FLIGHT SAFETY FOUNDATION
CABIN CREW SAFETY
Vol. 40 No. 3 *For Everyone Concerned With the Safety of Flight* May–June 2005

# Analysis of Evacuation-slide Problems Calls Attention to Recurrent Issues

***Based on their study of accident/incident data and data from other sources, researchers found that the most significant slide problem was failure to inflate.***

*Gerard van Es and Hans Post*
*National Aerospace Laboratory (NLR)–Netherlands*

The rapid deployment, inflation and stabilization of aircraft evacuation slides to quickly and safely evacuate occupants are essential elements of cabin safety. A problem with any one of these elements could increase the risk of injury or death during an emergency. In this context, researchers at National Aerospace Laboratory (NLR)–Netherlands analyzed data for Western-built[1] commercial passenger aircraft equipped with evacuation slides, compared categories of slide problems with those identified in earlier studies, and made safety recommendations.


The importance of properly functioning slides to prevent fatalities was underscored in the NLR study by a comparison of fatality rates — computed as the ratio of total onboard fatalities to total aircraft occupants — during survivable accidents[2] in which slides were used during the 1970–2003 period. The fatality rate for evacuations involving slide problems was 1.7 times higher than the fatality rate for evacuations not involving slide problems.

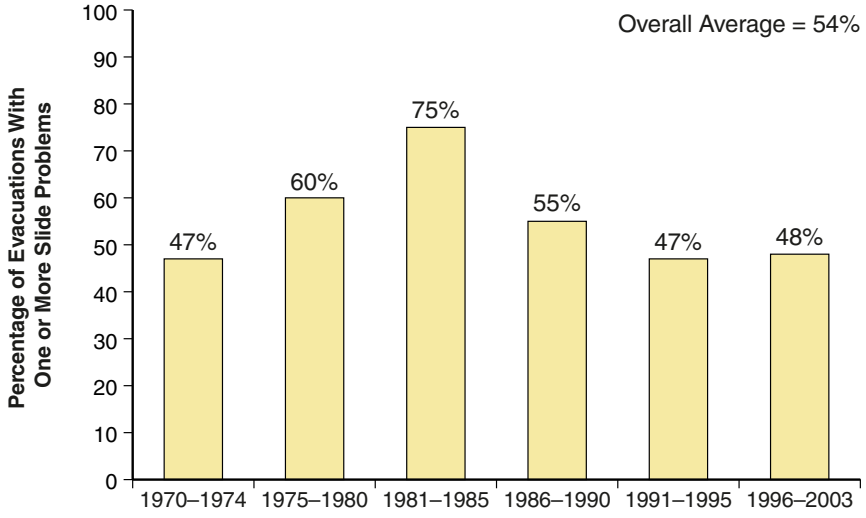
Civil aviation regulations generally require transport category aircraft that are equipped with emergency exits more than 6.0 feet (1.8 meters) above the ground to have an approved assisting means to enable the occupants to safely descend to the ground. Evacuation slides are used for this purpose. For the NLR study, an evacuation was defined as the disembarkation of passengers because of an actual emergency or a perceived emergency. The term "evacuation" was used in a generic sense to include precautionary evacuations and emergency-egress occurrences.[3]

The NLR analysis produced the following findings and conclusions:

- Examination of NLR's study sample of 150 survivable aircraft accidents in which slides were used during 1970–2003 showed that in 81 (54 percent), one or more slides did not function properly;
- Examination of NLR's study sample of 155 aircraft incidents in which slides were used showed that in 10 (6.5 percent) overall — combining Canadian data for 1995–2003, U.K. data for 1987–2003 and U.S. data for 1988–1996 — one or more slides did not function properly;
- The most significant slide problems involved inflation, aircraft attitude, wind, fire, incorrect rigging and rips; and,
- Various problems with slides have been reported since their introduction on commercial passenger aircraft. Despite safety recommendations by some accident-investigation authorities to improve slide reliability during the past 33 years, some previously identified slide problems continued to be reported during the NLR study period. Figure 1 (page 2) shows that the incidence of slide problems, expressed as a percentage of all accidents involving evacuation within a period, increased from the late 1970s until the early 1980s. These percentages decreased during the late 1980s. Since then, the incidence has not changed significantly.

NLR analyzed accident/incident data for emergency-evacuation occurrences in which slides were used and identified factors that hampered their use. The main objective of the study was to make an inventory of common evacuation-slide problems based on these data and other data sources.[4]

## NLR Incidence of Evacuations[1] With One or More Evacuation-slide Problems, 1970–2003




| | 1970–1974 | 1975–1980 | 1981–1985 | 1986–1990 | 1991–1995 | 1996–2003 | Total |
|---|---|---|---|---|---|---|---|
| Number of accidents involving evacuation in which slides were used | 19 | 15 | 20 | 29 | 19 | 48 | **150** |
| Number of these accidents involving slide problems | 9 | 9 | 15 | 16 | 9 | 23 | **81** |

NLR = National Aerospace Laboratory (NLR)–Netherlands

[1]Data show evacuations in which evacuation slides were used in survivable accidents involving Western-built commercial passenger jets worldwide.

Source: National Aerospace Laboratory (NLR)–Netherlands

**Figure 1**

The most significant slide problem identified in the NLR study was that some slides failed to inflate. Among data reviewed were service difficulty reports (SDRs) filed by U.S. aircraft operators during the approximate NLR study period. Among these, 803 (28 percent) of 2,868 SDRs involving slide problems cited inflation problems.[5] The SDRs showed that improper system packing/installation and improper maintenance of systems caused many of the slide-inflation problems.

Based on review of U.K. data[6] on 268 maintenance/test slide deployments from 1980 to 1994, NLR summarized the following slide problems that affected inflation:

- Incorrect assembly of the slides, 78 (29.1 percent);
- Girt-bar mechanism failure, 40 (14.9 percent);
- Misrigging, 30 (11.2 percent);
- Inflation-device malfunctions, 21 (7.8 percent);
- Failure to deploy with no obvious cause, 16 (6.0 percent); and,
- Other/unknown slide problem, 83 (31.0 percent).

In the period of the U.K. data, 62 emergency evacuations (with slides involved) occurred among U.K.-registered aircraft. In nine evacuations (15 percent), one or more slide problems were identified. No fatalities occurred during these evacuations, indicating that the evacuations occurred in low-severity occurrences (i.e., incidents).

Studies of emergency evacuations of U.S.-registered commercial passenger airplanes and Canadian-registered commercial passenger airplanes were conducted by the U.S. National Transporatation Safety Board (NTSB) and by the Transportation Safety Board of Canada (TSB), respectively.[7,8,9,10]

The 1974 NTSB study found that in 40 percent of 10 case-study evacuations, one or more slides did not operate correctly. The 1997 TSB study found that in 47 percent of the 15 evacuations where slides were used, some type of slide problem occurred. The 2000 NTSB study found that in 37 percent of the 19 evacuations where slides were used, at least one slide did not operate correctly.

Table 1 (page 3) shows NLR categories of slide problems derived from the TSB study and two NTSB studies of the 44

## Table 1
## Evacuation-slide Problems in NTSB/TSB Studies of 44 Evacuations of Commercial Passenger Aircraft[1]

| Problem Category | Number of Slide Problems | Percent[2] |
|---|---|---|
| Slide did not deploy/inflate automatically as designed | 15 | 46.9 |
| Wind caused problem(s) in using slide | 4 | 12.5 |
| Extreme attitude of aircraft caused problem(s) in using slide | 4 | 12.5 |
| Slide could not be deployed because of problems with emergency-exit door | 3 | 9.4 |
| Slide detached from aircraft | 3 | 9.4 |
| Slide inflated inside aircraft | 2 | 6.3 |
| Inadequate slide stability caused injury to evacuee(s) while descending | 1 | 3.1 |
| **Total** | **32** | **100.1**[3] |

NTSB = U.S. National Transportation Safety Board  TSB = Transportation Safety Board of Canada

[1]These categories of problems involving evacuation slides — identified in a 1972 study and a 2000 study by NTSB and in a 1997 study by TSB — were analyzed by researchers of the National Aerospace Laboratory (NLR)–Netherlands.

[2]More than one slide problem could be assigned to each accident.

[3]Values do not total 100 because of rounding.

Source: National Aerospace Laboratory (NLR)–Netherlands

total evacuations. Failure of the slide to inflate was identified in 15 (46.9 percent) of the total 32 slide problems.

For the NLR study, researchers first analyzed data about slide use from the NLR Air Safety Database, which contains data for accidents and major incidents involving civil aircraft worldwide. Because such occurrences are rare, the researchers also analyzed evacuations involving circumstances of lower severity. These often were precautionary evacuations.

For this part of the analysis, data from the following mandatory-occurrence-reporting systems also were used: the Canadian Civil Aviation Occurrence Reporting System (CADORS), the U.K. CAA Mandatory Occurrence Reporting (MOR) Scheme and the U.S. Federal Aviation Administration (FAA) Accident/Incident Data System (AIDS).

The search of the NLR Air Safety Database focused on survivable accidents in which the slides on Western-built passenger jets were used. The scope of the search was the period 1970–2003 and covered aircraft operations worldwide. NLR researchers identified 150 accidents in which slides were used. A total of 89 slide problems were identified. Table 2 (page 4) shows the categories of slide problems found by NLR researchers in the 81 accidents involving one or more slide problems. Table 2 also shows that in 25 slide problems (28.1 percent), at least one slide did not inflate automatically and/or the slide did not inflate manually.[11]

NLR researchers found absent from NTSB/TSB accident/incident reports a general explanation of why some slides did not inflate properly. NLR researchers identified a large number of different causes, however, such as empty inflation bottles and incorrect assembly of slide systems.

In 14 slide problems (15.7 percent), the final aircraft attitude caused one or more slides to be too steep for use by evacuees, prevented one or more slides from reaching the ground or left one or more slides curled under the aircraft (due to limited space to deploy the slide properly). Such final aircraft attitudes were mainly the result of the collapse of the aircraft nose gear or the collapse of the main landing gear. Moreover, in some cases, the aircraft stopped in a ditch or over an embankment.

Steep slide angles appeared to be the greatest problem for evacuees. At an angle of approximately 48 degrees, evacuees have tended to hesitate before jumping onto the slide because of its steep appearance.[12]

Wind had an adverse effect on the use of slides in 11 slide problems (12.4 percent) analyzed by NLR researchers. Typically, wind blew the slide against the side of the aircraft, preventing its use. Table 3 (page 4) shows the accidents involving one or more wind-caused slide problems and the corresponding reported wind speed. The mean wind speed during these evacuations varied from six knots to 28 knots. A similar range of wind speeds (three knots to 25 knots) was found for evacuations in which wind did not cause a problem while the slides were being used. A suggested explanation is that the wind direction relative to the aircraft's position/attitude played a key role.

The slides were burned in 10 slide problems (11.2 percent). In all of these, the slides had been deployed on a side of the aircraft where a fire was present. Because of the intensity of most of the fires, burning of the slides was unavoidable.

Incorrect rigging of the slide was identified as the category in seven slide problems (7.9 percent).

## Table 2
## Evacuation-slide Problems in NLR Study of 81 Accidents Involving Commercial Passenger Aircraft, 1970–2003[1]

| Problem Category | Number of Slide Problems[2] | Percent |
|---|---|---|
| Slide did not deploy/inflate automatically as designed | 25 | 28.1 |
| Extreme attitude of aircraft caused problem(s) in using slide | 14 | 15.7 |
| Other[3] | 12 | 13.5 |
| Wind caused problem(s) in deploying/using slide | 11 | 12.4 |
| Slide was burned | 10 | 11.2 |
| Slide was misrigged | 7 | 7.9 |
| Slide was ripped | 6 | 6.7 |
| Unknown | 4 | 4.5 |
| **Total** | **89** | **100.0** |

NLR = National Aerospace Laboratory (NLR)–Netherlands

[1]The categories of slide problems were identified in the NLR Air Safety Database from analysis of evacuations in which slides were used. One or more slide problems occurred in 81 of 150 survivable accidents involving Western-built commercial passenger jets worldwide.

[2]More than one slide problem could be assigned to each accident.

[3]Problems that did not fit other categories were designated as "Other." Examples were occurrences in which evacuation slides deployed inside the aircraft cabin and occurrences in which evacuation slides detached and fell from the aircraft.

Source: National Aerospace Laboratory (NLR)–Netherlands

## Table 3
## Accidents With One or More Evacuation-slide Problems Caused by Wind, 1970–2003[1]

| Date | Location | Aircraft Type | Wind Speed (knots) |
|---|---|---|---|
| July 30, 1971 | San Francisco, California, U.S. | Boeing 747-100 | 20 |
| Jan. 2, 1982 | Sault Ste. Marie, Ontario, Canada | Boeing 737-200 | 22 G 36 |
| May 12, 1983 | Regina, Saskatchewan, Canada | McDonnell Douglas DC-9-32 | 18 G 28 |
| Nov. 5, 1983 | Johannesburg, South Africa | Boeing 747-B | 6 |
| March 25, 1987 | Chicago, Illinois, U.S. | McDonnell Douglas DC-10-10 | 14 |
| Feb. 1, 1990 | Baltimore, Maryland, U.S. | McDonnell Douglas DC-10-10 | 12 |
| March 5, 1994 | Regina, Saskatchewan, Canada | McDonnell Douglas DC-9-32 | 22 G 27 |
| Dec. 24, 1997 | Amsterdam Schiphol, Netherlands | Boeing 757-200 | 32 G 42 |
| July 9, 1998 | San Juan, Puerto Rico, U.S. | Airbus A300-600 | 13 |
| July 12, 2000 | Vienna, Austria | Airbus A310 | 13 G 17 |
| Nov. 30, 2000 | Shannon, Ireland | Boeing 737-800 | 28 G 42 |

NLR = National Aerospace Laboratory (NLR)–Netherlands G = Gusting to

[1]The accidents were identified in the NLR Air Safety Database from analysis of evacuations in which slides were used and one or more slide problems were caused by wind. The evacuations occurred in 81 of 150 survivable accidents involving Western-built commercial passenger jets worldwide.

Source: National Aerospace Laboratory (NLR)–Netherlands

In six slide problems (6.7 percent), the slide was ripped. In four of these, the NLR researchers determined that the ripping was caused by shoes that some of the evacuees were wearing.

NLR analysis of incident data[13] from the three countries for several time periods yielded the following findings:

- Twelve evacuations involving slides were identified among Canadian-registered aircraft. No reported slide problems were found;
- The study identified 63 evacuations involving slides on U.K.-registered aircraft. In three evacuations (4.8 percent), slide problems were reported. In one incident, the slide twisted

during inflation. In another incident, the slide was punctured (possibly by high-heeled shoes). In the third incident, the slide deployed partially into the aircraft galley; and,

- A U.S. data sample comprised 130 occurrences (accidents and incidents) involving the deployment of slides.[14] For 80 of these, narratives were available. Analysis of the 80 evacuations showed that in seven occurrences (8.8 percent), the slides failed to operate properly. In three occurrences (3.8 percent), the slides failed to inflate and, in one incident, the slide detached and fell from the aircraft. The categories/details of slide problems involved in the remaining three of seven occurrences were not reported.

When analysis revealed significantly different rates for the accident data compared with the incident data, one reason advanced by NLR researchers was that incident reports perhaps did not consistently mention slide problems — even when slide problems had occurred.

Most likely, with an unfavorable wind direction, even moderate wind conditions typically caused a slide problem after the slides were deployed. Another factor could be the gustiness of the wind. With moderate wind conditions, strong gusts could cause difficulties when deploying and using a slide. To the knowledge of the NLR researchers, the influence of strong gusts on the proper functioning of slides has not been considered in civil aviation regulations.

Civil aviation regulations in Europe and the United States,[15] for example, say that an approved assisting means "must have the capability, in 25-knot winds directed from the most critical angle to deploy and, with the assistance of only one person, to remain usable after full deployment to evacuate occupants safely to the ground." "Critical angle" refers to the angle between the aircraft and the wind at which the resultant wind force on the assisting means would have the most significant effect. This rule — which became effective May 27, 1994, in European Joint Aviation Requirements and Dec. 9, 1996, in U.S. Federal Aviation Regulations — originated from a proposal in the mid-1980s.[16]

Except for the Boeing 737-800 (B-737-800), which was certified for manufacture in 1998, all of the aircraft in Table 3 were certified before 1990. This means that the slide problems in Table 3 involved aircraft exempted from the current requirement regarding the maximum wind speed in which the "approved assisting means" (self-supporting slide or equivalent) must function because aircraft certification for manufacture preceded this requirement. In the B-737-800 accident in Table 3, the mean wind was 28 knots — slightly more than the maximum wind in which the slides should have been able to function properly.

Based on this study, NLR made following recommendations to the airline industry:

- Disseminate these findings and conclusions to all interested parties (including civil aviation authorities, transportation safety authorities, aircraft manufacturers, evacuation-slide manufacturers and airlines);

- Analyze the influence of strong gusts on the proper functioning of slides; and,

- Analyze SDRs for slides to identify their relationship to problems found during accident evacuations and incident evacuations, and to monitor any influence of regulations that affect slide reliability.♦

## Notes

1. The National Aerospace Laboratory (NLR)–Netherlands Air Safety Database contains accident data for Western-built aircraft and Eastern-built aircraft. Because of insufficient data for aircraft evacuations and/or use of evacuation slides in Eastern-built aircraft, these aircraft were excluded from the NLR study.

2. The definition of the term "accident" in International Civil Aviation Organization Annex 13, *Aircraft Accident and Incident Investigation,* was used in the NLR study.

3. The definition used for the term "evacuation" was from the Transportation Safety Board of Canada (TSB).

4. Hynes, Michael K. *Frequency and Costs of Transport Airplane Precautionary Emergency Evacuations.* U.S. Federal Aviation Administration (FAA) report no. DOT/FAAJAM-99/30, 1999.

5. Data from service difficulty reports for 1997–2003 were obtained from FAA.

6. Safety Regulation Group, U.K. Civil Aviation Authority (CAA). "Data + Plus." 1995.

7. U.S. National Transportation Safety Board (NTSB). *Safety Aspects of Emergency Evacuations From Air Carrier Aircraft.* Special Study no. NTSB-AAS-74-3, Nov. 13, 1974.

8. NTSB. *Emergency Evacuation of Commercial Airplanes.* Safety Study no. NTSB/SS-00/01, June 27, 2000.

9. TSB. *A Safety Study of Evacuations of Large, Passenger-carrying Aircraft.* Report no. SA9501, 1995.

10. Fedok, J.T. "Evacuation Slide and Slide/raft Reliability." A paper presented to the NTSB International Aircraft Fire and Cabin Safety Research Conference, Oct. 22–25, 2001, in Atlantic City, New Jersey, U.S.

11. Occurrences in which the slide did not inflate automatically, but inflated immediately after the manual-inflation handle was pulled, were not recorded as slide problems in the NLR study. Nevertheless, when a significant delay in manually deploying the slide was caused by an equipment issue, and deployment subsequently was successful, a slide problem was recorded in the NLR study. Comparing Table 2 with Table 1 shows that relatively higher numbers of occurrences categorized as slide-inflation problems were found in the NTSB study and in the TSB study than in the NLR study. This is partly attributable to the difference in research methods. Unlike the NLR researchers, NTSB researchers and TSB researchers counted as a slide problem any occurrence in which the slide failed to deploy automatically but later was deployed manually.

12. Barthelmess, S.J. "Evacuation Slides: History and New Technology." *Cabin Crew Safety* November–December 1980.

13. For a better understanding of slide problems that occurred during lower-severity occurrences, the NLR researchers analyzed incident data — including precautionary evacuations — from the Canadian Civil Aviation Occurrence Reporting System (CADORS), the U.K. CAA Mandatory Occurrence Reporting (MOR) Scheme and the FAA Accident/Incident Data System (AIDS) to estimate the frequency/probability of slide deployment in mean wind conditions greater than 25 knots. The CADORS data were from 1995–2003, the MOR data were from 1987–2003 and the AIDS data were from 1988–1996. The AIDS data were supplemented with data about evacuation occurrences obtained from other sources, including a survey of 63 U.S. airports. Narrative reports were reviewed for all of the CADORS incidents (Canadian-registered aircraft) and MOR incidents (U.K.-registered aircraft). Narrative reports were not available for all of the AIDS incidents (U.S.-registered aircraft).

14. Hynes. These evacuations were limited to aircraft that operated under U.S. Federal Aviation Regulations (FARs) Part 121, air carrier operations. The FAA study evaluated precautionary emergency evacuations that occurred in 1988–1996 and involved U.S.-registered aircraft. The primary data sources included aviation safety databases of FAA, NTSB and the U.S. National Aeronautics and Space Administration, as well as the records of airport managers (collected via the survey sent to 63 U.S. airports). Additional data were obtained from airlines, insurance companies and court records.

15. Part 25.810, "Emergency Egress Assist Means and Escape Routes," in European Joint Aviation Requirements and FARs.

16. Joint Aviation Authorities. Notice of Proposed Rule Making (NPRM) no. 84-21. Aug. 20, 1990. FAA NPRM. Docket no. 26140, Notice no. 90–4. Feb. 22, 1990.

## *About the Authors*

*Gerard van Es is a senior consultant in Safety and Flight Operations, National Aerospace Laboratory (NLR)–Netherlands. His current research activities include safety assessments of flight operations, flight-data analysis, accident/incident analysis, development of safety indicators, analysis of aviation safety issues and occupant-survivability studies. He holds a bachelor of science degree in aircraft engineering from Haarlem Polytechnic and a master of science degree in aerospace engineering from Delft University.*

*Hans Post is a senior consultant in Safety and Flight Operations, NLR. During the past five years, Post has worked for NLR in flight testing and aviation safety. Post previously worked with Fokker Aircraft and Holland Railconsult for more than 16 years in various disciplines, including safety assessments, autoland certification and aircraft-system engineering. He holds a bachelor of science degree in information technology from Haarlem Polytechnic.*

## Acknowledgement

The authors acknowledge the cooperation and assistance of Joji Waites of the U.K. Civil Aviation Authority Safety Regulation Unit, Jennifer McCarthy of Transport Canada, System Safety, and Günther Raicher of the Flugunfalluntersuchungsstelle (Aircraft Accident Investigation Board) of Austria.



Staff: Roger Rozelle, director of publications; Mark Lacagnina, senior editor; Wayne Rosenkrans, senior editor; Linda Werfelman, senior editor; Rick Darby, associate editor; Karen K. Ehrlich, web and print production coordinator; Ann L. Mullikin, production designer; Susan D. Reed, production specialist; and Patricia Setze, librarian, Jerry Lederer Aviation Safety Library

Subscriptions: One year subscription for six issues includes postage and handling: US$160 for members/US$280 for nonmembers. Include old and new addresses when requesting address change. • Attention: Ahlam Wahdan, membership services coordinator, Flight Safety Foundation, Suite 300, 601 Madison Street, Alexandria, VA 22314 U.S. • Telephone: +1 (703) 739-6700 • Fax: +1 (703) 739-6708.