Controller and Pilot Error in Airport Operations: A Review of Previous Research and Analysis of Safety Data

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13. ABSTRACT (Maximum 200 words)

The purpose of this study was to examine controller and pilot errors in airport operations to identify potential tower remedies. The first part of the report contains a review of the literature of studies conducted of tower operations and of efforts to integrate systems in the tower. The second part of the report contains an analysis of 256 tower operational errors and deviations, 67 reports of pilot deviations, 326 reports submitted to the Aviation Safety Reporting System by pilots and controllers, and 23 National Transportation Safety Board final reports of accidents and incidents. The report identifies factors associated with these incidents and potential remedies.

The tower "shortfalls" that this study points to are the need for: better memory aids for controllers (and more consistent use of memory aids); improved means of controller-pilot communication; improved means to facilitate coordination among controllers; and improved surveillance and monitoring equipment. Additional recommendations were: improved aids for pilots situation awareness, such as better airport markings and lighting; airport-specific risk analyses, and revision of the means of recording operational errors.

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PREFACE

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gm)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
1 pint (pt)	=	0.47 liter (l)
1 quart (qt)	=	0.96 liter (l)
1 gallon (gal)	=	3.8 liters (l)
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	=	0.04 inch (in)
1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (km)	=	0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	=	0.036 ounce (oz)
1 kilogram (kg)	=	2.2 pounds (lb)
1 tonne (t)	=	1,000 kilograms (kg)
	=	1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION

Inches	0	1	2	3	4	5

Centimeters	0	1	2	3	4	5	6	7	8	9	10	11	12	13

QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

Updated 6/17/98

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EXECUTIVE SUMMARY

Runway incursions[1] and other surface incidents[2] are significant threats to aviation safety and efficiency. While the number of near mid-air collisions has remained relatively steady since 1995, runway incursions have steadily increased. It is no surprise that "nearly all runway incursions are caused by human error" (FAA, 1998 Airport Surface Operations Safety Action Plan, p. 1). While the opportunities for equipment malfunctions to cause such problems are relatively rare, the opportunities for human error are abundant. The proximity and number of aircraft in the terminal environment, combined with the complexity of operations and the requirement for split-second timing, conspire to make the airport surface and proximal airspace extremely unforgiving of pilot and controller errors.

Several studies have been conducted to examine the causes of these incidents and to identify solutions to the underlying problems. This report presents a review of the literature in two parts. The first is an examination of research on the causes of human errors involved in operations on the airport surface and other critical operations under the control of air traffic control towers (ATCT). This literature is reviewed to identify "shortfalls" in the tower and potential remedies; this report does not attempt to address training, procedures, work schedules, airport markings, etc. The second part of this examines previous efforts at system integration in the tower and the criteria that were used in these efforts.

The second half of this document describes the results of an analysis of safety data – operational errors and deviations, reports submitted by tower controllers and pilots on surface incidents to the Aviation Safety Reporting System (ASRS), and National Transportation Safety Board (NTSB) reports of accidents and incidents – in light of the conclusions and recommendations presented in the reviewed literature.

The results of the analysis of safety data were consistent with the results of previous work. The most common factors contributing to controller errors in the tower were:

- Forgetting about an aircraft, the closure of a runway, a vehicle on the runway, and/or a clearance that he/she had issued.
- Communication errors – readback/hearback errors, issuing wrong instruction or issuing instruction to wrong aircraft.
- Lack of, or incomplete, coordination between controllers.

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[1] A runway incursion is defined as "any occurrence at an airport involving an aircraft, vehicle, person, or object on the ground that creates a collision hazard or results in loss of separation with an aircraft taking off, intending to take off, landing or intending to land" (FAA, November, 1999, p. G-4).
[2] A surface incident is defined as "any event where unauthorized or unapproved movements occurs within the movement area or an occurrence in the movement area associated with the operation of an aircraft that affects or could affect the safety of flight" (Ibid., p. G-4).

An additional factor identified in the literature, absence of a supervisor (who was not working a control position), is supported by the data, but warrants further study. In many cases, it was the supervisor (or controller-in-charge) that prevented a bad situation from getting much worse.

The tower "shortfalls" that this study points to are the need to prevent, and mitigate the consequences of, errors due to: failures of controller memory, miscommunications between pilots and controllers, failures of coordination among controllers, failure of controllers to accurately project separation between aircraft. This could be accomplished in a number of ways. Some of which include:

- Improved surveillance and monitoring equipment (e.g., ASDE-X, AMASS, runway status lights, loops). Peripherally included in this is that pilots and/or controllers need a means of determining whether an aircraft is clear of the runway.

- Better memory aids for controllers (and more consistent use of memory aids).

- Improved means of controller-pilot communication (to reduce frequency congestion, eliminate blocked transmissions, and reduce the probability of an aircraft accepting a clearance intended for another aircraft).

- Improved means to facilitate coordination among controllers – this could be accomplished by a variety of means, such as shared displays, improved means of voice communication, and changes in procedure. The most appropriate means needs to be determined by the coordination required.

In addition, the following recommendations resulted from the analysis:

- Revise the method for investigating, collecting information, and recording information on controller operational errors and deviations so that it is more consistent and useful in determining the causes and potential remedies to incidents.

- Survey towers for "homemade" memory aids, runway incursion prevention mechanisms, and other unique facility inventions (such as a bar code mechanism to record delay times) so that the effects of these aids can be studied and the information can be disseminated to all towers.

- Provide support to towers to expedite the acquisition of needed equipment or other resources.

- Encourage individual towers to perform their own "risk analysis" identifying significant factors in their own incidents (e.g., where on the airport surface the incidence are taking place, the type of aircraft operators involved [helicopter, GA, military], etc.), and identify what can be done (markings, procedures, pilot education, etc.) to prevent future occurrences and provide the resources to assist towers in these analyses and remedies.

- Improve airport signage and markings, particularly the conspicuity of "hold short" points.

1. INTRODUCTION AND SCOPE

Runway incursions[3] and other surface incidents[4] are significant threats to aviation safety and efficiency. As can be seen in Figure 1, while the number of reported near mid-air collisions has remained relatively steady since 1995, the number of reported runway incursions has steadily increased. While it is impossible to know how much of this increase might be due to an increased awareness of the problem and increased willingness to report incursions, it is clear that runway incursions require intervention.

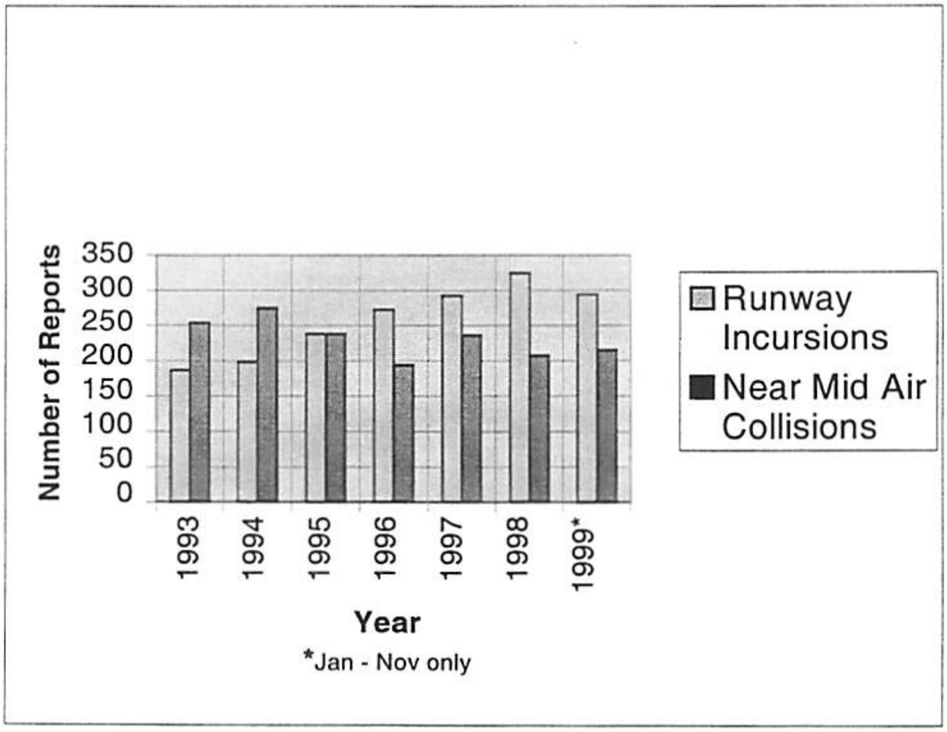

Figure 1. Reported Runway Incursions and Pilot Reported Near Mid-Air Collisions

It is no surprise that "nearly all runway incursions are caused by human error" (FAA, 1998 Airport Surface Operations Safety Action Plan, p. 1). While the opportunities for equipment malfunctions to cause such problems are relatively rare, the opportunities for human error are

[3] A runway incursion is defined as "any occurrence at an airport involving an aircraft, vehicle, person, or object on the ground that creates a collision hazard or results in loss of separation with an aircraft taking off, intending to take off, landing or intending to land" (FAA, November, 1999, p. G-4).

[4] A surface incident is defined as "any event where unauthorized or unapproved movements occurs within the movement area or an occurrence in the movement area associated with the operation of an aircraft that affects or could affect the safety of flight" (Ibid., p. G-4).

abundant. The proximity and number of aircraft in the terminal environment, combined with the complexity of operations and the requirement for split-second timing, conspire to make the airport surface and proximal airspace extremely unforgiving of pilot and controller errors.

The purposes of this paper were to provide a comprehensive review of relevant literature and to analyze current safety data; this information was used to identify "shortfalls" in the FAA air traffic control towers (ATCT) and potential remedies for these shortfalls. Several studies have been conducted to examine the causes of these incidents and to identify solutions to the underlying problems. This literature was reviewed in two parts. The first is an examination of research on the causes of human errors involved in operations on the airport surface and other critical operations under the control of ATCTs. The scope of this report excluded: training, procedures, work schedules, airport markings, etc; in short, it was not intended to address anything outside of the tower. The second part of this review looks specifically at work done on systems integration in the tower. As new systems are implemented in the tower to provide more useful information to controllers, the need for integration increases with the amount and complexity of the new information. Yet, the questions about specifically which displays should be integrated, and how they should be integrated, remain unanswered. This part of the literature review examined previous efforts at system integration in the tower and the criteria that were used in these efforts.

The second half of this document describes the results of an analysis of safety data – operational errors and deviations, reports submitted by tower controllers and pilots on surface incidents to the Aviation Safety Reporting System (ASRS), and National Transportation Safety Board (NTSB) reports of accidents and incidents – in light of the conclusions and recommendations presented in the reviewed literature.

2. RESEARCH ON SURFACE INCIDENTS

Several studies have examined the causes of runway incursions and other surface incidents and sought to identify solutions to the underlying problems. These studies will be examined in chronological order.

2.1 THE FIRST STUDY OF RUNWAY INCURSIONS

The first comprehensive study of runway incursions was begun in 1978 when the number of reported number of accidents and incidents on the airport surface in the past ten years was only 279. Bellatoni and Kodis (1981) examined 161 ASRS reports, 77 NTSB accidents, and 49 ATC system errors and interviewed tower personnel from the New England, Great Lakes, and Western Regions (each of these regions had conducted their own, unpublished, studies of runway incursions). Interviews with tower personnel revealed that runway and taxiway transgressions were much more frequent than formal reporting systems indicated, in part, due to the time and effort involved in the reporting process. The ASRS and NTSB reports examined contained 166 "runway transgressions," this included runway incursions and other surface incidents. Five percent of these transgressions were attributable to "airport, equipment, and other" and 95 percent were attributable to human error (p. 71). Of the latter, roughly 50 percent were attributable to pilot errors and 50 percent were attributable to controller errors. The most prominent types of errors in runway transgressions were pilots proceeding without a clearance and controllers issuing conflicting clearances. While such statistics are easy to understand, they do little more than satisfy our apparent need to identify the party "at fault." In order to be able to take corrective action to prevent such errors, the nature of the errors and the factors associated with the errors must be understood. The report concluded with a recommendation for the construction of a more detailed data base from which a more fruitful study of the causes of runway incursions could be based.

2.2 NTSB SPECIAL INVESTIGATION

In 1986, the National Transportation Safety Board issued a Special Investigation Report (NTSB/SIR-86/01) after investigating 26 runway incursions. The purpose of this investigation was to "investigate selected runway incursions to determine their underlying causes and to recommend appropriate remedial actions" (p. 1). For the purposes of the study, "runway incursion" was defined as "any occurrence involving an aircraft, vehicle, person, object or procedure that impedes the takeoff, intended takeoff, landing or intended landing of an aircraft" (p. 1). The FAA had identified 65 percent of these incursions as attributable to controller error and 35 percent to pilot error. However, the Safety Board acknowledged that in many of the incursions, both pilot and controller behaviors were involved and that "many of the incursions classified as operational errors could have been prevented by proper action by the pilots involved" (p. 34).

Most (65 percent) of the incursions that had been attributed to controller errors resulted from the actions of individual controllers and 35 percent of these errors resulted from "incomplete or misunderstood coordination between two controllers." The largest single category of controller errors (identified in 44 percent of the incursions attributed to controller error) was that controllers "had forgotten about an aircraft or about previously effected coordination with the other controllers" (p. 2). In terms of causal factors, the "primary controller-related factors identified in the runway incursion special investigation were forgetting aircraft and lack of or incomplete coordination between controllers" (p. 15). Forty-four percent of the incursions that the FAA had attributed to controller error involved the controller forgetting something significant, e.g., the presence of aircraft on a runway, the closure of a runway, or a clearance that he/she had issued.

The experience level of the controllers involved was not identified as a causal factor; controllers of all experience levels were involved in the incursions studied. However, the controllers with the most experience were acting in a supervisory (supervisor or controller-in-charge) role at the time of the incident and were usually working control positions simultaneously. "In almost all of the runway incursions classified as operational errors, the supervisor either was not in the tower cab or was working at least one control position" (p. 35). The report also states which "A lack of controller and/or supervisory redundancy in the tower cab is a factor common to many controller-induced runway incursions" (p. 35). This points to the need for increased redundancy in the tower. Clearly an "extra set of eyes" can go a long way toward providing the necessary oversight to prevent operational errors in the tower.

Lack of, or incomplete, coordination between local and ground controllers was a significant factor in 66 percent of the incidents attributed to controller error. "Several of the runway incursions classified as operational error could have been prevented if there had been more complete communication and coordination between the ground and local controllers" (p. 35). No other factors, were determined to be significant causal factors, in fact, "most incidents occurred in low traffic and under conditions of excellent visibility" (p. 34). It should be noted, however, that this does not mean that complex traffic situations or visibility are not important factors in determining the probability of an incident or accident. To determine this, one would need to know the incident rate for the various conditions (poor visibility, complex traffic, etc.). This would require, for example, comparing the number of incidents in poor visibility as a function of the number of operations in poor visibility to the number of incidents that occur in good visibility as a function of the number of operations in good visibility. Such analysis was not found in the literature.

Of the 35 percent of the incursions classified by the FAA as due to pilot error, all of them were attributable to a pilot entering, crossing, or taking off from a runway without a clearance. In "several" of these instances, runway and taxiway signs were "missing or inadequate." In "at least two [of the nine] instances, pilots did not comply with controller clearances which the pilots had acknowledged receiving" (p. 2). These runway incursions "usually involved either communication problems, such as misunderstanding clearances, or inadvertent entry of a runway because of disorientation" (p. 12).

As a result of this special investigation, the NTSB submitted several recommendations to the FAA. To address the problems associated with controller memory failure, there was a recommendation to "Establish an ad hoc task force, including controller and human performance expertise, to develop effective memory aids that would reduce incidents of air traffic controllers forgetting traffic, and to incorporate a description of these memory aids and how they should be used in ...controller training..." (A-86-32). This recommendation was classified as "closed – acceptable action" with the publication of the FAA pamphlet "Controller's Memory Manual – A Self-Help Guide."

The only NTSB recommendation contained in this report that identifies equipment needed in the tower speaks to the problem of controllers forgetting about vehicles on an active runway. This recommendation is to "Develop a mechanical/aural/visual (or combination thereof) alert device and require its use by local and ground controllers to coordinate their activities when a vehicle has been cleared to operate on the active duty runway for an extended period such as in snow removal operations" (A-85-15).

While memory aids are useful, we must recognize the fact that human memory is a fallible system. Memory will fail at times, no matter how experienced, well-trained, motivated, or conscientious an individual is; it is this fallibility that well-designed automated tools can and should be implemented to offset.

Finally, there is the recommendation to "Revise the current tower training curriculum at the ATC Academy to include more emphasis on practical standardized "hand-on" tower training dynamic laboratory and simulation facilities (A-86-30). While a tower simulator would be of obvious use in training, much of the training of tower controllers is necessarily "on-the-job" due to airport specific operations. Furthermore, since it is impossible to train human error out of a system, it is also necessary to invest in tools and other mechanisms that controllers can use to alert them to their own oversights and pilot errors.

2.3 MITRE'S ANALYSES OF RUNWAY INCURSIONS DUE TO ATC OPERATIONAL ERRORS

The MITRE Corporation has conducted two analyses of runway incursions that resulted from operational errors. The first study (Bales, Gilligan, and King, 1989) examined all runway incursions in 1985 and 1986 that resulted from an operational error and either occurred at a major airport or involved a commercial air carrier. The second study (Steinbacher, 1991) examined 109 runway incursions that occurred between January 1987 and October 1989 due to operational errors. Since the results of the two studies were nearly identical, they will be examined together. Most of the incidents occurred in daylight and good weather. Weather was considered to be a factor in 5 percent of the incidents in the 1989 study; in the 1991 study, "no report explicitly identified weather as a factor." With respect to controller workload, "complexity" was listed as less than average at the time of the incident in 35 percent of the incursions, as average in 29 percent of the cases and above average in 36 percent of the reports. The significant causal factors found in both of these studies were attributed to the controller's:

- "Failure to verify the location of the aircraft or vehicle" (identified in 37 percent of the incidents in the 1991 study).
- Forgetting about an aircraft, an instruction, the traffic or runway situation (34 percent).

- Failure to anticipate the required separation or miscalculation of the impeding separation (19 percent).

- Failure to coordinate with another controller (13 percent).

- Communication errors – readback/hearback errors, issuing wrong instruction or issuing instruction to wrong aircraft (11 percent).

- Supervisor working a position or engaged in activities other than directly supervising staff (9 percent).

The solutions to these incidents that were proffered by both reports were:

- Installation of ASDE-3 and AMASS (Airport Movement Area Safety System).

- Electronic flight strips.

- Development of a voice recognition system to monitor key words in transmissions and compare responses to detect errors.

- Development of a tool that will help controllers to ensure separation and will alert controllers to a potential loss in separation.

2.4 ANALYSIS OF SURFACE INCIDENTS AT 12 AIRPORTS BY ALARIS, CO. INC. (1992)

This study analyzed 235 "surface incidents" that occurred at the 12 selected airports (Atlanta, Boston, Cincinatti, Denver, Dallas/Ft.Worth, New York - JFK, Los Angeles, Chicago O'Hare, Pittsburgh, Phoenix, San Antonio, and Seattle) between 1988-1990. Fifty-five percent of these incidents were pilot deviations, 26 percent were operational errors/deviations, 17 percent were vehicle/pedestrian deviations and 2 percent were incident reports from NTSB files. Half of the 235 surface incidents were classified as runway incursions. Of these, 49 percent were attributed to controller operational errors, 32 percent were pilot deviations, and 19 percent were vehicle/ pedestrian deviations. Unfortunately, the usefulness of this report is limited for two reasons. First, since the purpose of this study was to look for patterns in these incidents at the individual airports, the results were not consolidated to identify overall patterns. Second, the analysis of the human errors (i.e., pilot deviations and operational errors/deviations) consisted solely of a classification of the type of error (e.g., pilot crossed an active runway rather than holding short as instructed); it did not attempt to identify the factors that contributed to the errors or information or tools that could have prevented the errors.

2.5 MITRE'S PILOT SURFACE INCIDENT SAFETY STUDY (1993)

Kelly and Steinbacher (1993) analyzed 75 reports submitted by pilots to the Aviation Safety Reporting System (ASRS) and their subsequent "structured call backs" (post-report telephone interviews). Although the study was cockpit-oriented and focused on factors that affect pilot performance, it does contain one recommendation that points to a tower "shortfall." The analysis showed that "radio frequency congestion contributed to numerous incidents" (p. 4-3) and resulted in blocked transmissions, incomplete messages, repeated communications, and misunderstood instructions. The report recommended that the FAA "develop means other than radio voice communications for exchanging information between pilots and controllers" (p. xii). This was deemed a necessity because "at many major airports and other facilities with high traffic volume, radio communication is approaching its limits of effectiveness as a mode for transferring information between pilots and controllers" (p. 4-4). This finding was strongly confirmed by controller and pilot opinion in extensive surveys of tower controllers (Kelly and Jacobs, 1998) and airline pilots on airport surface operations (Adam, Kelly, and Steinbacher, 1994; Adam and Kelly, 1996). These later reports also speak to the same "shortfall" in controller-pilot communications as mentioned in the study of ASRS reports:

> "The survey findings show this interface to be one of the weakest parts of the airport surface system. Surface operations have changed markedly in the recent years as ATC has accommodated more and more traffic. The voice communication that worked effectively with less traffic is now strained to the breaking point during peak traffic periods. At these times, the controllers cannot communicate with the pilots in the way ATC-pilot communication was designed to work. The original design intentionally included safety measures such as proper timing and readbacks, which are now being dropped so that more ATC instructions can be crowded onto the frequencies at busy times. Yet these are the very times when the consequences of errors may be more critical, and safety measures are needed the most. The complexity of some current operation means that any breakdown of the ATC-pilot interface can be critical to safety. The potential for such breakdown is now greater than ever" (p. 7-10).

2.6 STUDIES OF TOWER CONTROLLER-PILOT VOICE COMMUNICATIONS

It should be noted that the above findings and recommendations were based on controller and pilot opinion and ASRS reports - not data based on frequency of occurrence (i.e., incidence data). However, incidence data from studies of tower-pilot voice communications also support these conclusions. While controller-pilot communications are surprisingly accurate (with only one percent of the controller transmissions resulting in readback errors), the opportunities for problems are numerous due, in part, to the sheer number of communications. Radio frequencies in the terminal environment are far more congested than those in the en route environment. While en route controllers averaged less than two controller-to-pilot communications per minute (Cardosi, 1993) ground controllers averaged eight controller-pilot communications per minute (Burki-Cohen, 1995). The average for local controllers was three (Cardosi, 1994) and TRACON was 4.5 per minute (Cardosi, Brett, and Han, 1996). These numbers are now seven years old and so represent conservative estimates of today's communication activity. Perhaps because of the frequency congestion, 27 percent of the local controllers' transmissions and 33 percent of the ground controllers' transmissions were responded to by pilots with only an acknowledgement (e.g., "roger"); an additional 7 percent of the local control transmissions were responded to with only a mike click. Twenty-eight percent of the controllers' messages on the local control frequencies and 32 percent on ground control were responded to with a full readback. This is dramatically lower than the 71 percent of the controllers' transmissions en route and 60 percent of the TRACON controllers' transmissions that were fully readback. This same series of studies also revealed that the factor most consistent with miscommunications, i.e., readback errors and pilot requests for repeats, is similar call signs on the same frequency. This was a coincident factor in 12 percent of the miscommunications on the local control (tower) frequencies, 6 percent in the TRACON environment, and 4 percent of the miscommunications in the en route environment.. These incident data point to the same types of problems identified by pilots in the MITRE survey of pilots and to the MITRE identified "urgent need to both improve the current voice communication system and find other reliable and timely means for exchanging information critical to the safe and efficient flow of surface traffic" (p. 7-11).

2.7 SURVEY OF TOWER CONTROLLERS ON AIRPORT SURFACE OPERATIONS: THE CAUSES AND PREVENTION OF RUNWAY INCURSIONS

Kelly and Jacobs (1998) conducted an extensive survey of 1111 controllers and managers at 63 Level 3, 4 and 5 towers and asked for their opinions on a variety of different topics[5]. The results identified five areas for consideration of tower improvements:

- Stop lights on runways activated by surface surveillance systems.
- Improvements to ASDE-3:
    - Tag the targets with the aircraft ID.
    - Reduce the number of false targets.
    - Reduce the interference caused by rain.
- Relief from radio frequency congestion.
- Relief from tower cab features that interfere with the controllers' scan of the airport surface.
    - Placement of displays on top of the consoles obstructs vision.
    - Inadequate tower shades hinder controllers' ability to see the airport surface.
- Improving the use of "memory aids."

2.7.1 Stop Lights on Runways

Controllers were asked the extent to which stop lights that were automatically activated by surface surveillance systems would reduce the risk of surface incidents. Twenty-one percent of the respondents had no opinion (perhaps they were wisely waiting for data). Of those who expressed an opinion, only 11 percent thought that they would have no effect. Thirty percent thought that they would have a significant effect on reducing surface incidents, with the remainder anticipating that they would have a moderate (27 percent) or slight (31 percent) effect.

[5] Two thousand four hundred and nine questionnaires were distributed, 1111 were completed and returned.

Controllers were much less enthusiastic about the suggestion of stop lights operated by controllers, largely due to the concern for increased controller workload.

2.7.2 Improvements to ASDE-3

Most of the controllers at towers that had ASDE-3 said it was useful in controlling surface traffic. Seventy percent of the controllers at Level 5 towers with ASDE-3 rated its usefulness as "significant" and said it was "very reliable." Note that this is not actually a measure of the reliability of ASDE-3, but rather it is a measure of its perceived reliability (which is directly related to the controllers' tendency to trust and use it). Eighty-five percent of these controllers thought it would be useful to add aircraft identification information displayed on ASDE-3 (i.e., tagged targets) and 63 percent of them thought that it would be useful to add conflict detection capability to ASDE-3. The report recommended that the FAA pursue these improvements to ASDE-3 and determine the suitability of "low-cost ASDE-like radar systems (such as ASDE-X) for airports that are not scheduled to receive ASDE-3."

2.7.3 Frequency Congestion

The results of the controllers' survey echoed those of the pilots' survey on the subject of frequency congestion. Thirteen percent of the controllers surveyed and 19 percent of the controllers from Level 5 towers said that frequency congestion was a "significant" risk factor for surface incidents. An additional 37 percent said that it was a "moderate" risk factor. Only four percent said that it was not a factor. Nineteen percent of the respondents and 29 percent of the controllers from Level 5 towers said that an "inability to access the frequency when needed" was experienced "often" and an additional 40 percent (44 percent of Level 5) said that this was "sometimes" experienced. Only 25 percent of the Level 5 tower controllers said that an inability to access the frequency when needed rarely occurred.

Interestingly, when controllers were asked to describe pilot phraseology that is associated with a risk of surface incidents, they cited "abbreviated or incomplete readbacks," and "using microphone clicks as a substitute for verbal readbacks." In fact, 71 percent of the comments offered were critical of incomplete readbacks. [This figure was derived from the raw data in the appendices and is not contained in the actual report.] Analysis of ATC tapes revealed that, on local control frequencies, seven percent of the controllers' transmissions were responded to with only a mike click (Cardosi, 1994). While this lets the controller know that "somebody got something," it does not afford any opportunity to catch a communication error. It is certainly the case that full readbacks are the safest pilot response as they at least provide the opportunity for a communication error to be caught before it results in a surface incident. However, studies of controller-pilot voice communications have shown that only 28 percent of the local controllers' transmissions, and 33 percent of the ground controllers' transmissions, result in a full readback (Cardosi, 1994; Burki-Cohen, 1995). If pilots tried to respond to each transmission with a complete readback, the resulting increase in frequency congestion would be intolerable at busy facilities (p. 7-32).

Twenty-six percent of the respondents and 32 percent of the controllers from Level 5 towers said that there was a "significant" risk of surface incidents associated with a stuck mike. An additional 38 percent of the controllers said that there was a "moderate" risk associated with a stuck mike. Roughly half of the respondents and 62 percent of the controllers from Level 5 facilities said that transmissions were "stepped-on" "often." Forty percent of the respondents and 56 percent of the controllers from Level 5 facilities said that "blocked readbacks" were experienced "often." The report recommended that the FAA implement the use of anti-stuck microphone and antiblocking radio technology for all ATC ground radios and the radios of all aircraft operating in the ATC system (p. 7-30).

It should be noted that while these controller opinions are not a substitute for incidence data (i.e., how often something happens), they provide a subjective assessment of the severity of the problem. For the few cases in which we do have incidence data, we see that controllers tend to overestimate their occurrence. For example, 16 percent of the controllers believed that readback errors occurred "often" and 55 percent said that they occur "sometimes." Only 28 percent were "correct" in saying that they occur "rarely," since studies have shown that less than 1 percent of controller transmissions result in a readback error (Cardosi, 1994; Burki-Cohen, 1995). This does not detract from the potential severity of the consequences of a single readback or hearback error.

2.7.4 Tower Cab Features that Interfere with the Controllers' Scan of the Airport Surface

Controllers were asked about features of the tower cab that interfere with the visual scan of the airport. Two hundred forty-two controllers answered this open-ended question with some controllers listing more than one factor in their response. The report gave no analysis of these responses, only examples of them. The following information was derived from reanalyzing the original data contained in the appendices. Some of the responses were outside the scope of the question and pertained to either obstructions outside of the tower cab, or the position or height of the tower. Of the pertinent responses, there were three distinct categories: tower structures, placement of tower equipment and monitors, and problems with the windows/shades. Thirty-seven percent of the respondents mentioned non-movable (or not easily movable) tower structures such as support beams, consoles, window frames, etc., as obstructions to their view of the airport surface. Thirty percent mentioned movable equipment and displays, most notably monitors placed on top of the consoles. Interestingly, 11 percent of the respondents mentioned problems with the windows and/or shades. Most of the responses in this category referred to shades that did not work, did not cover enough of the window, or were inadequate in some other way; a few referred to dirty windows.

> "Roll up/pull down see though" shades ... are a hassle to operate, provide two additional surfaces to collect fingerprints, dust and grime, and once they've been rolled up and down a few dozen times they become creased and display semi-opaque wear spots. The sensation of working with full blinds is about as comfortable as working with the windows covered with budget trash can liners..." (p. C-217-218).

> "Constant problems with window shades interfere with controller's ability to pay attention to traffic (won't latch, fly up unexpectedly, etc.)" (p. C-215).

While we don't normally think of inadequate window shades as an "obstruction" to the controllers' view of critical information, the fact that so many of the respondents volunteered it as an answer to this question clearly suggests that controllers consider this to be a problem. New technologies that could become effective replacements for tower shades continue to develop. At the present, they would probably only be considered (because of the cost) in new towers that are being built. (See Appendix B for a full discussion of this issue.)

2.7.5 Memory Aids

An area identified in the report that is peripherally related to needed tower improvements is the controllers' reliance on memory for important information. We have already seen that the controller forgetting critical information has been a cause of many surface incidents. Yet, many controllers are relying on their (fallible) memory as their only tools for remembering that aircraft have been cleared to land, cleared to take off, or cleared to position and hold. When asked which memory aids they use to remember that an aircraft had been cleared for take off, the most common response was "depend mostly on my memory." This was the second most common response when asked how they remember that an aircraft had been cleared to land and cleared to position and hold. The most common method cited by controllers for helping them to remember that an aircraft had been cleared to land was to write the information down on a sheet of paper. The most common cue for an aircraft cleared to position and hold was to offest ("cock") the flight strip. In summary, the memory aids used, if any varied from facility to facility and from controller to controller. The recommendation contained in the report is for the FAA to develop and standardize memory aids (such as specific uses of flight strips, placards, runway intrusion lights.) for tower controllers to be used for control functions such as taxi into position and hold, intersection takeoffs cleared to land, cleared to takeoff, and closed runways (p. 7-36).

2.8 STUDIES OF CONTROLLER ACTIVITIES IN THE TOWER

There have been two major studies sponsored by the FAA on ATC tower activities. The first (Schmeidler and D'Avanzo, 1994) was conducted to support the development of staffing standards for tower cabs. The activities of tower controllers were observed, logged, and classified into "work elements" such as "look out of cab," "look at BRITE," "look inside cab." Radio transmissions were analyzed for number (count), duration, and content (e.g., clearance, pushback, position and hold). Traffic complexity was acknowledged as an important component of workload but there was no census among the members of the Terminal Staffing Standards Team on how to define or measure "complexity." However, they did identify factors that serve to complicate work in the tower cabs" (p. 35). The factors identified by the team were the following:

- Number of usable hard surface runways.
- Total usable surface runway length.
- Longest single hard surface runway length.
- Number of usable taxiways.

- Number of crossing runways.
- Number of converging runways.
- Number of Instrument Landing Systems.
- International traffic.
- Terminal type – VFR, Limited radar, Radar, Nonradar, or TRACAB.
- Ratio of total annual primary instrument operations to total annual airport operations.
- Most recent total annual airport operations.
- Practical Annual Capacity.
- Airspace restrictions (TCA, ARSA, none).
- Number of aircraft based at the airport.
- Percent of total annual airport operations that are heavy aircraft.
- Percent of total annual airport operations that are helicopter.
- Visibility.
- Wind speed (p. 36).

While this work contains useful information on the tasks that tower controllers perform, it falls short of the analysis of information requirements that would be necessary to provide the foundation for display integration. For example, while the number of times that the controllers looked out the window or at the BRITE display were counted, the information that the controllers used (i.e., the reason for looking at the BRITE or out the window) was not considered.

Another study (Bruce, 1996) examined the physical actions of controllers at six towers (Austin, Memphis, Milwaukee, Philadelphia, San Francisco, and Teterboro). The movements of controllers in the cab were recorded along with the displays and controls they used and how much time was spent using each of them. The purpose of the study was to define the mobility requirements for tower controllers to determine whether handicapped individuals could be assigned to towers. Many of the findings of this study point to the need for adherence to basic human factors principles of workspace design. For example, if the towers examined had been ergonomically designed (e.g., to accommodate the fifth percentile female), there wouldn't be the need for controllers who are 5 ft. tall and under to use a stool or climb on the console to monitor an aircraft pushback. A related finding was the movement required of controllers to obtain information from various parts of the tower. They noted that "There are differences by position and by facility, but in general, we can conclude that controllers cross some area of floor space an average of three times per minute" (p 30). They found that "on average, controllers move to use a piece of equipment approximately seven times per minute, or once every 8-9 seconds" (p. 31) and that "...numerous tasks require physical repositioning because needed information and equipment interactions cannot be accomplished within the envelope of reach for one work position" (p. 37). This alone suggests the need for consolidation of the present systems. With the addition of new subsystems, the need for system integration becomes more critical.

While it was not in the scope of the Bruce (1996) study to examine the information requirements of tower controllers, the results do include the time that ground and local controllers spent looking outside the window and at each of the displays in the tower. The time spent on specific activities varied by airport. However, on average:

Local controllers spent:

- 38 percent of their time looking out the window,
- 22 percent looking at the BRITE display,
- 16 percent of their time interacting with (looking at, writing on, passing to another controller, etc.) individual flight strips, and
- 5 percent of their time at the flight strip bay.

Ground controllers spent an average of:

- 47 percent of their time looking out the window,
- 22 percent interacting with individual flight strips,
- 11 percent of their time at the flight strip bay, and
- 2 percent of the time looking at the BRITE display.

Interestingly, these results are very similar to those of an unpublished study (Grossberg, 1995) that took similar measurements at three other towers (Baltimore, Dulles, and National). They found that local controllers at those towers spent an average of 70 percent of their time looking out the window and at the BRITE, and an additional 21 percent of their time with flight progress strips. The ground controllers observed spent over 50 percent of their time viewing the airport surface (out the window and on the BRITE) and 30 percent of their time looking at the strips.

While these results are useful, an analysis of information requirements is still needed. Both studies addressed how long controllers spent looking at the various displays; however, the focus of the Bruce (1996) study was to determine controller's physical requirements, not the information requirements. Similarly, the purpose of the measures taken in the Grossberg (1995) study was to assess the impact of a new system on controller workload and situation awareness. For the purposes of consolidating displays and developing tools for controllers, the question of what information the controllers are looking for when they look at the display is as important as how long the controllers find it necessary to look at a display. While this type of "cognitive task analysis" has been done for the en route environment (e.g., Human Technology, Inc., 1990), no published reports of this type of study could be found for the tower.

2.9 AIRPORT SURFACE OPERATIONS SAFETY ACTION PLAN TO PREVENT RUNWAY INCURSIONS AND IMPROVE OPERATIONS

The Federal Aviation Administration's 1998 Airport Surface Operations Safety Action Plan to Prevent Runway Incursions and Improve Operations was drafted in direct support of the Administrator's goal to reduce runway incursions by 15 percent of the 1997 level by the year 2000. (FAA, 1998). The plan identified five major goals under the overall goal to reduce runway incursions. These goals were the following (FAA, 1998, p.2):

- To improve strategic planning, data collection and analysis, human resources management and stakeholder participation – through enhancements in internal management, revised guidance and procedures, better data collection and analysis capability, progress on human resource issues, and partnership with stakeholders.

- To seek improvements in pilot/controller communications, pilot and crew training, and in-cockpit techniques by addressing frequency congestion and voice delivery issues, ensuring pilot ground safety awareness training, addressing cockpit procedures and intra-cockpit communication issues, conducting aircraft lighting research, and improving aircraft conspicuity.

- To provide controllers with enhanced capabilities, tools, and techniques – by completing Airport Surface Detection Equipment (ASDE) and Airport Movement Area Safety System (AMASS) installations and pursuing cost-effective alternatives for mid-sized and smaller airports; by continuing research and development on data fusion technology, multi-lateration, and other sensors; and by addressing controller human resource needs through training and human factors initiatives.

- To seek improvements in airport surface facilities, design, and operations – through enhancements in airport surface navigation aids; use of objective methods to determine the adequacy of existing aids and services; improvements in aircraft positioning technique; and through communication of lessons learned.

- To improve communications with the aviation community to enhance incursion awareness – by highlighting incursion problem areas to create awareness and seek solutions; conducting an airport surface safety awareness campaign; and improving dissemination of safety-related information."

As a result of the studies described above, and other efforts, several improvements have been made over the years. For example, the need for reliable and conspicuous airport markings (i.e., runway crossings and hold short lines) has received considerable attention resulting in improved signage and markings at many airports. Also, pilots are now required to readback all "hold short" instructions as well as clearances for take-off or landing. However, despite the progress made in these areas, the rate of runway incursions to total number of operations has not decreased. There were 292 runway incursions reported in 1997 and 322 in 1998 (FAA, April 1999). With 66.2 million operations in 1998, the rate of runway incursions was 4.91. In 1999 (January – November), there were 295 runway incursions and 59.2 million operations for a runway incursion rate of 4.96 (FAA, November 1999). The number of surface incidents (which includes runway incursions and potential runway incursions) has also increased. The number of surface incidents recorded from January to November was 774 in 1998 and 959 surface incidents reported in 1999. It is possible that increased awareness has resulted in an increase in the reporting of these incidents over the years. However, there is nothing that suggests that the threat to aviation safety posed by runway incursions is on the decline.

2.10 RUNWAY INCURSION JOINT SAFETY ANALYSIS TEAM (JSAT)

The most recent analysis of pilot and controller errors in airport operations, prior to the present study, was conducted by the Runway Incursion Joint Safety Analysis Team (JSAT) In its Results and Analysis report (August 11, 2000), the JSAT, sponsored by the Commercial Aviation Safety Team (CAST) and the General Aviation Joint Steering Committee (GAJSC), reports on the results of their detailed examination of:

- 5 NTSB "blue book" accident reports.
- 26 additional NTSB reports of runway incursion accidents at non-towered airports.
- 49 operational errors that occurred between 1997 and 1998.
- 12 pilot deviations that occurred between 1997 and 1998.
- 123 proprietary reports of pilot deviations from airline data bases.

While there is some commonality of purpose in the JSAT study and the current one, there are several differences that distinguish the two. First, whereas the JSAT sampled NTSB, operational error reports and reports of pilot deviations, the present study analyzed more recent and a greater number of these incidents. Second, the JSAT did not consider ASRS reports in their analyses. Third, while the focus of the JSAT work was to lead to recommendations to prevent runway incursions at towered and non-towered airports alike, the focus of the present analysis was towered airports. Fourth, the unique aspect of the JSAT analysis was the information acquired from proprietary airline data bases. The largest volume of data, and the most useful information, examined by the JSAT came from reports from pilots and accident investigators submitted by proprietary airline databases. These data bases contained 665 reports from 1994 – 1999. However, only 123 were judged to be relevant and to contain sufficient detail for analysis.

Causal factors were examined in the analysis process, but not detailed in the results. The contributing factors were described as follows:

- "Loss of situational awareness by controllers and/or pilots was the main causal factor in many of the incidents reviewed" (p. 29).
- "Inadequate and/or confusing ATC procedures have contributed to surface incidents and runway incursions" (p.30).

- "Several accidents/incidents resulted from inadequate or misunderstood clearances between ATC and the flight crew, including phraseology, readback and hearback problems" (p. 36).

- "Several incidents identified combined controller positions and controllers simulcasting as factors in reducing pilot situational awareness or creating confusion" (p. 36).

- It states that at least one FAA study concluded that there is a "strong correlation between teamwork, or more precisely a lack of teamwork, and the occurrence of operational errors" (p.35, but no reference is provided).

- With respect to pilot procedures, complying with standard operating procedures (SOPs) was stressed as important as well as developing procedures for ground operations where none exist.

The recommendations from the report fell into the following categories:

- Air traffic controller and pilot training.

- Training/techniques/technology to increase pilot and controller situational awareness.

- Improving ATC and flight deck procedures.

- Improved technology in the areas of:

    - Enhanced surveillance.
    - Cockpit heads-up displays and moving map displays.
    - Aircraft lighting.
    - Airport lighting.

- Crew resource management for flight crews and controllers.

- Improved equipment and procedures for pilot-controller voice communications and implementation of data-link

- Improved data collection techniques.

- Exploration of issues related to ATC supervision, airport capacity and runway incursion prevention awareness.

The report recognized that improvements are needed in the communication realm:

> "One of the weakest areas of the modern aviation is the industry's continued reliance on a relatively archaic method of communicating information, specifically via one-at-a-time radio transmissions. These

> transmissions are rather frequently garbled, "stepped-on", blocked, and otherwise difficult, if not impossible, to understand" (p.36).

The recommendations regarding tower communications concerned wider use of data link and technology that would allow the combination of controller positions without simulcasting to aircraft on different frequencies. The other recommendations in the report that specifically address improvements to the tower are the following:

- FAA shall provide new technology tools for enhanced surveillance information and conflict detection.
- Air traffic service providers shall install surface surveillance systems.
- Air traffic service providers should provide airport surface surveillance equipment with conflict alerting capability at all air traffic control towers.

(p.33)

It is currently the role of the Joint Safety Implementation Team (JSIT) to implement the recommendations. As of September 2000, this work is in progress and expected to continue at least through spring of 2001.

2.11 AN INDEPENDENT STUDY OF AMASS/ASTA BENEFITS

Although almost 10 years old, *An Independent Study of AMASS/ASTA Benefits* (Skaliotis, 1991) is as valuable now as it was when it was published. It is an independent and unbiased analysis of the projected benefits of the Airport Movement Area Safety System (AMASS), Airport Surface Traffic Automation (ASTA) and "low tech" solutions (such as markings, signs, lights and education). The analysis was intended to be preliminary in nature, and refined as the acquisition and implementation of these systems progressed. (While benefits studies have been conducted for individual programs, no other "big picture" analyses were found in the literature.) The report details projected benefits in terms of safety, efficiency, and savings in delays and aircraft operating costs. It estimated that the total ten year expected safety loses were $120 to $210 million from runway incursion accidents. It estimated that between 57 and 74 percent of this could be prevented by all planned system elements. The AMASS/ASTA share of the benefit ranged from $34 to $93 million; lower technology approaches were estimated to save from $31 to $56 million. These data lend further support to the need for attention to low-technology solutions as well as the development of improved surveillance and monitoring tools for controllers.

Another interesting conclusion of this study was that the actual number of runway incursions may be more predictive of where the next incursion or accident will occur than the incursion rate (i.e., the number of incursions per 100,000 operations). The study found that the number of incursions was not well correlated to the number of operations. It suggested that local factors at particular airports are more important than high operations levels at determining the risk of an accident/incident.

3. STUDIES OF SYSTEM INTEGRATION

> "What often happens in the evolution of system design is a proliferation of unintegrated subsystems, each with its own unique interface... Integrating separately developed components ...is one of the biggest human factors challenges facing the FAA...lack of integration into existing operational and technological contexts is an obstacle to improved usability and productivity."
>
> Cardosi and Murphy (1995) p. 228.

3.1 SYSTEM INTEGRATION

The tower environment is a human factors "poster child" for the need for system integration. It is crucial, however, that the goal of the integration is to support the controllers' tasks, and not solely for the sake of integration, or to save space. Ideally, system integration would be based solely on operational requirements. That is, the primary goal of integrating displays and controls should be to structure the controller's task to maximize efficiency and minimize the probability of human error. A related goal is to make the system "error tolerant," since some human error is inevitable, the system needs to be designed to be able to catch controller errors and bring them to the attention of the controller in time for the effects of the error to be mitigated. Because system integration must, by definition, be system-specific, nothing in the existing literature can provide a roadmap for system integration in the tower today. The components of existing systems that satisfy the controllers' information requirements need to be integrated with the controllers' information requirements of the follow-on subsystems to best determine if/how the displays (or components of the displays) should be integrated. The goal of this integration should be to support the controllers' tasks; this will help to minimize controller error and increase efficiency. Despite the fact that work needs to be done to determine how today's (and tomorrow's) tower displays should be integrated, the studies that have been done to date on system integration in the tower are worth reviewing for the "lessons learned."

3.1.1 Air Traffic Control Towers Equipment/System Integration Study Conducted by Transport Canada

The most comprehensive study of the integration of tower systems was conducted by Reynolds, Last, Camp, Matthews, Kwan, and McDonald (1994) for Transport Canada. The aim of this study was the "identification of operational requirements and assessment of present Human-Machine Interface (HMI) with a view to equipment integration [in Canada]" (p. 5). The subsystems that were considered for integration included the tower cab workstation, airport lighting, Airport Surface Detection Equipment (ASDE), Airport Terminal Information System (ATIS), the communications systems, and others.

Many of these subsystems (if not their functionality) were specific to Canada. While a specific mapping of the systems to those used in towers in the U.S. is outside the scope of this report, the goals of the Canadian effort are the same as what we hope to achieve in the U.S. The six criteria used for system integration in the 1994 Canadian study are broadly applicable; they consisted of the following:

1. Input/Output Devices – the integration of subsystems should result in the reduction of display clutter and simplification of input devices without compromising the operational environment. The number and complexity of input devices and the number of operator actions required to access a particular piece of information should be minimized.

2. Functional Requirements Specifications – subsystems should be integrated if this will assist in meeting operational requirements.

3. Shared Data – subsystems that utilize common data should be integrated to simplify the interfaces and reduce the number of communication paths.

4. Compatible Technology – subsystems that are based on compatible technology are better candidates for integration than subsystems that are not technologically compatible.

5. Age – the functions performed by older subsystems may be candidates for integration because equipment replacement can be justified, whereas the integration of functions performed by new subsystems making new equipment redundant may be more difficult to justify.

6. Space – the integration of subsystems in the tower should minimize space requirements.

While it is interesting to consider this effort at system integration, it is important to note that the goal should not be solely to reduce clutter without compromising the operational environment. Rather, the goal of system integration should be to *enhance* the operational environment. As the amount and complexity of traffic increases, the need for displays that support the controller's task, e.g., ones that decrease the likelihood of critical errors, becomes even more important. Also, it is simply sound human factors practice to require that all of the information that a controller needs to perform critical tasks is present and that minimum action is required to access information that is frequently used. Furthermore, all subsystems should be designed and integrated so that the controller does not need to enter the same data into more than one system. A workstation with subsystems that are technologically incompatible can place an undue burden on the user. Such incompatibility can result in distracting nuisances or require the controller to choose between discrepant information.

3.1.2 <u>System Integration Analysis for Future Tower Cab Configurations/Systems in the U.S.</u>

In 1978 a "tower-cab integration analysis" was conducted in the United States to identify issues associated with the introduction of (the then) new systems into the tower cab (Hobbs, et al., 1978). The existing tower cab environment was extensively studied, along with the characteristics of the systems to be introduced. For the purposes of this study, these "new" systems were the following:

- Airport Surface Detection Equipment – ASDE-3.
- Tower Airport Ground Surveillance System.
- Terminal Information Processing System.
- ARTS-2 and ARTS-3 Enhancements.

The motivation for integrating the new systems with the existing systems was primarily one of space; several of the new systems had large displays associated with them and the limited space in the tower necessitated some consolidation. While the human factors aspects of this integration were to be examined, they were clearly not the driving force of the integration. In fact, the only human factors issues that were addressed were maintaining the controllers' abilities to: maintain visual contact with aircraft, move about the cab as necessary, use the displays/controls from a standing position and under the wide range of ambient lighting conditions inherent in tower operations. The purpose of integration, as seen in this study, was to reduce controller workload and to reduce the crowding of the workspace. These goals were seen as paramount to safely increasing controller productivity.

The Hobbs, et al. (1978) report stated that "no broadly applicable findings can be established through these efforts" (p. 18-2) in part because of the unique nature of each tower cab and airport layout. This caveat will always be applicable to tower issues. While the *specific* errors that are most likely to be made at a given airport may be airport specific, the *types* of errors are somewhat universal. Similarly, there are many tower-specific factors that need to be considered in the design of individual towers, such as: the physical layout of the airport surface, buildings on and around the airport surface, visual obstructions in and outside of the tower cab, etc.), runway and taxiway configurations, and local weather patterns (visibility, winds, etc.). However, the type of information needed and human factors principles that should govern the integration of this information are generally applicable.

This series of three documents (Hobbs, et al., 1977; Clapp, et al., 1978; Hobbs, et al., 1978) contains a thoughtful approach to system integration in the tower. While the details of the suitability of these particular systems for system integration are outside the scope of this report, they should be of interest to anyone charged with the task of system integration. The specific recommendations contained in the documents, however, are out-dated and point to the need for similar work to be conducted on today's systems with an eye toward the implementation of new subsystems.

4. SUMMARY OF RESEARCH ON SURFACE INCIDENTS AND STUDIES OF SYSTEM INTEGRATION

The studies reviewed offer a consensus on the causes of surface incidents that occur as the result of controller errors. The primary controller-related factors identified were:

- Forgetting about the presence of aircraft on a runway, the closure of a runway or a clearance that he/she had issued (includes failure to verify the location of the aircraft).
- Failure to anticipate the required separation or miscalculation of the impending separation.
- Communication errors – readback/hearback errors, or issuing an instruction other than the one the controller intended to issue.
- Lack of, or incomplete, coordination between controllers.
- Absence of a supervisor (who was not working a control position).

The experience level of the controllers involved was not identified as a causal factor, as controllers of all experience levels were involved in the incursions studied. However, the controllers with the most experience were acting in a supervisory (supervisor or controller-in-charge) role at the time of the incident and were usually working control positions simultaneously. No other factors were determined to be significant causal factors.

All of these factors point to the need for increased redundancy in the tower. Clearly an "extra set of eyes," whether they be human or electronic, (preferably with some analytic ability attached) can go a long way toward providing the necessary oversight to prevent operational errors in the tower. Memory (and to a lesser extent, judgment) will fail at times, no matter how experienced, well-trained, motivated, or conscientious an individual is; it is this fallibility that well-designed automated tools can, and should, be implemented to offset.

The need to both improve the current voice communication system and find other reliable and timely means for exchanging information critical to the safe and efficient flow of surface traffic has been demonstrated by both pilot and controller opinion (survey data) and objective measures of voice communications. With most of the controllers at the busiest airports reporting that they could not always access the frequency when needed which transmissions were often stepped-on, the implications for the effect of the projected increases in air traffic are clear. While voice communications are surprisingly accurate, the increasing volume and complexity of the traffic at busy airports makes voice communications a tenuous safety link.

As the amount and complexity of traffic increases, the need for systems that support the controller's task, e.g., ones that decrease the likelihood of critical errors, becomes even more important. With more systems being introduced into the tower environment, the need for thoughtful integration of these systems becomes increasingly critical; a workstation with subsystems that are technologically incompatible places an undue burden on the user and can threaten safety and efficiency. The need for attention to system integration issues in the tower was evident from the frequent movements needed by tower controllers to accomplish their tasks, by the obstructions to controllers' vision of the airport surface created by multiple monitors on the consoles, and by the steady stream of additions of new subsystems. Because system integration must, by definition, be system-specific, nothing in the existing literature can provide a roadmap for system integration in the tower today. However, there are human factors principles to guide the integration process.

The primary goal of integrating displays and controls should be to structure the controller's task to maximize efficiency and minimize the probability of human error. A related goal is to make the system "error-tolerant," that is, since human error is inevitable, the system needs as a whole needs to be designed to catch errors and bring them to the attention of the controller in time to be able to remedy the situation. All subsystems should be designed and integrated so that the controller does not need to enter the same data into more than one system. Similarly, the systems should not offer conflicting information (e.g., based on data from different sources). Each sub-system needs to be examined with respect to the information it requires (i.e., data-entry), the information it displays, and the overlap, if any, with other systems. It is only through such a holistic approach safety and efficiency can be maximized.

5. ANALYSIS OF SAFETY DATA

In order to determine whether the most recent safety data support the conclusions of previous work, an extensive analysis of data was undertaken. The following safety data were examined:

- FAA reports of tower operational errors and deviations.
- NTSB accident and incident reports (and recommendations to the FAA).
- Reports filed by tower controllers to the Aviation Safety Reporting System (ASRS).
- ASRS reports filed by pilots involving runway transgressions.
- FAA pilot deviations in tower airspace.

These accidents and incidents were analyzed in an attempt to determine the types of errors made in the airport environment; to identify significant factors associated with these errors, and to determine what improvements to the tower could help to prevent or mitigate these errors. As in the previous section, a "runway incursion" is defined as "any occurrence at an airport involving an aircraft, vehicle, person, or object on the ground that creates a collision hazard or results in loss of separation with an aircraft taking off, intending to take off, landing or intending to land" (FAA, November, 1999, p. G-4); and a "surface incident" is defined as "any event where unauthorized or unapproved movements occurs within the movement area or an occurrence in the movement area associated with the operation of an aircraft that affects or could affect the safety of flight" (Ibid., p. G-4). Again, the recommendations offered in this document were intended to focus on identified tower "shortfalls" and not training, procedures or problems peculiar to an individual facility. However, the same analysis had other applications: for example, it was used to develop recommendations for the runway safety workshops and to develop a booklet on runway incursion prevention for pilots and controllers.

5.1 OVERVIEW OF REVIEWED DATA BASES

There are several useful data bases contained in the National Aviation Safety Data Analysis Center (NASDAC). Each has its own advantages and limitations. The data base as a whole is extremely well designed and, in the hands of an experienced analyst, allows for quick and informative searches and summaries. It is no less than amazing that analyses that five years ago would have taken weeks (without this well-structured data base) can now be accomplished in less than an hour. Nonetheless, such analyses can only be based on the information that is coded into the system. Anything beyond this must be gleaned from other sources.

Some incident reports are more useful than others, from a human factors standpoint. It is not enough to know *what* happened, we must also be able to discern *why* it happened; it is the causes of the errors that point to the remedy. For example, a report may say that Aircraft 1 was cleared to takeoff on Runway X and Aircraft 2 was cleared to land on intersecting Runway Y resulting in a runway incursion. With this information alone, it is impossible to determine the nature of the error. Did the same controller issue both clearances and forgot that one had been issued? Was there an unanticipated delay in a takeoff that went unnoticed by the controller? Did a controller fail to coordinate a clearance with another controller?

Investigations of operational errors and deviations describe what happened and attempt to determine the underlying factors that contributed to the errors. From an objective standpoint, there are several concerns about these data. First, there is the perception that not every operational error is reported and included in the data base. If this is the case, then the data may be biased towards including some type of errors over others; this could affect what would suggest effective remedies. A second concern is that the investigation is of a nature that may not lend itself to full disclosure on the part of the controllers involved or generate an interest in preventing such errors. Thus, there may have been factors that contributed to the error that were not identified in the reports. Nonetheless, the reports of operational errors and deviations are very useful. The events are investigated by a specialist from the facility who is (or at least should be) intimately familiar with the operations at that facility and the reports contain a great deal of information on the operational conditions at the time of the incident.

The reports of pilot deviations, usually filed by a controller, contain an extremely succinct account of what happened. The reports usually lack any detail as to why the incident occurred, thus, their usefulness is extremely limited. Reports submitted to the ASRS, on the other hand, are often very helpful in identifying why certain errors happened, since the reporters often include details that they would be reluctant to report to investigative officials. However, ASRS reports often lack critical objective details. More importantly, since reporting is voluntary, this data base cannot provide incidence data (that is, they cannot provide information on *how often* something happens).

Reports of accidents and incidents investigated by the NTSB can vary from brief and succinct to lengthy and detailed, depending on the extensiveness of the investigation. NTSB also issues recommendations to remedy the problems identified in their investigations.

While none of these data bases can present a complete picture of incidents that affect the safety of tower operations, each of them provides a different perspective that complements the others. These data bases were examined to ascertain converging evidence on the nature of pilot and controller errors in the tower environment and to identify potential remedies.

5.2 TOWER OPERATIONAL ERRORS AND DEVIATIONS

FAA reports of tower operational errors and deviations from the busiest towers in the U.S. (what was then Levels 3, 4, and 5) that were contained in the NASDAC data base as of November 15, 1999 were examined. This included 89 reports from Level 3 towers, 68 from Level 4 facilities and 99 from Level 5 towers for a total of 256 reports. These reports were of incidents that occurred between January 1997 and June 1999. These errors were analyzed in an attempt to determine the types of errors made by tower controllers and identify significant factors associated with these errors in order to determine what improvements to the tower could help to prevent or mitigate these errors. Again, the recommendations offered were intended to focus on identified tower "shortfalls" and not training, procedures or problems peculiar to an individual facility.

The FAA reports of operational errors and deviations are lengthy form-filled reports completed by an FAA investigator (usually a supervisor or quality assurance specialist) from the facility. These reports provide detailed information on the operational environment at the time of the error or deviation. The reports describe the event, identify contributing factors (such as traffic complexity, weather, number of aircraft, or whether training was in progress at the time) and list "controller contributions" that describe the types of errors (e.g., readback/hearback, phraseology). The standardization of these reports allows for easy analysis and summary statistics.

The reports of operational errors and deviations also contain a rating of the complexity of the traffic at the time of the incident. The complexity is rated on a five-point scale consisting of the following responses: "easy," "below average," "average," "above average," and "complex." Twenty-three percent of the reports specified that the complexity was above average (16 percent) or complex (7 percent). Thirty-two percent of the reports specified an average level of complexity, 20 percent below average and 25 percent as easy. While the rating of the complexity of the traffic does not appear to be a significant factor in operational errors and deviations, the *number of aircraft* was listed as a contributing factor in 27 percent of the reports. Weather was listed as a factor in 8 percent of the reports. It is important to note that this information alone – for these and other factors - is not able to speak to the effect of that factor (such as complexity) on errors and deviations. In order to determine the relative risk associated with a factor (such as complex traffic), one would have to look at the number of errors and deviations associated with that factor as a function of the total number of operations associated with that factor.

An analysis of the contributing factors as identified in the reports revealed that the top five factors overall were: "aircraft observation," "coordination," "communication error," "visual data," and "ground operations." [The definitions of these terms as contained in the data base are presented in Appendix A.] As can be seen in Figure 2, "aircraft observation" was the most common factor noted in the operational errors and deviations, followed by "coordination," "communication error," "visual data," and ground operations. The different level facilities had a slightly different order of the top five factors listed. For Level 5 towers (the busiest) the top five factors were:

- "Aircraft observation" - 55 percent.
- "Coordination" - 39 percent.
- "Visual data" - 39 percent.
- "Complex runway configuration" - 37 percent.
- "Communication error" - 36 percent.

- "Complexity – number of aircraft" - 29 percent.

For Level 4 towers, the most frequently identified factors were:

- "Aircraft observation" - 68 percent.
- "Coordination" - 59 percent.
- "Ground operations" - 46 percent.
- "Visual data" - 34 percent.

For Level 3 towers, the top five factors were:

- "Aircraft observation" - 58 percent.
- "Communication error" - 45 percent.
- "Coordination" - 39 percent.
- "Visual data" - 35 percent.
- "Ground operations" - 31 percent.

The most common "controller contributions" listed overall were:

- "Aircraft observation – actual observation of aircraft" - 42 percent.
- "Improper use of visual data – taking off" - 28 percent.
- "Ground operations – taxiing across runway" - 22 percent.
- "Improper use of visual data – landing" - 16 percent.
- "Communications error - misunderstanding" - 16 percent.

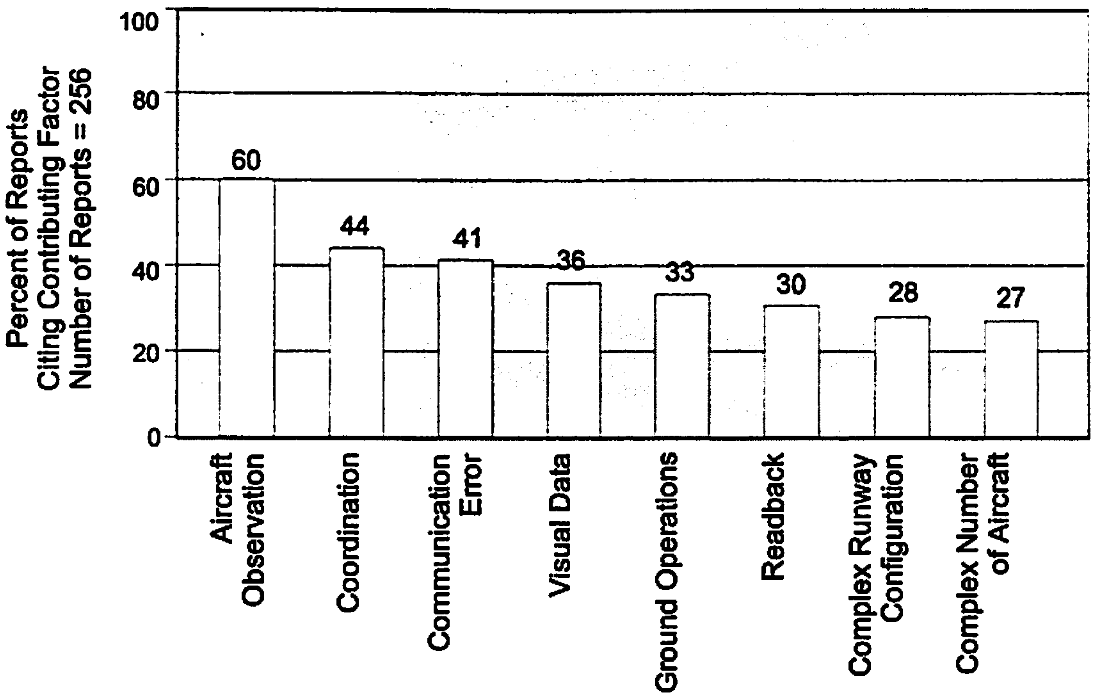

Figure 2. Factors Contributing to Tower Operational Errors and Deviations Identified by FAA

Generally, the factors do not lend themselves to remedies for the errors. A notable exception is "inappropriate use of displayed data – failure to project future status of displayed data." To illustrate, if several reports identify "aircraft observation – actual observation of aircraft," this could mean a number of different things, such as: the controller did not verify the position of the aircraft as required; that the aircraft was at one location (e.g., runway intersection) when the controller assumed the aircraft was at another (e.g., full length); or that the controller forgot he/she had cleared an aircraft into "position and hold" and then (less than one minute later) cleared another aircraft to land on the same runway. In none of these cases, does "aircraft observation" point to a remedy, because the potential remedies in each case are slightly different. One the other hand, "failure to project future status of displayed data" - if it were to prove to be a significant factor in operational errors - points to a need for a tool that projects the aircraft's position and predicts conflicts.

There were no factors in the form (available for the investigation or to check) that listed a common type of error identified in the literature, i.e., forgetting. If a controller forgot that a runway was closed, it was often coded as "failure to coordinate runway closure." In a case in which the controller forgot that he cleared an aircraft into position and hold and then cleared another aircraft to land on the same runway, the controller contribution codes were listed as "aircraft observation – actual observation of aircraft," "improper use of visual data – landing," "ground operation – holding in position for takeoff," and "communication error – other."

Other key human factors information is either not coded or is coded inconsistently. For example, one of the factors identified in the literature as being potentially problematic was the absence of a supervisor (or "another set of eyes") who was not (busy) working a control position. While many of the reports state whether or not the supervisor was aware of the developing error, or engaged in other tasks, most of the reports do specify whether the supervisor or controller in charge was also working a position.

For these reasons, each of the reports in the data base was analyzed independently so that a human factors assessment of the errors, independent of the FAA analysis, could be conducted. During this analysis, it was determined that five of the reports from the Level 5 towers did not contain enough detail to determined why the events occurred. Furthermore, the events were too old to have the original report on file at the FAA. Because of this, those five reports were dropped from subsequent analysis, leaving a total of 251. The results of this analysis are shown in Figure 3.

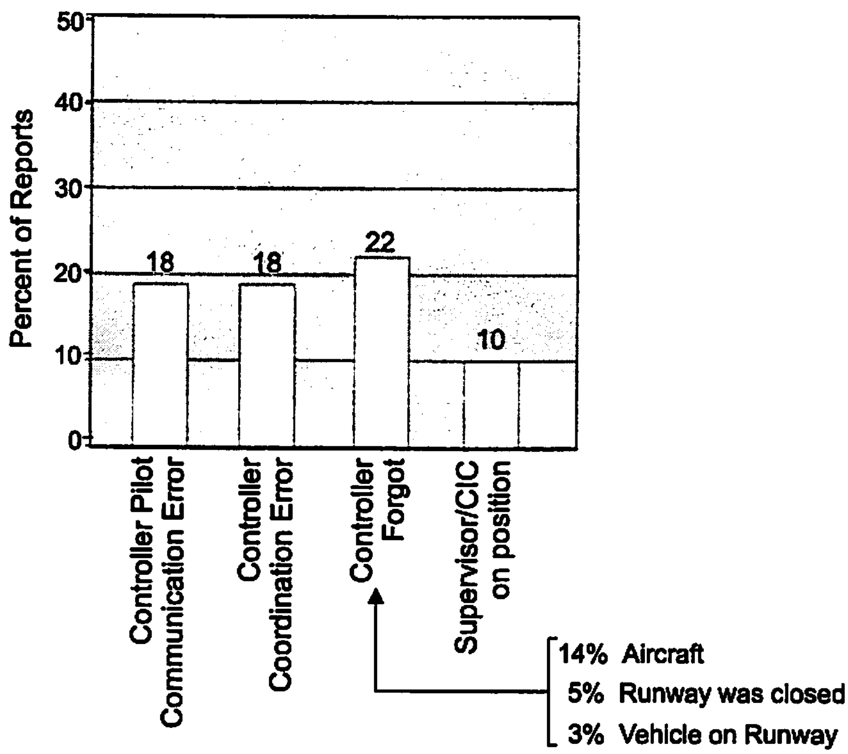

Figure 3. Factors Contributing to Tower Operational Errors and Deviations Identified by Independent Analysis

Recall that the review of the literature showed that the most common controller-related factors identified in surface incidents were:

- Forgetting about the presence of aircraft on a runway, the closure of a runway or a clearance that he/she had issued (includes failure to verify the location of the aircraft).

- Failure to anticipate the required separation or miscalculation of the impeding separation.

- Communication errors – readback/hearback errors, issuing an instruction other than the instruction the controller intended to issue.

- Lack of, or incomplete, coordination between controllers.

- Absence of a supervisor (who was not working a control position).

Each of the 251 reports were analyzed for significant human factors, including the following:

- Controller forgot [about an aircraft (e.g., that the controller had cleared an aircraft for takeoff, landing or to cross a runway); about a vehicle on the runway; that a runway was closed].
- Communication error between controller and pilot.

- Poor coordination between controllers.

- Absence of a supervisor who was not working a control position.

- Whether improved memory aids would have been useful.

- Whether improved surveillance and monitoring equipment would have been useful[6].

5.2.1 Memory Lapses

The most common contributing factor, occurring in 27 percent of the operational errors and deviations examined, was the controller "forgetting" something. In 15 percent of the reports, the controller had forgotten about an aircraft (such as one that had been cleared to land or one holding at the end of a runway). In 3 percent of the operational errors and deviations examined, the controller forgot that there was a vehicle on the runway. In an additional 5 percent of the cases, the controller forgot that the runway was closed. Other memory failures accounted for an additional 4 percent of the incidents examined.

5.2.2 Controller-Pilot Voice Communication

The second most common element found in this analysis of operational errors and deviation was a communication error between pilots and controllers; miscommunication was found to be a factor in 19 percent of the incidents. Interestingly, the "communication" flag was checked in 41 percent of the reports by the FAA investigator of the error. The primary reason for this difference was the presumed definition of "communication error." In the FAA analysis, the flag was checked in a variety of instances, such as a miscommunication between a pilot and controller, two controllers, or a vehicle driver and a controller; or when there was an issue of

[6] Improved surveillance and monitoring equipment was judged to have been potentially useful in cases in which: the controller could not see the aircraft from the tower, the runway was occupied by a vehicle or another aircraft (while another vehicle was cleared to cross, takeoff from, or land on, that runway), and the situation was such that it would have been possible for an alerting system to provide a warning in time for the controller and/or pilot to take effective action.

phraseology. In the present analysis, the definition of "communication" was limited to a miscommunication between pilots and controllers, usually readback/hearback errors; if there was a miscommunication between two or more controllers, it was coded as a "coordination" issue.

5.2.3 Controller-Controller Coordination

Another notable difference is the frequency of the indication of a "coordination" issue. In the present analysis, this was noted if there was a failure of one controller to relay needed information to another controller or a failure to obtain approval for a specific operation (such as a failure to coordinate a runway crossing). The "coordination" issue was noted in 18 percent of the reports in this analysis, and 44 percent in the FAA analysis, the reasons for this difference are unclear.

5.2.4 Absence of a Supervisor

The absence of a supervisor (who was not working a control position) was noted in 11 percent of the operational errors and deviations examined. However, it is important to note that this factor was not able to be consistently coded because many of the reports do not explicitly contain this information. The reports may say that the supervisor was "unaware" that an error was developing; however, many did not specifically state whether or not the supervisor was in the tower cab at the time. In many cases, it was the supervisor (or controller-in-charge) that prevented a bad situation from getting much worse. Obviously, this is an issue that merits further investigation.

5.2.5 Areas Suggesting the Need for Further Research

There were four other factors that suggest the need for further research; these were: peripheral duties imposed by traffic management duties, Land and Hold Short Operations (LAHSO), effects of working combined positions, situation awareness at the onset of assuming a position, and intersection takeoffs.

5.2.5.1 Peripheral Traffic Management Duties - The additional duties imposed by automated traffic management systems, such as recording delay times, do nothing to enhance the controllers awareness of the traffic situation and, in fact, can be a distraction. One controller involved in an operational error commented that "DSP (Departure Sequencing Program) staffed at the ground control position is a safety hazard –position should be manned by TMC (traffic management coordinator) position" (operational error report 10/6/98). Another operational error report states that, "Although not a direct causal factor to this error, some members of the [investigation] team felt that because there was not a TMC [Traffic management coordinator] on duty, the controller was preoccupied with ensuring that correct delay times were recorded on the flight progress strip at the time of the incident." The degree to which these peripheral duties interfere with primary duties needs to be investigated. Meanwhile, it is clear that duties that are peripheral to the primary duties of the tower controllers should be automated or performed by a traffic management coordinator, whenever possible.

5.2.5.2 LAHSO - Another area of concern in the operational error reports concerns Land and Hold Short Operations (LAHSO). Seven percent of the operational errors and deviations examined from the Level 5 facilities cited that LAHSO operations were in effect at the time of the incident. Some of these incidents were a direct result of the LAHSO operations. There were cases in which the pilot acknowledged the clearance but didn't, or wasn't able to, comply. There was a case in which the controller thought he had issued the hold short clearance and even wrote in on the strip, but in actuality had not issued it. There were other incidents in which LAHSO were indirectly involved; while the controller's attention was focused on ensuring that the aircraft held as instructed, there was an incident elsewhere. Whether or not LAHSO were in effect at the time of an operational error needs to be routinely recorded as part of the effort to assess the risk of LAHSO and how the risk can be mitigated. It may be the case that the extra attention which LAHSO require necessitate additional support of some sort.

5.2.5.3 Combined Positions - Ten percent of the reports of operational errors and deviations specified that the controller was working combined positions at the time of the incident. Some of these reports specifically mention that this was a contributing factor to the complexity of the traffic, others do not. The reports routinely record whether there were combined positions at the time of the incident; 60 percent of the reports stated that this was the case. However, the reports do not consistently state whether this combination was normal for the time of day and traffic level, or whether the combination of positions was a contributing factor to the incident. Whether particular combinations of positions make the operation more complex or simplifies things (e.g., because the controller does not have to coordinate with another position) depends on many factors. However, it is clear that the conditions under which combined positions may contribute to, or protect from, operational errors merit further study.

5.2.5.4 Situation Awareness Upon Assuming a Position - "Time on position," that is, how long the controller(s) was on position before the incident occurred, is routinely recorded. It was an interesting finding that 20 percent of the operational errors and deviations occurred in first 10 minutes on position. While this may suggest that an inadequate position relief briefing may be partly responsible, this factor was cited in only four percent of the reports. Further study is required to determine if this finding of a "vulnerability" to operational errors in the first 10 minutes of assuming a position is a stable one. Also, correlating the time on position with the type of error may help point to specific remedies. Meanwhile, controllers should be aware that the first ten minutes on position is a particularly vulnerable time.

5.2.5.5 Intersection Take-Offs - While intersection take-offs were cited in some of the reports of operational errors and deviations, it is not a factor that is automatically coded. In more than one instance, the controller assumed that the pilot would taxi to the departure end of the runway when in fact the pilot taxied to the intersection. The risks associated with intersection takeoffs, and the potential benefits of runway status lights or other tools need to be determined.

5.2.6 Operational Errors and Deviations – What do they tell us about what can be done?

While the reports of operational errors and deviations detail the aftermath of the incident as far as the controller involved is concerned (training, scheduled performance checks, videos, etc.), they do not necessarily contain recommendations for remedies for the type of error that occurred.

Occasionally, however, the operational error or deviation report does specify a potential remedy to the incident reported. For example, one report recommended that the facility "aggressively pursue the acquisition of AMASS and perimeter taxiways" since "the redundancy provided by the installation of AMASS may have prevented this surface error. In addition, it was determined if perimeter taxiways were built and used, this too would have prevented the occurrence." Since such specific recommendations were not usually contained in the reports, the circumstances of the error were examined for indications as to what tools – such as memory aids surveillance and/or monitoring systems (conceptually similar to AMASS) - could have been helpful in preventing, or mitigating the consequences of, these errors.

5.2.6.1 Aids to Controller Memory - Memory aids, or better memory aids, were considered as a potential remedy in nine percent of the errors and deviations. Of course, memory aids only have a chance at being effective if they are used (in some cases they were available, but not used), and no common type of memory aid (e.g., placards) is infallible. Nonetheless, they are a simple and cost-effective countermeasure. Some memory aids are better than others. While effective memory aids and other tools are often invented at individual towers, a mechanism is needed for towers to share these potential remedies and to study their effectiveness. The generic sounding "runway incursion device" (RID) means different things to different controllers; an illuminated airport diagram that indicates active runways is one example of such a memory aid.

5.2.6.2 Better Surveillance and Monitoring Equipment - A surveillance and monitoring system that contains alerting algorithms to indicate to the controller that an aircraft was on approach to a runway that was not clear (i.e., occupied with part or all of an airplane, occupied by a vehicle, or is closed) would be very useful (assuming that the false alarm rate was acceptably low and the alerts were timely). Many of the errors and deviations involved situations in which the error developed so quickly that no such warning system would have been effective. However, such a system was judged to have been potentially useful in 51 percent of the incidents examined. That is, 51 percent of the operational errors and deviations involved situations in which currently proposed functionality – runway status lights, AMASS, loops, etc. – are expected to be effective countermeasures. Runway status lights at runway intersections that automatically turn red when an aircraft is on final approach to that runway has received anecdotal approval from both pilots and controllers. However, it is clear that the lights need to be capable of displaying more than "red" or "off;" another color (such as yellow) needs to be displayed to indicate to the pilot that the system is working even when red is not displayed.

5.2.6.3 Communication and Coordination - Voice communication between pilots and controllers is a critical safety link in airport operations. The results of the independent analysis showed that miscommunications between controllers and pilots were a contributing factor in almost 20 percent of the operational errors examined. Previous studies of ground and local control operations have shown that less than 1 percent of controller-pilot communications result in a readback error and at least half of these readback errors are corrected by the controller (Burki-Cohen, 1995; Cardosi, 1994). While not all clearances are read back, the pilot's readback is the controller's only opportunity to catch a misunderstanding before it results in an incursion; pilots should read back critical information (e.g., call sign, runway number, hold short). The readback and hearback error rates demonstrate that pilots' and controllers' performance in this area are better than can reasonably be expected. It is possible to conceive of a voice recognition

system that codes the clearance as it is spoken by the controller, checks for pilot readback errors, monitors for conflicting clearances issued to different aircraft, and monitors the flight path and taxi routes for potential deviations from the clearance. While such a system would be very useful, it is far from being developed.
Coordination among controllers in the tower is necessary for efficient and safe operations. Poor coordination was noted as a contributing factor in tower operational errors in 18 percent of the reports in the independent analysis (and even more in the FAA analysis). There is an effort underway to enhance coordination among controllers; this training, called Air Traffic Teamwork Enhancement (ATTE) is one mechanism that has the potential to enhance the effectiveness of tower controller coordination.

5.2.6.4 Staffing - Safe operations require adequate staffing for the number and complexity of the operations. Sufficient staffing implies the presence of a supervisor or controller-in-charge (CIC). When supervisors also work a control position, however, they are not afforded the opportunity to devote their full attention to the "big picture." The value of an "extra set of eyes and ears" cannot be underestimated for catching errors before they escalate.

Airport Specific Analysis – Studies of individual airport operations and errors to determine what can be done to prevent accidents and incidents are very valuable, as are the insights of the operations specialists at that facility. Recall that one report (Skaliotis, 1991) identified that it is airport specific factors and the number of runway incursions (rather than the rate) that is most predictive of future problems. While it is beyond the scope of this report to make airport-specific recommendations, such analyses are a critical step toward finding effective solutions. For example, Los Angeles tower has analyzed their runway incursions and identified areas on the airport surface that are particularly problematic. Furthermore, they were able to determine that building an additional taxiway could help to alleviate the problem. While it is beyond the scope of this report to make airport-specific recommendations, such analyses are a critical step toward finding effective solutions. Los Angeles tower has analyzed their runway incursions and identified areas on the airport surface that are particularly problematic. Furthermore, they were able to determine that building an additional taxiway would help to alleviate the problem. Often, there is a pattern to operational errors. Identifying the pattern of errors can help point to solutions. For example, the following is an excerpt from an operational error report:

> "Three of the four operational errors/deviations that have occurred in this facility on the past 12 months were readback/hearback errors. All four involved an ATCS [air traffic control specialist] working combined local control positions where arrivals and departures were segregated on separate runways. Indeed, 75 percent of all operational errors/deviations since February 1995 have occurred in this configuration. This scenario necessitates a field of vision of 140 degrees or more to accommodate all operations. (Decombined positions require a field of vision of no more than 90 degrees.)...I recommend that, staffing permitting, either the CC, OSIC, or a local assist be mandated to actively monitor (via the ICSS) any combined local control position where arrivals and departures are segregated on separate runways or the positions be decombined."

5.3 REPORTS SUBMITTED TO THE AVIATION SAFETY REPORTING SYSTEM

The Aviation Safety Reporting System is a wealth of information submitted by pilots and controllers regarding specific events and concerns. Self -reports of errors typically present a candid portrayal of causal factors that the person may or may not wish to relay to the investigative authority. In an effort to determine the causal factors of tower controller errors (and potential solutions) as well as the general concerns of tower controllers, the most recent 300 ASRS reports submitted by tower controllers were examined. Of these, some were duplicates and others did not contain enough information to merit analysis. This left 249 reports on which the following results are based. The results of this analysis are presented in Table 1 – Results of Analysis of Controller ASRS Reports. Note: While some reports listed multiple contributing factors, others did not describe any. Thus, there is not a 1:1 correspondence between errors and contributing factors.

Table 1. Results of Analysis of ASRS Reports Submitted by Tower Controllers (N = 249)

Pilot Deviated from, or Proceeded Without, Clearance – Air • 23 - Heading/altitude • 5 - Entered airspace without authorization Resulting in • 16 - Near Mid Air Collision (NMAC) • 12 - Potential conflict/other • 22 - Would have benefited from improved surveillance and monitoring equipment o 6 -specifically mention the need for radar at that facility	28
Pilot Deviated from, or Proceeded Without, Clearance – Ground • 21 - Runway incursions • 6 - Surface incidents	27
Vehicles Proceeded onto Runway Without Authorization • 3 - Runway Incursions	3
No incident/Controller Reports of Pilot Error/Other • 16 - Didn't proceed as instructed • 1 - Landed without a clearance • 3 - Penetrated airspace without authorization • 2 - Pilot error in judgment • 8 - Other incidents (e.g., mechanical problem, ran out of fuel, bird strike)	30

Table 1. Results of Analysis of ASRS Submitted by Tower Controllers (N = 249) (Cont.)

No Incident/Controller Concerns Regarding
• Problems with equipment
  o 17 - Radar outages/malfunction
  o 2 - Want radar
  o 13 - Communication equipment
  o 3 - Other equipment concerns
  o 21 -Weather equipment
    ▪ 5 - Need wind information
    ▪ 5 - Need LLWS indication
    ▪ 11 - Problems with ASOS
• 13 - Local procedures, problem traffic (e.g., military, student pilots)
• 7 - Letters of Agreement (LOA)
• 3 - "Unnecessary" TCAS RA's
• 3 - Need indication of approach lights inoperative
• 5 – LAHSO
	87

Controller 'Forgot' • 8 – Aircraft cleared to land • 4 – Runway was closed • 4 - Vehicle on runway • 4 - Aircraft holding in position • 1 - Aircraft cleared for takeoff • 1 - Aircraft on approach Results • 18 - Runway Incursions • 2 - Aircraft taxied to closed runways • 2 - Aircraft landed on closed runways Contributing factors mentioned by respondents • 7 - Combined positions • 3 – Fatigue • 2 – Workload • 1 - Poor position relief briefing • 1 – Distraction caused by visitors • 1 – Exhaust fumes in tower	22
Didn't Know About, or Didn't Know Location of, Aircraft	4

Table 1. Results of Analysis of ASRS Submitted by Tower Controllers (N = 249) (Cont.)

Poor Controller-Controller Coordination Results • 2 - Runway Incursions • 6 – NMAC • 10 - Loss or potential loss of separation Contributing factors • 4 - Poor position relief briefing • 1 - Combined positions	18
Controller Error in Projecting Separation - Air Results • 1 – NMAC • 13 - Loss of separation o 4 – Combined positions	14
Controller Error in Projecting Separation - Ground Results • 9 - Runway incursions • 1 - Loss of separation	10
Controller Misidentified/Issued Clearance to Wrong Aircraft • 1 –NMAC • 5 - Loss of separation	6

5.3.1 Reports Submitted by Tower Controllers

5.3.1.1 Controller Concerns - Of the 249 reports submitted by tower controllers, 87 (35 percent) did not contain reports of surface incidents, but rather described issues of concern to controllers. The majority (64 percent)) of these reports described problems with, or other concerns about, equipment. Of the reports concerning equipment 38 percent of these reports concerned weather information: ASOS (Automated Surface Observation System) inaccuracies, the need for wind information or the need for low-level wind shear indication. An additional 34 percent of these reports were regarding radar outages, malfunction, or cited the need for radar at that facility. Twenty-three percent of the controller concerns were regarding local procedures, local "problem traffic" (such as training centers or high speed military traffic) and reports of problems with local letters of agreement (LOAs) or reports of controllers at other facilities failing to comply with LOAs. The remaining controller concerns contained in these reports concerned LAHSO (land and hold short operations), and miscellaneous issues (such as air quality in the tower) each comprising less than four percent of the reports of controller concerns.

5.3.1.2 Controller Reports of Pilot Errors - Thirty-two percent of the reports submitted by tower controllers describe pilot error and other incidents unrelated to controller errors or concerns. One-third of these reports were non-specific and did not describe surface incidents or potential loss of standard separation. The remaining 55 reports described incidents in which pilots deviated from, or proceeded without, a clearance in the air (28 reports) or on the ground (27 reports).

Of the 28 incidents in which pilots deviated from their clearance in the air:

- 82% involved pilots deviating from their assigned heading or altitude.
- 16% involved pilots entering controlled airspace without authorization.
- 57% of them resulted in Near Mid-Air Collisions (NMAC).
- 78% of them were judged to be situations that would have benefited from better surveillance and monitoring equipment; in fact, in 21 percent of these reports, the reporter specifically mentions that if they had radar at the facility, the controller would have been able to detect the problem much earlier.

Of the 27 incidents in which pilots deviated from their clearance on the ground:

- 78% resulted in runway incursions.
- 22% resulted in surface incidents.
- 11% occurred because the pilot was lost.
- 71% cited the need for better airport markings.
- 82% of these reports did not offer insights as to why the event occurred.

5.3.1.3 Controller Errors – Self-Reports - Perhaps the most informative reports submitted by controllers are those that describe errors that they themselves committed. There were 74 (30 percent) such reports in the 249 reports examined. In general, these reports show similar trends as the operational error data. The errors fall into three distinct categories: memory lapses, controller-controller coordination, and judgment errors in predicting separation.

The most common type of error reported involved memory lapses. Instances in which the controller forgot about an aircraft, that a runway was closed, or that a clearance had been issued accounted for 29 percent of the 76 self-reports of controller errors. Eighty-two percent of these errors resulting from memory lapses resulted in runway incursions. Additionally, two aircraft were cleared to land on a closed runway. While not all respondents reported factors that contributed to these errors, the most common contributing factor reported was that the controller was working combined positions; this was cited in 32 percent of the errors involving memory lapses.

There were 24 reports involving instances in which the controller made a judgment error in predicting separation. Fourteen of these involved separation in the air; 13 of these errors resulted in a loss of standard separation and one resulted in a NMAC. Four of these reports specified that the controller was working combined position at the time of the incident. An additional 10 reports of controller judgment errors involved separation on the ground (nine resulting in runway incursions); none of these reported that the controller was working combined positions at the time of the incident.

Twenty-four percent of the controller errors involved poor coordination between controllers. Thirty-three percent (6) of these instances resulted in NMACs, and 7 percent resulted in runway incursions (the remainder resulted in a loss or possible loss of standard separation). In four of these cases, the reporter cited a poor position relief briefing as a primary cause (e.g., the controller was not informed of an aircraft); in one case the controller was working combined positions.

In summary, the self-reports of controller errors fell into three distinct categories: memory lapses, failure in judging or predicting separation, and inadequate controller-controller coordination. Although most of these reports did not identify causal factors, 16 percent stated that the controller was working combined positions at the time, 6 percent identified a poor position relief briefing as contributing to the error, 4 percent identify fatigue as a contributing factor, and 4 percent mentioned controller-pilot communication errors (one report involving a blocked communication).

5.3.2 Reports Submitted by Pilots

The 100 most recent ASRS reports of runway transgressions submitted by pilots were examined. "Runway transgression" was defined by ASRS as the "erroneous or improper occupation of a runway or its immediate environs by an aircraft or other vehicle so as to pose a potential collision hazard to other aircraft using the runway, even if no such aircraft were actually present." However, the present analysis uses the terms "runway incursions" and "surface incidents" as defined on page 1. Nineteen reports were excluded from further analysis for one of the following reasons:

- The event occurred at an uncontrolled field, when the tower was closed or at a foreign airport.
- The event was unrelated to pilot error (i.e., due to an airplane equipment failure or controller error).
- The report was of a safety concern peculiar to that airport.

An additional five reports did not fit into any category for analysis. They described incidents in which: a student pilot took-off without a clearance resulting in a NMAC with a larger aircraft; a

Cessna entered controlled airspace without a clearance, resulting in a NMAC with a departing aircraft; a pilot who was cleared for an intersection take-off, but took-off in the wrong direction; a pilot who landed at the wrong airport; and a pilot who aborted a take-off after seeing another aircraft on the runway (but the report lacked sufficient detail for the nature of the error to be identified).

The results of the remaining 76 incidents are shown in Table 2. As with the reports submitted by controllers, some reports listed multiple contributing factors while others did not list any. Thus, there is not a 1:1 correspondence between errors and contributing factors. The same trends were found in these data as in the earlier survey of airline pilots conducted by MITRE (Adam, et al., 1994). Thirty-seven (49 percent) of the reports involved aircraft crossing the "hold short" line. These instances resulted in 12 runway incursions (six aborted take-offs and six "go-arounds"). Most (67 percent) of these errors were attributed to the pilot not being able to see the hold short line or otherwise poor markings. Thirty six percent of the 76 reports involved pilots taxiing onto, or crossing, the runway without authorization. These incidents resulted in 22 surface incidents and five runway incursions. Where a causal factor was mentioned, the report cited a communication error between controller and pilot or the need for better airport markings. In summary, the 76 incidents reported by pilots resulted in 19 runway incursions and 57 other surface incidents. Fifty-one percent of these 76 reports cited the need for better airport markings and 35 percent were attributable to controller-pilot communication errors (36 percent of these communication errors involved aircraft accepting another aircraft's clearance).

5.3.3 Pilot and Controller Errors Reported to ASRS - What can be done to prevent runway incursions?

The tower "shortfalls" that the analysis of ASRS reports points to are the need to prevent, and mitigate the consequences of, errors due to: failures of controller memory, miscommunications between pilots and controllers, failures of coordination among controllers, failure of controllers to accurately project separation between aircraft. The reports from the controllers and pilots support the recommendations gleaned from the literature review:

- Improve surveillance and monitoring equipment for controllers.
- Improve means of communication between pilots and controllers.
- Improve airport markings and signage - particularly more conspicuous "hold short" markings.

The reports from controllers also point to the need for improved coordination among tower controllers and the need for controllers to verify that the runway is clear before allowing an aircraft to take-off or land. This task could be aided by a system (for pilots and/or controllers) that displays whether or not the runway is occupied.

Reports from pilots also point to the need for cockpit standard operating procedures (SOPs) for ground operations. Such SOPs would help to ensure that:

Table 2. Pilot Reports of "Runway Transgression" Incidents (N = 76)

Failure to "hold short" as instructed/crossed "hold short" line Results • 2 runway incursions • 25 surface incidents Contributing factors • 25 couldn't see the hold short line or thought the marking was poor (includes 3 obscured by snow) • 7 miscommunication/misunderstood the clearance • 1 was confused as to where to hold • 1 cockpit distraction • 1 accepted "LAHSO" clearance and then forgot to hold short • 1 instruction to hold short was issued to late for pilot to comply • 2 poor crew coordination (one pilot knew the clearance, the other didn't)	37
Taxied to (includes one aircraft that took-off from) wrong runway Results • 8 surface incidents • Contributing factors • 2 need better airport markings • 5 controller-pilot miscommunication/misunderstood the clearance	8
Taxied onto, or crossed, the runway without authorization Results • 22 surface incidents • 5 runway incursions Contributing factors • 11 controller-pilot miscommunication/misunderstood the clearance (includes 4 incidents in which aircraft accepted a clearance intended for another aircraft with a similar call sign) • 12 cited need for better airport markings (one obscured by snow)	27

Table 2. Pilot Reports of "Runway Transgression" Incidents (N = 76) (Cont.)

Took off without authorization Results • 2 surface incidents • 4 runway incursions Contributing factors • 4 controller-pilot miscommunication/misunderstood the clearance	4
Summary data • 76 incidents (19 runway incursions 57 surface incidents) • 39 were attributed to poor airport markings/signage • 27 involved miscommunications (including 5 instances in which an aircraft accepted a clearance intended for another aircraft with a similar call sign)	

- Non-essential tasks are completed during relatively low workload and non-critical phases of operation.

- Pilots are aware of the location of their aircraft on the airport surface, the location of all critical elements in the airport environment (e.g., hold short points, intersecting runways, aircraft on approach) and their ATC clearance.

5.4 FINAL REPORTS OF AVIATION ACCIDENTS AND INCIDENTS INVESTIGATED BY THE NATIONAL TRANSPORTATION SAFETY BOARD (NTSB)

As of November 15, 1999, there were 42 final reports in the NASDAC data base of accidents and incidents in airspace controlled by air traffic control towers. These reports covered the period of December 1983 to July 1995. Eighteen of these reports were excluded from further human factors analysis for the following reasons. Seven were duplicate reports of the same accident or incident, since one report is filed for each aircraft involved; these reports were excluded so that each accident/incident would be represented only once. Four were reports of aircraft mechanical failure. Two reports involved non-movement ramp areas (i.e., not controlled by the tower). One report was of an aircraft landing at the wrong airport. One report was of a hard landing due to extreme weather. Another report involved an aircraft that hit a localized after flying through windshear. One report involved a "bird strike," and another involved a pilot becoming incapacitated. The remaining 24 reports – six accidents and 18 incidents - were analyzed for causal factors and potential remedies. Two of these incidents consisted of loss of standard separation between two take-offs as a result of controller error in anticipating separation; they did not result in NMACs or surface incidents.

Of the 22 accidents and incidents, the results were formally classified as:

- 8 "near collisions between aircraft."
- 1 "collision between aircraft."
- 7 "collisions with object."

The remaining six incidents were runway incursions. Of the seven "collisions with objects," six of the "objects" that aircraft collided with were other (stationary) aircraft and one was a snow sweeper.

Of these 22 accidents and incidents, by far the largest common factor, occurring in 70 percent of these reports, was the failure to verify that the runway was clear before allowing an aircraft to takeoff or land. In three of these cases, the pilots reported that their aircraft were clear of the runway, when in fact it was not; in one case, a fleet of vehicles reported clear when they were not. Five (22 percent) involved miscommunications between pilots and controllers; in three of these cases an aircraft accepted a clearance intended for another aircraft. Another three cases (13 percent), involved a "memory lapse" on the part of the controller; (one instance each of the controller forgetting that he/she had cleared an aircraft to land, takeoff, and position and hold on the runway). Only one case involved a controller that was working combined position. Only one report mentioned that the supervisor was working a control position. Two of the reports cite poor airport markings (in one of these cases a sign had blown over).

Visibility also appears to be more of a factor in these accidents than in incidents. Of the six accidents, only one occurred in VMC conditions during the day. Two occurred in IMC during the day. Two occurred in VMC at night (this includes one with some fog). One accident occurred in VMC at dusk. Of the 16 incidents, 8 occurred in VMC during the day (this includes one with haze and another with rain and haze). Five occurred during VMC at night (one with haze and one with snow). Two incidents occurred during IMC at night and one occurred during IMC during the day.

5.4.1 NTSB Final Reports of Accidents and Incidents – What do they tell us about what can be done?

The NTSB compiles recommendations to the FAA (to which the FAA must respond in a timely manner). All of the NTSB recommendations to the FAA concerning tower airspace were reviewed for tower shortfalls. The recommendations cover a wide range of topics unrelated to tower shortfalls. Among them were recommendations regarding: procedures, staffing, training, traffic restrictions, pilot training, training for airport vehicle drivers, controller phraseology, controller-pilot communications, airport markings, runway lighting, and aircraft conspicuity. The recommendations that target tower "shortfalls" address the need for improved surveillance and monitoring systems and specifically mention - AMASS and ASDE-3.

5.4.1.1 AMASS – In recommendation A-91-29, the NTSB recommended that the FAA, "Expedite efforts to fund the development and implementation of an operational system analogous to the airborne conflict alerts system to alert controllers to pending runway incursions at all terminal facilities that are scheduled to receive ASDE-3." Later, the NTSB recommended,

> "For these air traffic control facilities with operational ASDE- 3 systems to operate that equipment between sunset and sunrise, regardless of weather or visibility. Current operational requirements for the AMASS specify that the system be capable of 240 hour a day operation. Before the first AMASS is commissioned, require by order that the AMASS/ASDE 3 be operational 24 hours a day" (A-95-32).

Most recently, a letter from the NTSB dated March 10, 2000 states: "The Safety Board considers airport runway incursions an extremely serious safety problem. This safety issue has been on our Most Wanted Transportation Safety Improvements list since the list's creation in September 1990. The Safety Board is disappointed that 4 ½ years have passed since A-95-32 was issued requesting expeditious action, during which time the FAA has not completed the work necessary to meet the intent of these recommendations. Because the number of near runway incursions has increased over the last few years, the problem needs to be solved immediately. Therefore, the board reclassifies Safety Recommendation A-95-32 and A-91-29 "Open – Unacceptable Response," pending immediate action to meet these recommendations.

5.4.1.2 ASDE - The first recommendation concerning ASDE was for the FAA to, "Conduct research and development efforts to provide airports that are not scheduled to receive Airport Surface Detection Equipment with an alternate cost effective system to bring controller and pilot attention to pending runway incursions in time to prevent ground collisions" (A-91-30). Later, the NTSB recommended that the FAA "Continue research and development efforts to provide airports that are not scheduled to receive Airport Surface Detection Equipment with an alternate, cost-effective system, such as the ground induction loop, to bring controller and pilot attention to pending runway incursions in time to prevent ground collisions" (A-95-94).

The plans for testing and implementation of ASDE-X and ground induction loops satisfy these recommendations. The FAA's plans for "runway status lights" were also seen as supportive of the intent of these recommendations. These lights would activate when "the runway is "hot" based on radar sensing of aircraft on the approach or aircraft accelerating and decelerating on the runway. The lights would be positioned at the edge of the runway in order to be visible from the cockpit while an aircraft is holding short of the runway. Additional lights would be visible by the pilot in an aircraft that is in position and holding for departure. These runway status lights would operate independent of the controller by acting as an automated backup for the pilot." (FAA letter to NTSB dated August 12, 1991).

As was noted previously in this report, the concept of automated runway status lights has received anecdotal approval from both pilots and controllers. However, it is clear that the lights need to be capable of displaying more than "red" or "off," another color (such as yellow) needs to be displayed to indicate to the pilot that the system is working even when red is not displayed; (otherwise, the pilots are likely to query the controller, resulting in a potentially unacceptable increase in voice communications).

5.5 1977 FATAL RUNWAY INCURSION AT TENERIFE, CANARY ISLANDS

While not covered in the NTSB data base, no discussion of accidents in the tower environment would be complete without reference to the 1977 collision on the runway at Tenerife that resulted in 583 fatalities. In this tragic event:

> "The Pam Am crew was alarmed by the way in which the Air Traffic Clearance was issued. The captain... feared that... the KLM could possibly take the ATC clearance as a take off clearance and, immediately after the tower controller had said 'Okay', and pauses for almost two seconds, he and his first officer jumped in to inform the KLM crew that they were still taxiing on the runway. The message of the Pan Am crew coincided with the message of the tower controller who, at that moment, told the KLM aircraft to wait for take-off clearance. The coinciding transmission on the same frequency resulted, in the KLM cockpit only, in a strong squeal. Because of this, both vital messages were lost to the KLM crew resulting in the worst collision in the history of aviation. Every day there are incidents of blocked communication that are less dramatic, but have the same potential for disaster."
>
> *Extracted from the conclusions presented to the Netherlands Board of Inquiry by the Director General of Civil Aviation.*

As the amount of air traffic and radio frequency congestion increases, blocked and partially blocked transmission present an increasing risk to aviation safety. While the incidence of such events in unknown, the risk that is imposed by even a single event is self-evident. When the controller is not able to access a frequency due to a "stuck mike," the most fundamental safety net – that provided by voice communications between pilots and controllers – is gone. It is not surprising that 32 percent of the controllers from Level 5 towers said that there was a significant risk of surface incidents associated with a stuck mike (Kelly and Jacobs, 1998). Partially blocked transmissions or "step-ons" are far more common; recall that one-half of the respondents to the controller survey (Kelly and Jacobs, 1998) and 56 percent of the controllers from Level 5 facilities said that transmissions were stepped on "often". While these events are typically less dramatic than that of a stuck mike, they also present potential for disaster – as in the sample cited above.

Anti-blocking technology exists and has been in use both at the Bournemouth ATC facility in the United Kingdom and in commercial aircraft for several years. While NEXCOM is proposed to incorporate anti-blocking capability, the technology to be used has not yet been defined. Furthermore, the implementation schedule does not project this capability to be available at airports before the year 2015.

5.6 FAA PILOT DEVIATIONS IN TOWER AIRSPACE

The 67 FAA records of pilot deviations that occurred in tower airspace (as contained in the NASDAC data base in November, 1999) were examined. While these reports do not contain enough detail to be able to provide insight as to why the events happened, they do allow for a descriptive analysis of the types of events that were reported. Of the 67 reports, two were too cryptic to be included in the analysis. Of the remaining 65 deviations, 33 (51 percent) involved pilots entering controlled airspace without authorization. Fifty-two percent of these 33 deviations resulted in Near Mid-Air Collisions (NMAC), 6 percent resulted in runway incursions and the rest were classified as "other – no NMAC." In an additional 20 (31 percent) of the pilot deviations, the pilot did not follow an ATC instruction. (There is not enough information in the report to determine whether the instruction was read back or just acknowledged.) There were 3 instances in which a pilot entered/crossed an active runway without authorization; one resulted in an NMAC, one resulted in a runway incursion and one resulted in "other." There were three instances in which a pilot said that the traffic was "in sight," but then proceeded to loose separation with that traffic; two of these incidents were classified as NMACs. There were two instances in which an aircraft landed on a taxiway; one cited no VASI or other clear runway indications. The remainder of the deviations involved one instance of the following:

- Aircraft accepted a clearance intended for another aircraft, resulting in a NMAC.
- Aircraft landed without a clearance.
- Aircraft landed on the wrong runway.
- Aircraft took-off on a closed runway resulting in a NMAC.

Over half of the deviations recorded in tower airspace consisted of aircraft entering without authorization. There were only 32 (49 percent) deviations that consisted of surface incidents. These reports do not contain enough detail to merit further analysis or lend themselves to recommendations regarding the needs of tower controllers other than the need for the controller to be able to "see" or otherwise be alerted to traffic entering the airspace without authorization.

5.7 SUMMARY OF THE RESULTS

In summary, the data bases present converging evidence. While the failure to anticipate the required separation or miscalculation of the impending separation is an implied factor, the other four of the five factors that were found to contribute significantly to tower controller errors in MITRE's earlier work (Bales, Gilligan, and King; (Steinbacher, 1991) are more directly supported. That is, the most common controller-related factors identified in the surface incidents examined in this study were the same as those identified in previous studies:):

- Forgetting about an aircraft, the closure of a runway, a vehicle on the runway, and/or a clearance that he/she had issued.
- Communication errors – readback/hearback errors, issuing an instruction other than the one the controller intended to issue.
- Lack of, or incomplete, coordination between controllers.

The fifth factor identified in the literature, the absence of a supervisor (who was not working a control position), is supported by the data, but further study is necessary to determine the degree to which this is a factor, since it is not consistently coded in the operational error and deviation system, nor is it reliably mentioned (one way or the other) in the ASRS or NTSB reports. In many cases, it was the supervisor (or controller-in-charge) that prevented a bad situation from getting much worse. Many reporters lamented the need for another "set of eyes" in the tower cab. Obviously, this is an important issue that merits further investigation to determine staffing needs. It also supports the need for more effective monitoring aids in the tower. "Another set of eyes" can be electronic as well as human. While the flexibility and speed of human judgment is not able to be duplicated by artificial intelligence, tools that display traffic and alert the controllers to potential problems can be quite useful in preventing accidents and incidents. This is a difficult task for automation to perform because too many false alarms, or too little time allowed for the controller to respond to an alarm, makes the system ineffective. If the system "cries wolf" too often, then the controller will eventually ignore it. On the other hand, for the system to be useful, it must be able to warn the controller that an action is required with enough time to formulate and execute that action. Warnings that serve as little more than an indication as to where to look to witness an accident are as useless as warnings that are more often false alarms than legitimate alerts.

Frequency congestion, blocked communications, and similar call signs continue to pose a threat to safe operations. On the pilot's end, similar call signs is the primary factor in an aircraft accepting a clearance intended for another aircraft. On the controller's end, it has been associated with a controller confusing two aircraft and issuing a clearance to the "wrong" aircraft. Expanded use of data link for controller-pilot communications will remedy some of these errors. For example, it will be impossible for a pilot to accept a data link clearance that has been sent to another aircraft. While it would still be possible for the controller to send a clearance to one aircraft thinking it has been sent to another, a well-designed controller interface would ensure that these errors are easy to detect and fix.

Recall that the solutions offered by both reports were:

- Installation of ASDE-3 and AMASS (Airport Movement Area Safety System).
- Electronic flight strips.
- Development of a voice recognition system to monitor key words in transmissions and compare responses to detect errors.
- Development of a tool that will help controllers to ensure separation and will alert controllers to a potential loss in separation.

The results of this study support three of the four above recommendations. While nothing in the present data suggests the need for electronic flight strips, the data do support exploring the benefits of ASDE, AMASS, and the other tools mentioned.

5.7.1 Revisiting Controller Suggestions (from Kelly and Jacobs, 1998)

Recall that an extensive survey of 1111 controllers and managers at 63 Level 3, 4 and 5 towers identified five areas for consideration of tower improvements:

- Stop lights on runways activated by surface surveillance systems.
- Improvements to ASDE-3.
  - Tag the targets with the aircraft ID.
  - Reduce the number of false targets.
  - Reduce the interference caused by rain.
- Relief from radio frequency congestion and the problems associated with it.
- Relief from tower cab features that interfere with the controllers' scan of the airport surface.
  - Placement of displays on top of the consoles obstructs vision.
  - Inadequate tower shades hinder controllers' ability to see the airport surface.
- Improving the use of "memory aids."

While the operational errors and deviations examined do not contain information that speaks to false targets displayed on ASDE-3 or interference caused by rain, problems with radar was the most common equipment concern seen in the ASRS reports submitted by tower controllers. Similarly, "inadequate tower shades" is not identified as a contributing factor in the operational error data base, but was identified in controller-submitted ASRS reports. New technologies that could provide an effective improvement to traditional tower shades continue to develop and merit attention. (See Appendix B for a full discussion of this issue.) In general, the need for improved surveillance and memory aids are well supported both by the pilot and controller errors examined in this study and by controller opinion.

6. CONCLUSIONS

The tower "shortfalls" that this study points to are the need for:

- Improved surveillance and monitoring equipment that is most appropriate for a specific airport or part of an airport (e.g., ASDE-X, AMASS, runway status lights, loops). Included in this is that pilots and/or controllers need a means of determining whether an aircraft is clear of the runway. Sophisticated systems, such as AMASS, require significant investment for site adaptation and only will be useful if the warnings are timely and false alarm rate is acceptably low. However, because of their significantly lower price tag, less sophisticated systems such as loops and runway status lights and unsophisticated solutions such as markings (particularly, more conspicuous indicators of runway hold points) and lighting show potential for a higher (and more certain) return on investment.

- Better memory aids (and more consistent use of memory aids).

- Improved means of controller-pilot communication to reduce frequency congestion, eliminate stepped-on and blocked transmissions, and reduce the probability of an aircraft accepting a clearance intended for another aircraft.

- Improved means of facilitating coordination among controllers – this could be accomplished by a variety of means, such as shared displays, improved means of voice communication, or changes in procedure.

In addition, the following are recommended:

- Revise the method for the investigating, collecting information, and recording information on controller operational errors and deviations so that it is more consistent and useful in determining the causes and potential remedies to incidents. This mechanism should be standardized with unambiguous categories (e.g., contributing factors). The categories should be revised to include the most common types of controller errors (such as "forgetting") and ambiguous categories should be eliminated. It should include operational variables that would benefit from more research, such as: whether the supervisor or controller-in-charge was working a position, whether positions were combined (and if the combination was normal for that facility at the time), LAHSO, and intersection takeoffs.

- Survey towers for "homemade" memory aids, runway incursion prevention mechanisms, and other unique facility inventions (such as a bar code mechanism to record delay times) so that the effects of these aids can be studied and the information can be disseminated to all towers.

- Provide support to towers to expedite the acquisition of needed equipment or other resources.

- Encourage individual towers to perform their own "risk analysis" identifying significant factors in their own incidents (e.g., the intersections or other locations on the airport surface where the incidents are likely to occur, and the type of aircraft operators involved [helicopter, GA, military]), identify what can be done (markings, procedures, pilot education, etc.) to prevent future occurrences, and provide the resources to assist towers in these analyses and remedies. Develop a protocol for this analysis that will assist facility specialists in identifying potentially troublesome operational situations at their facility, such as particular intersections or specific combinations of positions.

- Investigate more conspicuous means of indicating runway hold locations.

APPENDIX A - DEFINITIONS

Definitions of Factors Contributing to Operational Errors and Deviations as Listed in the Operational Errors and Deviations System (OEDS) Data Base.

Aircraft Observation: Indicates whether the control tower observed any contributing factors related to aircraft.

Communication Error. Indicates whether any contributing factors were related to a communications error.

Complex Runway Configuration: Indicates that runway configuration was associated with traffic complexity.

Complexity-Number of Aircraft: Indicates that the number of aircraft was associated with traffic complexity.

Coordination: *Indicates whether any contributing factors were related to coordination.*

Ground Operations: Indicates whether any contributing factors were related to ground operation.

Inappropriate Use of Visual Data: Description of other inappropriate use of visual data contributing factors. Examples: failed to observe/remember vehicle on runway; controller misjudged separation

Inappropriate Use of Displayed Data: Indicates whether the contributing factors were related to inappropriate use of displayed data.

Operational Error: An occurrence attributable to an element of the air traffic control system that results in less than the applicable separation minimum between two or more aircraft, or between an aircraft and terrain or obstacles and obstructions as required by Handbook 7110.65 and supplemental instructions. Obstacles include vehicles, equipment, and personnel on runways.

Runway Incursion. Any occurrence at an airport that involves an aircraft, vehicle, person, or object on the ground that creates a collision hazard or results in loss of separation with an aircraft taking off, intending to take off, or intending to land.

Visual Data: Indicates whether any contributing factors were related to improper use of visual data.

APPENDIX B - PROMISING TECHNOLOGIES FOR THE CONTROL OF SUNLIGHT IN AIR TRAFFIC CONTROL TOWERS

Daniel J. Hannon, Ph.D.

Uncontrolled sunlight is one of the biggest obstacles to the use of full-color, commercial-off-the-shelf (COTS) electronic displays in air traffic control (ATC) towers. Although full color displays are readily available, they suffer from image washout when exposed to sunlight. Currently, the FAA is developing new ATC systems that rely on the display of colored symbology. These systems, however, also rely on the use of COTS displays for displaying information to the controllers. Traditionally, high brightness monitors that have been specifically designed for high brightness environments have been employed in the ATC tower. Unfortunately, technical restrictions limit these displays to a monochromatic (i.e., single-color) output. Antiglare coatings can provide some improvement to the performance of full-color display screens, but this is often at the expense of total light output, making displays appear darker. In order for the systems with color displays to be fully utilized in the tower environment, therefore, adequate control of ambient sunlight is required.

ATC towers have used strategic placement of the displays and mechanical, pull-down window shades to mitigate the effects of sunlight on display washout. Display screens can be oriented to minimize their exposure to direct sunlight. The possible location of the displays, however, is limited by the need for the controllers to be able to both see the displays and see out of the windows. The window shades are transparent, neutral density, filters (similar to sunglasses) that block some of the light. Mechanical failures in the retraction mechanisms and gaps in the between the shade and the window, however, often reduce the effectiveness of the shades. At times, controllers in the tower must resort to wearing sunglasses to control the amount of sunlight to which they are exposed. The wearing of sunglasses, however, can make colors harder to see and may make it impossible to see some colored symbols. Furthermore, these effects will be as variable as the types of sunglasses worn. That is, while some sunglasses can make certain colors harder to see, other sunglasses – with different optical characteristics – will have a different effect on color perception. This means that it is impossible to predict which colors on a display will be effected without knowing the optical properties of the sunglasses.

Improvements to the mechanism for shading the windows that eliminates the mechanical failures of the shades and eliminates the gaps between the shades and the frame of the window will provide the greatest potential benefit for the future use of color displays in the ATC tower. There are two ways of approaching this problem. One is through the development and/or application of an alternative window shading technology. The second is through the use of 'smart windows' that incorporate a dynamic filter into the glass that adjusts the light transmission through the glass in response to an electric input.

Federal Aviation Administration (FAA) specification E-2470b/1250-5 determines the design of the window shades currently used in ATC towers. This includes the material of the shade, the retraction mechanism, the mounting brackets, the method of mounting, etc. According to a representative from the Solar Screen Company, a supplier of ATC window shades, any change to the design and function of the shades would require a new specification. However, some control towers have used supplemental strips of shade material and attached them to the edges of the windows to eliminate the problem of the gaps. These strips are narrow, but permanently attached. The drawback to this approach is that when the shades are not in use there is a permanent shade around the edge of the window. Additionally, the presence of this window edge shading is probably not detectable at night, but would most likely diminish, if not completely obscure, vision around the edge of the window. Controllers would not be able to tell if there was simply nothing outside or if the light from an object was just too dim to detect through the shaded edge of the window.

An alternative technique to the permanent application of strips of window shade material is the use of removable window shade material that sticks directly to the window. This type of window shading is most commonly seen in automobiles. A plastic sheet is stuck to the window and peeled off when not needed. Strips of this material could possibly be constructed for ATC tower windows to shade the edges of the windows when needed and removed as the sunlight changes throughout the day.

A completely different approach to the problem is the use of 'smart windows'. Although there are three different technologies that have been lumped under this term, the only one that has potential for ATC application is called "electrochromic" windows. Electrochromic materials are transparent chemicals that change their transmittance with an applied electrical current. Thin films of electrochromic materials can be applied to a sheet of glass and banded by an electrode. After applying an electric potential to the electrodes, the transmittance of the window can be modulated in accordance with the applied voltage.

The advantage of this technology over the use of window shades is that it completely eliminates both of the problems with window shades noted above. Electrochromic materials fit the entire window so gaps in the shades are eliminated. Also, there are no moving parts so the mechanism problem is removed as well. Electrochromic windows are transparent in their off state so that failure of the circuit would result in a perfectly useable window. These devices have been tested under a variety of environmental conditions and shown to be rugged, with warranties expected for a minimum of 10 years or more. A photocell that is connected to the electrical circuit could continually adjust the transmittance of the window throughout the day from dark during the day to clear at night.

Electrochromic windows are still primarily in the development stage with only a small number of manufacturers around the world. In the United States, the US Departments of Energy, Defense and Commerce are supporting programs for the development of this technology. Presently, the largest panels available are on the order of 3' x 2'. Most development efforts are currently focusing on scaling this technology to larger sizes.

The present application of electrochromic windows to the ATC tower would require human factors evaluation of certain aspects of the windows that are not yet known. First, the small size of the panels relative to the current size of ATC windows would require that the panels be tiled on the windows. Every panel would require a surrounding electrode creating additional opaque areas in the windows resembling the frames around windowpanes. Second, although electrochromic panels are designed to be spectrally neutral, there is a tendency to block more long wave light with increasing voltage, giving the shades a slightly bluish appearance. This is most likely a desirable property, but could effect chromatic adaptation and the perception of color on displays. Third, the response time of electrochromic materials is not close to instantaneous, but is on the order of seconds or at worst minutes. While this should make them responsive enough to adjust to fluctuations in daylight, an analysis would be required to determine whether this responsiveness would be sufficient for the tower.

ANNOTATED BIBLIOGRAPHY

Adam, G., Kelly, D., and Steinbacher, J. (May 1994). Reports by Airline Pilots in Airport Surface Operations: "Part 1. Identified Problems and Proposed Solutions for Surface Navigation and Communications." MITRE Report Number MTR 94W0000060. MITRE, McLean, VA. *This is an excellent report based on an extensive survey of pilots from two major airlines on surface navigation aids (signs, markings, lighting, and published charts), cockpit procedures for pilot orientation on the airport surface, and intracockpit and ATC communications).*

Adam, G., and Kelly, D. (March 1996). Reports by Airline Pilots in Airport Surface Operations: "Part 2. Identified Problems and Proposed Solutions for Surface Operational Procedures and Factors Affecting Pilot Performance." MITRE Report Number MTR 94W0000060v2. MITRE, McLean, VA. *Part II of the above reference, this report deals with pilot's memory, attention, and other factors that affect the pilots' ability to comply with FARs and ATC clearances.*

Alaris, Co. Inc. April 1992. "Airport Surface Incidents and Runway Incursions Data Analysis - Interim Report II: Summary by Incident Type and Characteristics at Twelve Selected Locations (1988-1990) (ATL, BOS, CVG, DEN, DFW, JFK, LAX, ORD, PIT, PHX, SAT, and SEA)." Unpulished interim report. *This study analyzed 235 "surface incidents" that occurred at the 12 selected airports between 1988-1990, 55 percent were pilot deviations, 26 percent were operational errors/deviations, 17 percent were vehicle/pedestrian deviations and 2 percent were incident reports from NTSB files.*

Bales, R., Gilligan, M., and King, S. (April 1989). "An Analysis of ATC-Related Runway Incursions with Some Potential Technological Solutions." MITRE Report Number MTR-89W00021. MITRE, McLean, VA. *This analysis of 97 runway incursions was the first to offer suggestions for tools for controllers that could help prevent such occurrences.*

Bellatoni, J., and Kodis, R. (April 1981). "An Analysis of Runway-Taxiway Transgressions at Controlled Airports." FAA-EM81-5. *This was the first comprehensive study of runway incursions. It was begun in 1978 when the number of reported number of accidents and incidents on the airport surface in the past ten years was only 279. The study examined 161 ASRS reports, 77 NTSB accidents, and 49 ATC system errors and included interviews with tower personnel from the New England, Great Lakes, and Western Regions.*

Blumenstiel, A. (August 2000). "U.S. Runway Transgressions Calendar Year 1999". Unpublished draft report.

Bruce, D. (May 1996). "Physical Performance Criteria for Air Traffic Control Tower Specialists." Unpublished report. *This study analyzed time and motion data (i.e., where the controllers were in the cab and for how long) from controllers at six air traffic control towers. The purpose of the study was to define the mobility requirements for tower controllers to determine whether handicapped individuals could be assigned to towers. The results include the* *time that ground and local controllers spend looking outside the window and at each of the displays in the tower.*

Burki-Cohen, J. (1995). "An Analysis of Tower (Ground) Controller-Pilot Voice Communications." DOT/FAA/AR-96/19. *This report contains an analysis of 48 hours of controller-pilot voice communications from ground control frequencies at 12 airports.*

Cardosi, K. (1993). "An Analysis of En Route Controller-Pilot Voice Communications." DOT/FAA/RD-93/11. *This report contains an analysis of 48 hours of controller-pilot voice communications from eight ARTCCs.*

Cardosi, K. (1994). "An Analysis of Tower (Local) Controller-Pilot Voice Communications." DOT/FAA/RD-94/15. *This report contains an analysis of 49 hours of controller-pilot voice communications from the local control positions at 10 ATCTs.*

Cardosi, K. and Murphy, E. (1995). "Human Factors in the Design and Evaluation of Air Traffic Control Systems." DOT/FAA/RD-95/3. *A 700-page compendium of human factors topics which are important in the design and evaluation of ATC systems. It is geared to controllers who are involved in these processes and as a companion checklist that maps to the book.*

Cardosi, K., Brett, B., and Han, S. (1996). "An Analysis of TRACON (Terminal Radar Approach Control) Controller-Pilot Voice Communications." DOT/FAA/AR-96/66. *This report contains an analysis of 48 hours of controller-pilot voice communications from eight TRACONs.*

Clapp, D., Rempfer, P., Devoe, J., Bellantoni, J., Stevenson, L, Coonan, J., Kuhn, J., O'Brien, A., Bland, R., and Dumanian, J. (March 1978). "Tower-Related Major System Development Programs." FAA-EM-78-2. *This report contains complete descriptions of the following systems: DABS (Discrete Address Beacon System), ASDE-3, TAGS (Tower Airport Ground Surveillance), TIPS (Terminal Information Processing System), ARTS II and III enhancements, Flight Service Station Automation, Vortex Advisory System, Wake Vortex Avoidance System, Wind Shear Detection System, and MLS (Microwave Landing System). This report was part of the foundation for the system integration work by Hobbs, et al.*

Federal Aviation Administration's Runway Incursion Program Office (ATO-102) (1998). "1998 Airport Surface Operations Safety Action Plan to Prevent Runway Incursions and Improve Operations." U.S. Department of Transportation, Federal Aviation Administration.

Federal Aviation Administration's Air Traffic Resource Management Program Planning, Information and Analysis (ATX-400) (April 1999). "Aviation Safety Statistical Handbook." U.S. Department of Transportation, Federal Aviation Administration.

Federal Aviation Administration's Air Traffic Resource Management Program Planning, Information and Analysis (ATX-400) (November 1999). "Aviation Safety Statistical Handbook. Volume 7, No. 11." U.S. Department of Transportation, Federal Aviation Administration.

Grossberg, M. (March 1995). "Impacts of HAB TCCC Tasks on Controller Work." Unpublished manuscript. *This study provides a good example of a human factors evaluation of a prototype system to determine whether the expected benefits of "increased situation awareness and decreased controller workload" would be realized.*

Hobbs, V., Clapp, D., Rempfer, P., Devoe, J., Bellantoni, J., Maddock, L., Raudseps, J., Stevenson, L, Coonan, J., Kuhn, J., and Hilborn, E. (November 1977). "Characterization of Current Tower Cab Environments." FAA-EM-77-19. *This report describes the general tower cab environment* (as it existed in 1977) *in terms of breakdown of tasks by personnel, and tower systems and procedures.*

Hobbs, V., Clapp, D., Rempfer, P., Stevenson, L., Devoe, J., Bellantoni, J., Kuhn, J., and Coonan, J. (June 1978). "System Integration Analysis for Future Tower Cab Configurations/Systems." DOT-EM-78-10. *While this report contains a thoughtful approach to system integration in the tower, the specific recommendations are out-dated and point to the need for similar work to be conducted on today's system with an eye toward the implementation of new subsystems.*

Hill, J. (November 1993). "A Human Factors Analysis of 504 Runway Incident Investigations." MITRE Report No. MTR 93W0000007. MITRE, McLean, VA. *Two of the conclusions of this work were that "No underlying human factors causes of the incidents could be identified." and "The development of safety recommendations was not supported because of the lack of underlying human factors information." (p. xi).*

Human Technology, Inc. (October 1990). "Cognitive Task Analysis of Prioritization in Air Traffic Control." Unpublished report. *This analysis was conducted in cooperation with the En Route Curriculum Redesign Project Team to support improvements in training for en route controllers. It looked at the tasks, knowledge, and abilities involved in routine controller activities and interviewed controllers about "critical incidents" (usually operational errors) that they had experienced.*

Joint Safety Analysis Team (JSAT) (August 11, 2000) Results and Analysis.

Kelly, D., and Jacobs, G. (September 1998). "Reports by Airport Traffic Control Tower Controllers on Airport Surface Operations: The Causes and Prevention of Runway Incursions." MITRE Report No. MTR 98W0000033. MITRE, McLean, VA. *This report, with its appendices that contain the controllers' original responses, is a gold mine of tower controller opinion on equipment, training, procedures, and more. The report is quite lengthy (300 pages plus the appendices) but its organization makes it easy to locate specific topics.*

Kelly, D., and Steinbacher, M. (1993). "Pilot Surface Incident Safety Study." MITRE Report No. MTR 92W0000116. MITRE, McLean, VA. *This reports contains recommendations to reduce the incidence of runway incidents as a result of an analysis (including structured call backs) of 75 reports submitted to ASRS.*

Nader, E., DiSario, R., Nebgert, P., and Sussman, E.D., (1990). "A Simulation Study of the Effects of Communication Delay on Air Traffic Control." DOT/FAA/CT-90/6.

National Transportation Safety Board (1986). Special Investigation Report – "Runway Incursions at Controlled Airports in the United States." NTSB/SIR-86/01. *This analysis of 26 runway incursions in the U.S. was the first NTSB attempt to determine the causes of runway incursions and recommend remedial actions.*

National Transportation Safety Board (1990). Aircraft Accident Report – "Runway Collision of Eastern Airlines Boeing 727, Flight 111 and EPPS Air Service Beechcraft King Air A100, Atlanta Hartsfield International Airport Atlanta, Georgia, January 18, 1990." NTSB/AAR-91/03.

National Transportation Safety Board (1990). "Aircraft Accident Report - Northwest Airlines, Inc. Flights 1482 and 229 Runway Incursion and Collision, Detroit Metropolitan/Wayne County Airport, Romulus, Michigan, December 3, 1990."

National Transportation Safety Board (1991). "Aircraft Accident Report - Runway Collision of USAir Flight 1493 Boeing 737 and Skywest Flight 5569 Fairchild Metroliner, Los Angeles International Airport, Los Angeles, California, February 1, 1991."

National Transportation Safety Board (1994). "Aircraft Accident Report - Runway Collision Involving TransWorld Airlines Flight 437 and Superior Aviation Cessna 441 Bridgeton, Missouri, November 22,1994."

Reynolds, V., Last, L., Camp, D., Matthews, B., Kwan, T., McDonald, G. (June 1994). "Air Traffic Control Towers Equipment/System Integration Study – Volume 1." Transport Canada Publication Number TP 12218E. *This report provides a thoughtful approach to system integration. While the general approach is applicable, the usefulness of the recommendations is limited to the specific systems considered in the study.*

Reynolds, V., Last, L., Camp, D., Matthews, B., Kwan, T., McDonald, G. (June 1994). "Air Traffic Control Towers Equipment/System Integration Study – Volume 2, Appendices." Transport Canada Publication Number TP 12218E. *The appendices contained in Volume 2 of this study contain: the detailed work plan of this work, the specific functions of the systems examined in the report, a human factors analysis of Ottowa and Toronto tower operations, human factors engineering design guidelines for ATC tower systems and equipment, and discussions of requirements for, and potential suppliers of a tool to model system integration in the tower. While more complete human factors guidelines for system design can be found in "Human Factors in the Design and Evaluation of Air Traffic Control Systems" (DOT/FAA/RD-95/3, and its accompanying checklist), the discussion of a tool to aid system integration is highly recommended.*

Schmeidler, N., and D'Avanzo, J. (September 1994). "Development of Staffing Standards for Air Traffic Control Functions in Tower Cabs." Unpublished Technical Report. *This work provides a model for predicting necessary levels of staffing, given levels of aircraft activity.*

Skaliotis, G. (December 1991). "An Independent Survey of AMASS/ASTA Benefits." Project Memorandum RSPA/VNTSC-FA2P8-PM1. *A trustworthy, easy to read, report of an excellent benefits study of the Airport Movement Area Safety System (AMASS), Airport Surface Traffic Automation (ASTA) and "low tech" solutions such as markings, signs, lights and education.*

Steinbacher, J. (August 1991). "An Analysis of ATC-Related Runway Incursions in the National Airspace System." MITRE Report Number WP-91W00234. MITRE, McLean, VA. *This report contains a comprehensive human factors analysis of 109 runway incursions due to ATC operational errors and recommends the following: installation of ASDE-3 and AMASS, changes in shift schedules to eliminate rapid-turnarounds (and hence, reduce fatigue), use of a "associate controller position to monitor all displays, strips and the radio frequency of the local controller."*