out of this phenomena included instances where the pilot flying (PF) kept following previous ATC clearances (since then updated). Many instances of working memory capacity (short-term memory) limitations were seen where the crew could not maintain even partial lists of tasks to execute (often forgetting them). These were particularly evident in high-traffic airport vicinities and airports with parallel runways (with crews having to maintain visual separation of traffic *outside* the cockpit). In fact, it may turn out that short-term memory limitation may be the main category of cognitive limitation errors with all other categories being subsets of it!

Attention and Perception problems are closely connected and these surfaced several times in the incidents reviewed. Specifically they included one or more categories identified below.

Inappropriate selection
Tendency to be distracted
Inability to divide attention
Stress-induced narrowing of attention channels

Lag in modality switch
Parallel processing within a channel

This was another large category, elements of which occurred with regular frequency in the incidents recorded. Stress-induced narrowing of attention channels occurred in almost every instance of an emergency and sometimes in high traffic airport vicinity. Slow switching between modalities was responsible for some task initiation late/lack errors (for example, responding to a TCAS traffic alert (auditory) while tracking an ILS approach (visual). Resolution Alerts (RA's) were even more dramatic in their effect with a momentary lag in crew response (while tracking the ILS) ; in some instances the crew hesitated momentarily as if to confirm the RA before taking evasive action. There were several instances of crews complaining of "false alerts by TCAS II".

Time-sharing or the process of attending to more than one task concurrently, varied greatly among cockpit crews in the incidents reviewed. In general, time sharing effectiveness is dependent on a number of factors including difficulty of the tasks, types of modalities involved (conflicting or non-conflicting), and a number of other workload-related factors. The more common manifestations of cognitive deficiencies in this category are discussed below.

Resource limited performance
Individual differences in time-sharing ability
Decreased performance with increased workload

Some were better able to deal with the tasks (these were not documented as no CTM errors were committed) while a number of the 231 reports classified did involve some failure, among crew members, to time-share effectively. Emergencies, in general, appeared to result in poorer execution of multiple tasks. Weiner and Nagel (1988) identify preparation as an important component that decides effective response to stimuli. Hence, if the crew was prepared for an emergency then it would be better equipped to deal with multiple concurrent tasks than if it happened to an unprepared crew. This appeared to be validated in at least one situation where the pilot summarized the incident report with the statement that "..such compound emergencies (the crew had a fire and an explosion on board) did not occur in our simulator sessions..".

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

The non-random nature of report submittals in the ASRS system has been alluded to in the Section 2 and Section 4. These sampling characteristics made quantitative analysis of the incident record difficult, resulting in a situation in which it is known that errors occur, but without the corresponding ability to determine how often they occur (Nagel, 1988).

Nevertheless, this research has provided some valid and useful results. First, it has confirmed that CTM errors were significant factors in a large number of incidents. In fact, CTM errors occurred in 231 out of 470 ASRS incidents (49.2%). When this research started, I looked at 260 ASRS incidents for CTM error classification; 109 of those incidents (which included all phases of flight - not just the approach and landing phase) involved CTM errors (42%). The consistency with which specific task management errors surfaced in all the reports reviewed, suggested that there was a definite pattern to the error occurrences. Indeed, I have no reservations about extending these findings and predicting the same CTM error rate to cover incidents that occurred but were not reported.

Second, it has assigned specific error categories and established the relative proportionality that may be attributed to each type of CTM error. Three levels of segmentation or layering of CTM error categories were established - the general CTM error (e.g. Task Initiation), the specific level (e.g. **Task Initiation Lack**) and also a further breakdown of the common errors inside this specific level (e.g. omitted tuning Navaids or specific radio frequencies on final approach).

Third, a structured method of error classification into the specific error categories has been developed. This would enable future researchers to recognize and classify CTM errors in a consistent manner. In addition, this research has provided a basis on which more focused future analyses could be made into investigating the complex subject of cockpit task management errors.

Based on the study of the 231 ASRS incident reports that were analyzed in detail, cockpit crew errors in CTM could be summarized as follows:

1) **Task Initiation Early** errors involved mostly early descents (80% of all **Task Initiation Early** errors).

2) **Task Initiation Late** errors comprised largely late configuration of aircraft (83% of all **Task Initiation Late** errors).

3) **Task Initiation Lack** errors involved mostly the failure to tune navigational aids and radios to the correct frequencies (77% of all **Task Initiation Lack** errors).

4) **Task Prioritization Incorrect** errors were a direct result of three major distractions - a traffic watch (44% of all **Task Prioritization Incorrect** errors) and a weather watch (19% of all **Task Prioritization Incorrect** errors). The other major category (37% of all **Task Prioritization Incorrect** errors) resulting in incorrect prioritization errors was more diffused and due to crew confusion during TCAS II alerts, pilot-not-flying (PNF) watching pilot flying's (PF) performance to the exclusion of their own duties, entertaining flight attendants etc.

5) **Task Termination Early** errors were few in number (7% of all **Task Termination Early** errors) and involved mostly crews dis-engaging the auto-pilot too early .

6) **Task Termination Late** errors involved altitude overshoots (89% of all **Task Termination Late** errors) and involved mostly altitude overshoots. ATC clearances to specific altitudes resulted in crews arresting their descent *after* the target altitude (the goal) had been achieved.

7) **Task Termination Lack** errors consisted largely of crews electing to make a landing (wrong choice) instead of aborting the landing and making a second approach or diverting to the alternate (72% of all **Task Termination Lack** errors).

7.2 Other Non-CTM Errors

While these errors were not listed under any of the CTM error categories, they deserve some mention as they were also central to the various error occurrences in the other CTM error categories.

Mistakes, slips, violations and judgmental (decision-making) errors were defined earlier in Section 3. There were compelling reasons to include them as an adjunct to the CTM error taxonomy since their mitigation paralleled the remedies for CTM errors. In any case, these errors have to be addressed in some manner, possibly as an integral part of a cockpit crew training curriculum. Their frequency of occurrence in the 470 reports that were original analyzed is given in Table 7.2.

Table 7.2 Error rate for Mistakes, Slips, Violations and Judgment (in 470 incidents)

Error Category	Frequency of Occurrence
Mistakes	51
Judgment	11
Violations	9
Slips	6
Total	77

7.3 Recommendations

The results of this research have implications that are largely training-based as opposed to design-based. Reason (1988) suggested that the most productive strategy for dealing with active errors was to focus on controlling their consequences rather than upon striving for their elimination. The aim in CTM error mitigation should be to have a structured method of reducing or eliminating these errors. Reason (1988) once again suggested that if the pilot errors were truly stochastic in nature then the focus should be on a reduction of this variability.

The following guidelines are presented as a means to mitigate CTM errors. A number of these suggestions had already been proposed by Chou (1991), Funk (1991), Reason (1988) and Wiener and Curry (1980).

1) Provide comprehensive crew *education* (at all stages of flying career) in CTM errors and associated cognitive limitations.

Besides electronic aiding to reduce mental workload of pilots, crew training has to emphasize that Cockpit Task Management (CTM) is a valid concept that could be easily integrated into existing Cockpit Resource Management (CRM) programs. The current practice of assigning CRM training at the end of simulator training sessions (indeed, the last item before crew departure) implies that management's attitude towards it is something other than a priority item. The crew, consequently, ends up treating CRM as an adjunct to the primary task or as another "company policy requirement" to satisfy. CTM training would have to be introduced as the *focus* of on-going crew training efforts if it is not to suffer the same fate as current CRM programs. CTM relies on the *education* of the professional pilot rather than the *training* skills he/she must acquire (CRM provides this). The current training efforts of most airlines concentrate on the latter with little attention given to the former. The distinction is an important one; the training has to be complemented by a sufficient amount of the attendant education in crew training efforts of airlines. In particular, if crews could be made aware of human cognitive limitations and CTM errors that could result as a consequence, they would be better equipped to deal with the situations as they arise. In the research, there were two incidents involving pilots arriving "half a dot low" on the GS (Glide Slope)" which they ascribed to pilots newly transitioning to wide-body aircraft. Such "memory lags" (physical body in the new plane but the brain in the old one) may be addressed by an exposure of the crew to cognitive limitation processes.

2) Provide structured crew training (at all stages of flying career) that optimizes training resources and pilot learning abilities.

The current methods of crew training rely heavily on getting pilots through the simulator sessions as quickly as possible. The traditional approach by airlines in conversion or re-currency training has been to bring a group of their pilots (drawn from operations in the US and abroad) to their simulators and cycle them out within three days. During that time, the pilots are introduced to a new aircraft they will be upgrading to (for those on conversion training) and which will require almost all of their attention to "fly it" to acceptable performance limits. Besides also learning to fly, they will have to understand the aircraft's limitations and its control systems theory. At the close of the simulator and theory sessions the pilots are introduced to CRM concepts! This is a considerable amount to digest in a couple of days before the line-oriented-flight-training (LOFT) exercises. This is done by the airlines in the interests of economy. CTM concepts could be introduced, instead, at this stage with a structured program that staggers the simulator, LOFT and CTM and CRM sessions such that optimal learning is achieved which would impact flight safety. It is recommended that simulator and LOFT sessions be staggered such that the two day simulator sessions become a simulator/CTM and CRM session followed by a LOFT/CTM and CRM session followed by a Simulator/CTM and CRM session and then a LOFT/CTM and CRM session. At the very least, all existing CRM training sessions should have a strong CTM component emphasizing the associated task management errors.

While this procedure may be expensive, due to having crews come in on several occasions, it has the potential of improving crew performance and thus reducing error rates. Indeed, one major airline in the US, which has changed its crew training policy recently, has reported a remarkable rate of success with its new program which follows a similar philosophy.

3) All training sessions (simulators and LOFT) should emphasize safety preparedness as the basis for all CTM (and other) exercises.

Airlines should strive to remove pressures on flightcrews to keep aircraft on tight schedules. There were a number of CTM errors as well as violations of procedures where captains elected to ignore crew inputs and land their aircraft in marginal weather conditions. *Safe* arrivals, not *early* arrivals, should be the emphasis in all flying training. In the case of aircraft emergencies necessitating a landing at the alternate airport, the crews need to be aware that the alternate runway should be rated to carry the weight of their particular aircraft. This problem occurred several times when the crews of aircraft diverted to the alternate only to find that they had exceeded the weight capacity of the runway, which led to their aircraft being denied take-off clearance pending inspection by the FAA. The crews were too pre-occupied with their respective emergencies that they forgot to check this vital information on the alternate airfield. In extreme cases (and there were a few of these) crews did not even have sufficient information on alternate runways with at least one that did not have the approach plates at all for the alternate. Many pilots identified TCAS II alerts (real and false) as potential sources of distraction on approach. Incorporating TCAS II alerts in simulators during the approach to land phase therefore (rarely done, if at all now) should help in getting crews to be comfortable operating in multiple emergency situations. Get crews to read back clearances more often and always confirm runway clearances; for example, if an aircraft is on vectors, ask specifically, " Confirm vectored for 24L"? This requires a definite response from ATC. In an emergency, crews should not waste time and energy with a VFR approach; unless flying conditions prove otherwise, crews should always ask for vectors. This is especially important for a two-man cockpit crew team.

4) Provide cockpit crew with a continuous assessment of task status and its priority in the agenda and also allocate system resources accordingly.

Task prioritization errors were central to the error occurrences in the other categories. Although this is borne out by the slightly higher incidence rate of task prioritization errors (122 out of 349 errors), the number belies its actual significance. Task prioritization errors occurred with every situation that were identified by the pilots as high workload situations. Where the workload situation was not identified, there were a number of consequential errors committed as a result of failure to prioritize tasks. Emergencies in particular (explosion, engine failure, etc.) caused crews to forget to initiate certain tasks (even forgetting to declare an emergency!). A fully integrated Cockpit Task Management System (CTMS) would help pilots walk through the particular emergency in a systematic manner without any task omissions. An integrated CTMS will have emergency procedures (engine failure, shut-down procedures, relight procedures, fire, explosion, etc.) programmed into it. These could be invoked with a single push of a button. A hierarchical menu system is envisaged where the first recall would result in a screen showing a choice of emergencies (fire on board or an engine fire, engine failure or an explosion, say). The second recall (the crew having made the selection - engine failure, say) would result in a second screen showing engine shut down procedures which, having been initiated by the crew and verified thus by the CTMS, would result in an engine relight procedure screen. Each of these layered screens would walk the crew through the necessary steps to ensure that no tasks were omitted in dealing with the emergency. The EICAS system, now appearing on some of the newer aircraft, is a step in this direction. The integrated CTMS would also have a system to monitor flight progress (crew punches in Initial Descent, Final Approach etc., say) and the system would recognize that certain activities (such as lowering of flaps at higher than approach speeds) would result in a non-obtrusive but positive warning. In one of the incidents the aircrew was 500 feet from touch down when they realized that they had forgotten to deploy the landing gear.

Having thus established the priority of tasks to be executed in sequence, resources have to be allocated for the execution of these tasks. The captain would allocate responsibilities to execute these tasks to other crew members and the CTMS would serve only as a monitor for which each task's completion would be checked-off (crew member confirms execution by pressing button on flagged items). Any tasks remaining would also be flagged (aural or visual or both) for the crew's attention. Tasks that had been suspended by unexpected conditions could also be displayed by the CTMS and such tasks that might need resumption would be automatically re-prioritized in the context of the then current condition. For example, if the crew had been asked to contact Tower frequency (for a "delayed hand-off" by Approach Control - a very common occurrence and gripe, of pilots) on an ILS approach when they contacted patchy fog (high crew concentration), then the CTMS would remind them of the need to contact tower for landing clearance. There were 27 such incidents of failure to contact tower for landing clearance resulting in un-authorized landings.

5) Provide a holistic view of the aircraft state (system state) and its relation to the outside world (world state) to the pilot.

There were numerous instances in the reports of pilots losing their bearings - where the aircraft was in relation to the destination airport, where in the flight pattern (on final approach) the aircraft was in relation to the runway or where the aircraft was in relation to other nearby traffic (in the vicinity of high-traffic airports). In many of these instances, crews thought that they were already at specific waypoints when they had not arrived there and errors were committed in early descents and early termination of tasks. Chou (1991) identified instances where crew members initiated engine recovery procedures (when they were too high) without any reference to the re-start envelope. A dynamic computerized support system that systematically updates information on the aircraft state and world state could also double as an inter-active electronic check list. The aircraft system state and its relation to the world could be presented to the pilot with automatic countdown of check list items that should be actioned at each stage. The check list would flag items (aural or visual warnings) that were incomplete. This would circumvent almost all of the early descent errors (**Task Initiation Early**) and the late configuration errors (**Task Initiation Late**) while the radio/navaid tuning errors (**Task Initiation Lack**) errors would be greatly reduced.

6) Provide training to Air Traffic Controllers in CTM and CRM concepts.

ATC problems, as reported by pilots often referred to the "delayed hand-off" procedure as a major source of problem. Pilots on approach were usually asked to contact tower frequency for the necessary landing clearance but *after* they had arrived at the Outer Marker (usually). In the ensuing high workload situation on short finals, pilots often forgot to switch to tower resulting in un-authorized landings. Compliance with "un-doable" clearances, issued by ATC, and changing clearances at short notice (on finals) by ATC were also a common gripe with pilots. In several of the incidents, tower control was issuing instructions to pilots on roll-outs. In addition, pilots often complained that ATC sometimes did not listen to read backs (by pilots) of clearances resulting in mis-interpreted clearances and consequential errors. All these problems indicated a serious lack of teamwork on the part of the major players. The Air Traffic Controller is an important and integral member of the aviation trinity comprising the pilots (and airlines), the regulatory bodies (the FAA and the NTSB) and the ATC. Automation such as the Voice Data Link (VDL) system may only partially mitigate some of the communication problems between ATC and pilots. Until a serious attempt is made to integrate the efforts of all these groups to help one another as team members (and they all rely on each other for their own existence) rather than treat each other as adversaries, little progress is going to be made in resolving the CTM error rate. Hence, it is recommended that ATC personnel be able to attend CTM and CRM training sessions and this should be coordinated/facilitated by the regulatory bodies (in a supportive role) and supported by all the airlines.

As the present research got underway, it appeared as if all the errors committed by the flightcrew could be traced, eventually, to some shortcoming in human cognitive abilities. It is therefore recommended that the connection between CTM errors and human cognitive limitations be investigated in earnest. In addition, the special category of mistakes, slips, violations and judgmental errors should be analyzed in some detail since there appears to be a case for including them as a sub-set of the CTM error umbrella. The consequences of errors in this category have a direct impact on CTM errors; certainly, the remedies to mitigate errors in this category parallel those classified under the CTM category. Perhaps an adjunct category to the CTM error categories could be devised to accommodate this category of errors.

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Appendices

Appendix I

Summary of CTM errors in 231 ASRS incident reports

ASRS Report # \ CTM Error Category	Task Initiation			Task Prioritization	Task Termination		
	Early	Late	Lack	Incorrect	Early	Late	Lack
191956			●				
192018		●	●	●			
192660		●					●
192798				●			
192808				●			
196716							●
197269		●					
197363			●	●			
197423			●				
197432						●	
197525				●			
197777				●			
198394						●	
198398			●	●			
199191			●	●			
199285			●	●			
199526				●			
199964			●	●			●
200203		●	●	●		●	
201415				●			

CTM Error Category / ASRS Report #	Task Initiation			Task Prioritization	Task Termination		
	Early	Late	Lack	Incorrect	Early	Late	Lack
201857			●				
201970				●			
202129		●		●			
202233			●	●			
202324			●				
202340			●	●			
202666			●			●	
202788						●	
202948			●	●			
203110		●	●	●			
203313			●	●		●	
203352			●	●			
203357			●				●
203531						●	
203587				●			
203692			●				
203839			●	●			
203926			●				
204174				●			●
204739				●			

CTM Error Category / ASRS Report #	Task Initiation			Task Prioritization	Task Termination		
	Early	Late	Lack	Incorrect	Early	Late	Lack
204919				●			
205273			●	●			
206310			●	●			
207846		●					●
207957			●			●	
209614	●			●			
209795			●	●			
209868	●			●		●	
210234			●	●			
210434			●	●			
210692		●				●	
210716			●		●		
210807			●				
210904		●	●	●			●
210912			●	●			
212660				●			
213286				●			
215707			●				
216066			●			●	
216283			●				

ASRS Report # \ CTM Error Category	Task Initiation			Task Prioritization	Task Termination		
	Early	Late	Lack	Incorrect	Early	Late	Lack
216617					●		●
217129				●			
217430		●					
217784						●	
218661			●	●		●	
221662				●		●	
221762		●		●			
223200			●	●			●
223672			●				
224139	●					●	
224197				●		●	
224500			●				
228154						●	
228824			●	●			
228827			●	●			
197423						●	
90732				●			
112867				●			
119472							●
133899		●					

CTM Error Category / ASRS Report #	Task Initiation			Task Prioritization	Task Termination		
	Early	Late	Lack	Incorrect	Early	Late	Lack
137705							●
144766		●		●			●
153049				●			
156654				●			
159689				●			●
165425			●	●		●	
171669	●			●			
192660		●					●
194905	●						
196627			●				
201642							●
202159				●			●
202324				●			
202642				●			●
204883				●			●
216902				●			●
222508			●			●	
224472				●		●	
228696	●						
229152				●		●	

CTM Error Category / ASRS Report #	Task Initiation			Task Prioritization	Task Termination		
	Early	Late	Lack	Incorrect	Early	Late	Lack
193460			●	●			
193521			●	●			
193828				●			
193848	●		●				
194098						●	
194435				●			
194664				●			
195498				●			
196103				●			
196447			●				
196736		●		●	●		
197311			●	●		●	
197431			●	●			
197819	●			●		●	
198777			●	●			
200978				●			
201848			●	●			
202238	●	●					
202390		●	●	●			
202771	●			●		●	

CTM Error Category / ASRS Report #	Task Initiation			Task Prioritization	Task Termination		
	Early	Late	Lack	Incorrect	Early	Late	Lack
202948			●	●			
203086		●		●			
203467						●	
203586			●				
203659			●				
204512			●				
204531				●			
204823			●	●			
224359						●	
206005	●		●				●
211425	●					●	
212551			●				
213428			●				
215437	●		●	●			
216140							
216228			●				
219832				●		●	
219847				●			
221135	●						
224236	●		●	●			

CTM Error Category / ASRS Report #	Task Initiation			Task Prioritization	Task Termination		
	Early	Late	Lack	Incorrect	Early	Late	Lack
225374			●			●	
225831			●				
226068				●			●
228441				●			
228445							●
198358			●	●			
50006				●			●
50664						●	
57612			●			●	
58070						●	
54096				●			
53936				●			
53261				●		●	
61384			●	●			
163962				●		●	
68569	●						
127358			●	●		●	
104260	●			●			
169789			●	●			●
153202	●			●			

ASRS Report # \ CTM Error Category	Task Initiation			Task Prioritization	Task Termination		
	Early	Late	Lack	Incorrect	Early	Late	Lack
149672	●						
98235					●		
70731				●	●		
113070		●				●	
82787		●					
90126				●			
142367							●
132717				●		●	
129262				●			
129253	●						●
118461				●			
82995	●					●	
163284			●				
163791			●				
50669	●	●	●	●		●	
127456		●					
100133				●			
94508			●	●			
95266			●				
109856				●			

CTM Error Category / ASRS Report #	Task Initiation			Task Prioritization	Task Termination		
	Early	Late	Lack	Incorrect	Early	Late	Lack
124168			●				
127348	●						
88595				●			
92181				●			
122545				●			
61384				●			
135085						●	
167166				●			
78665			●	●			
72600		●					
71374				●			
71668			●				
169584						●	
169351				●	●		
101423				●			
102576		●					
102493				●			
103556				●			
103473	●			●			
103272	●						

CTM Error Category / ASRS Report #	Task Initiation			Task Prioritization	Task Termination		
	Early	Late	Lack	Incorrect	Early	Late	Lack
102966				●			
105151			●				
105528	●						
105511			●				
105869			●				
110576			●	●		●	
105824				●		●	
114086	●						
162286			●	●			
162203	●			●			
155069							●
154405	●			●			
166507	●		●				
120217	●						
132120				●		●	
115787	●						
114421				●			
62638				●		●	
64961	●						
66976							●

CTM Error Category / ASRS Report #	Task Initiation			Task Prioritization	Task Termination		
	Early	Late	Lack	Incorrect	Early	Late	Lack
70419				●			
132112			●				
132100	●						
133889			●				
136878			●				
136799			●	●		●	
137204				●		●	
149158	●						
147891			●	●			
153390	●	●		●			●
154249				●			
Total	35	24	86	122	6	44	32

Appendix II

Glossary of Aviation Terminology

ADF	Automatic direction finder. A navigation aid that indicates the direction to a non-directional radio transmitter from which signals are being received
ASRS	Aviation Safety Reporting System. A reporting service for airman, ATC, maintenance personnel and others to report actual or potential hazards to air safety. It is a voluntary and anonymous reporting service.
ATC	Air Traffic Control
Capt.	Captain
CAT III LANDING SYSTEM	Airport is equipped with an Automatic landing system.
CAVU	Ceiling and visibility unlimited.
CB	Cumulo nimbus. Thunderstorm clouds.
CIRCUIT	The rectangular flight path around the airport comprising the take-off, cross-wind leg, the downwind leg, the base leg and finals for landing.
CRM	Cockpit Resource Management.
CTM	Cockpit Task Management
EICAS	Engine Indicating and Crew Alerting System
FAA	Federal Aviation Administration

FLARE	To round out a landing approach to touch down smoothly by gradually raising the nose of the aircraft.
F/O	First Officer. Second in command after the Captain.
GLASS COCKPIT	A generic term used in reference to a flightdeck instruments that display information via electronic means rather than the traditional electromechanical devices. Most of these are computer displays.
GLIDE SLOPE (GS)	A radio beam transmitted by an instrument landing system that defines a desired glidepath - normally inclined three degrees with deviations above and below the desired glidepath within + 0.5 degrees (or 1/2 dot spacing).
GPWS	Ground proximity warning system. A warning device on the flight deck that is activated when the rate of closure with terrain or departure from the GS is outside prescribed limits.
IMC	Instrument meteorological conditions. Flying with reference to instruments only.
ILS	Instrument landing system. A pilot interpreted radio navigation aid providing vertical (glideslope) and lateral (localizer) angular displacement from a final approach path to a runway.
LOFT	Line oriented flight training.
MDA	Minimum descent altitude. The lowest altitude to which descent is authorized without visual contact with the runway in a non-ILS approach.
NDB	Non directional beacon that emits a continuous radio wave, the directional origin of which can be sensed by an ADF to guide the aircraft to a fixed position.

NTSB	National Transportation Safety Board
OVERSHOOT	landing past the intended touchdown point, execution of a missed approach or the exceedence of a specific ATC altitude clearance by the aircraft.
RVR	Runway visual range. The minimum length of runway that can be seen with the naked eye. Used in making decisions in executing missed approaches.
TCAS II	Traffic alert and Collision Avoidance System. Gives two main signals, the traffic alert (TA) when too close to traffic and the resolution alert (RA) to take immediate evasive action.
VFR	Visual flight rules. The regulations governing flight operations when the weather conditions are at or above a certain minima.
VOR	Visual omni range. An omni directional radio (more sophisticated than an NDB) that provides indications of the bearing of the aircraft to or from the ground transmitter.
WX	Weather