FLIGHT SAFETY FOUNDATION
Airport Operations
Vol. 30 No. 1 *For Everyone Concerned With the Safety of Flight* January–February 2004

Data Limit Ongoing Analysis of ARFF-vehicle Rollover Accidents

Preventing lateral loss of control in aircraft rescue and fire fighting vehicles with a high center of gravity can require countermeasures such as vehicle-specific driver-operator training, vehicle-suspension modifications and lateral-acceleration warning devices.

—

FSF Editorial Staff

International efforts to prevent rollover accidents involving aircraft rescue and fire fighting (ARFF) vehicles produced several countermeasures in the late 1990s. Rollover accidents, also known as turnover accidents, occur when physical forces suddenly cause the vehicle to rotate around its longitudinal axis so that the vehicle comes to rest with its wheels no longer in contact with the ground. To fully understand past and future ARFF-vehicle rollover accidents, accident data must be shared more effectively than during the 1990s, international specialists said.

FLIGHT SAFETY FOUNDATION SINCE 1947

In a March 2002 report, the U.S. Federal Aviation Administration (FAA) said that from 1977 to 2002, a total of 48 ARFF-vehicle rollover accidents had been documented in Argentina, Bermuda, Cambodia, Canada, Egypt, Iceland, Jamaica, Malaysia, Mexico, Portugal, South Africa and the United States. Twenty-seven of the accidents occurred between 1995 and 2002. Various vehicle models produced by U.S. manufacturers and Canadian manufacturers were involved.[1]

"The current generation of heavy rescue vehicles places the large-capacity water tank on top of the vehicle chassis frame," the report said. "This situation results in rescue vehicles with the center of gravity (CG) 5.0 feet to 6.0 feet [1.5 meters to 1.8 meters] off the ground. Vehicles with a high CG do not exhibit good dynamic stability. As the vehicle commences into the turn, a large shift of the water content can occur."

Vehicles must be able to withstand large shifts of CG in the high-speed turning radius at intersections of taxiways and runways while carrying sufficient water and extinguishing agents — for example, water-tank capacity as large as 4,500 gallons (17,034 liters) and aqueous-film-forming foam-tank capacity as large as 630 gallons (2,385 liters) — for potentially massive fuel fires resulting from accidents involving the largest aircraft at an airport. The circumstances of two ARFF-vehicle rollover accidents were as follows, the report said:

- "As the vehicle [driver-operator] left the station on an actual declared emergency-response run, the [driver-operator] exited the station, accelerated and traveled approximately 85.0 feet [25.9 meters] straight out of the firehouse. The vehicle then made close to a 90-degree right-hand turn onto a roadway. The vehicle then drove straight for approximately 75.0 [feet; 22.9 meters] to 85 feet. The vehicle then made close to a 90-degree left-hand turn onto a roadway and rolled over. This turn had a measured radius of 86.0 feet [26.2 meters]. It is estimated that the vehicle was traveling more than 17.0 miles [27.4 kilometers] per hour when it made this final left-hand turn. The combination

Tilt-table tests alone proved inadequate to evaluate aircraft rescue and fire fighting vehicle resistance to rollover. (U.S. Federal Aviation Administration photo)

of these left and right turns and running over the taxiway light caused the instability situation, which resulted in the rollover, and substantial damage to the vehicle. Therefore, the vehicle did not arrive at the scene, which, in itself, created another emergency; [and,]

- "The [driver-operator] reported that he made a slow left-hand turn, under 20 miles [32.2 kilometers] per hour, while turning the [steering] wheel and applying the brakes at the same time. He reported that the vehicle pitched over into the rollover situation before he realized that he had a vehicle problem."

Analysis of seven detailed responses (from a total of 10 responses) to a survey of airports by the Risk Management Section of Dallas/Fort Worth (Texas, U.S.) International Airport (DFW) also was cited in the FAA report.[2] The DFW report said that all but three accidents studied occurred in a non-emergency situation, and, "The average age of the driver-operator is 33 years old, with 12 years of fire-service experience [and nearly four years of experience as a driver-operator]."

Efforts to prevent these accidents have included the following, said Keith Bagot, airport safety specialist and program manager for the ARFF Research Program of FAA's William J. Hughes Technical Center in Atlantic City, New Jersey, U.S.:[3]

- Updating the international standard for new vehicles;
- Redesign of ARFF vehicles to incorporate stability-enhancing changes such as wider track, lower center of gravity, improved suspensions, anti-lock braking systems, lateral-acceleration warning devices and central tire-inflation systems;
- Engineering improvements in new vehicles during the manufacturing process, without complete redesign of the model, to lower the center of gravity and increase stability; and,
- Retrofitting struts to suspension systems of high-CG ARFF vehicles.

The FAA report said that suspension modifications are effective in improving vehicle anti-roll characteristics by increasing roll stiffness and shock-absorber damping force, based on research conducted with the U.S. Air Force Research Laboratory, Emergency One Corp. and Davis Technologies International. Suspension enhancements currently are eligible for funding under the FAA Airport Improvement Program.

"By replacing the shock absorbers with struts, the amount of [vehicle] body roll that is experienced as a result of both steering and ground inputs was reduced," the report said. "As a direct result, steering response and handling feedback to the [driver-operator] are greatly improved, resulting in greater vehicle stability. … The most noteworthy vehicle-handling characteristic [after adding struts] was the apparent change in the way that the vehicle reacted to extreme maneuvers."

NFPA 414, *Standard for Aircraft Rescue and Fire-Fighting Vehicles,* reclassified all ARFF vehicles to recognize the performance changes that enable the largest vehicles to be used for purposes formerly limited to smaller rapid-intervention vehicles, said Mark Conroy, NFPA senior fire protection engineer.[4]

Updates to NFPA 414 related to the prevention of rollover accidents include the following requirements:[5]

- Static side-slope stability of 30 degrees (tilt angle) using a revised tilt-table test procedure;
- Dynamic balance demonstrated on a circular course with a radius of 100 feet (30 meters);
- Passing an evasive-maneuver test (also called a double-lane-change test);
- Reinforced vehicle-cab construction; and,
- Using a lateral-acceleration warning device.

"If any lesson came out of all the discussions of rollover accidents, it was that no one should overlook the importance of driver training to operate these vehicles — it is critical," Conroy said.[6] NFPA 414 also contains advisory information about characteristics of specialized suspensions and tires that are most appropriate for the physical characteristics of the airport, and safety precautions about overloading vehicles.

Occurrence of ARFF-vehicle rollover accidents in North America since 1999 has been difficult to confirm, said Bernard Valois, senior specialist, aircraft rescue and firefighting standards, for Transport Canada and chairman of the task group for the revision of NFPA 414. Valois also was chairman of the earlier NFPA Vehicle Stability Task Force, which studied results of ARFF-vehicle testing in the late 1990s by National Research Council Canada (NRCC) and Oshkosh Truck Corp.[7]

"I have not heard of any ARFF-vehicle rollover accidents in Canada since 1999, and I do not believe that any have occurred in the United States — so no news is a positive sign," Valois said. "This seems to be due partly to vehicle design and partly to educational efforts."

The assumption for the older ARFF vehicles was that their width was limited by off-airport road-safety standards and current ARFF-station door width, he said. The task group agreed that, in view of the accidents, enhancing stability — including making ARFF vehicles wider — required higher priority, given that these vehicles primarily are used on airports rather than on roads off airports.

"In NFPA technical-committee meetings, we pushed the vehicle manufacturers to enhance stability," Valois said. "Crash trucks being manufactured today are totally different — they are far more stable. Before, there were various ideas of how to conduct NFPA 414 tilt-table tests and how to interpret them. Current test methods have been specified more exactly. Operators also see many new warnings, including the warning that if they move the location of equipment carried on the vehicle, the vehicle's lateral stability must be retested. Airport-roadway design for high-speed use and fire-hall [ARFF-station] design and placement also are keys to making a safe emergency response. I recommend involving ARFF professionals in these safety-related design decisions; otherwise, the compromises made — such as designating airport real estate for ARFF use only because it has no marketable value — can cause operational difficulties."

Bagot continues to request data about all ARFF vehicle rollovers through FAA's voluntary online reporting system at <www.airporttech.tc.faa.gov/safety/heavy.asp>.

"FAA does not have a mandatory-reporting system for ARFF vehicle accidents," Bagot said. "We typically get informal second-hand information, and we have to chase down what details we can. If airports were more forthcoming with voluntary data, we could be more effective in channeling our research dollars in the right directions. We need to look at what else is happening each time a rollover accident occurs, whether a human error or a physical component of a vehicle … needs to be improved.

"FAA's current advisory circular — AC 150/5220-10C, *Guide Specifications for Water/Foam Aircraft Rescue and Fire Fighting Vehicles* — describes stricter requirements and a tougher testing standard; before, there was only static tilt-table testing of ARFF vehicles. Manufacturers are making new vehicles much more stable."

FAA's upgraded dynamic vehicle performance-testing requirements in the AC include a constant-turning-radius test, J-turns and the evasive-maneuver test at simulated rescue-response speeds.[8] In the J-turn, the driver-operator attains a constant speed on level ground, then performs a sudden 90-degree turn with hard braking approximately 45 degrees into the turn and maintains brake application until the vehicle stops.

Training emphasizes known causes of rollovers; human limitations in correctly judging speed and lateral-acceleration forces; use of the lateral-acceleration warning device; how to drive aggressively to an aircraft-accident scene within the performance limitations of a specific vehicle; and how to administer rollover-prevention programs within an ARFF department.[9]

One example of a training course was developed for Transport Canada in 1998 by NRCC's Centre for Surface Transportation Technology to supplement other courses and the driver-operator manual. The instructors recommend that ARFF departments catalog the routes and turns from each ARFF station to various points on the airport, set a preferred path for each turn and identify the entry point, braking point and the entry speed based on practice with the lateral-acceleration warning device.

The concept of the lateral-acceleration warning device originated as a "wish-list item" in the summary of an ARFF-vehicle rollover-accident investigation by Transport Canada, said Jon Sheaff, vice president of engineering for Stability Dynamics of Campbellford, Ontario, Canada. The company's device is called LG Alert. Enabling the device every time an ARFF vehicle is operated was suggested by early participants in rollover-prevention training, he said.[10]

"Drivers told us that removing it at the end of training was like taking out the speedometer, so we began to bolt them into the vehicles permanently," Sheaff said. "The current three-axis sensor, installed in the cab as close to the front axle as possible, measures … lateral acceleration [centrifugal force] generated by a vehicle while turning corners, plus any side forces generated from operating the vehicle on a side slope, adds these forces together and almost instantly displays the resulting signal on a 10-light bar of light-emitting diodes [LEDs] on a display within the driver's field of vision."

The sensitivity can be adjusted to reflect the cornering capabilities and side-slope capabilities of a specific vehicle. On the recommendation of NRCC, and later as a common practice, trainers set the device to display and sound the highest level of visual warning and audible warning at approximately 70 percent to 75 percent of the vehicle's capability (as calculated from measurements in the static tilt-table test) to provide a safety margin, Sheaff said. Trainees are taught that these warnings advise the driver-operator not to continue to accelerate or tighten the turning radius, or the vehicle may roll over.

"After training, driver-operators rarely look at the LEDs," Sheaff said. "They mainly listen for the beeper and then the siren indicating that they are approaching the safe limits of vehicle performance. During training, they were told to 'let off the accelerator' and 'don't turn any sharper' when they saw the device's flashing red lights and heard its beeper and siren.

"Overly aggressive drivers learn that they are pushing too hard, and back off to safer driving, and more timid drivers, with the confidence of knowing they will be alerted to vehicle instability, push a little harder and respond to the emergency in less time."

Sheaff said that more than 1,000 of the devices are in use by ARFF departments and driver-training organizations in several countries, and they are required equipment on some new ARFF vehicles.

Countermeasures are believed to have prevented the types of ARFF-vehicle rollover accidents that occurred during the 1990s, but certainty about their effectiveness will require airports to routinely provide data about them for ongoing safety research.♦

Notes

1. Bagot, Keith. "Evaluation of Retrofit ARFF Vehicle Suspension Enhancement to Reduce Vehicle Rollovers." Office of Aviation Research, U.S. Federal Aviation Administration (FAA) William J. Hughes Technical Center, Report no. DOT/FAA/AR-02/14. March 2002.
2. Wekenborg, Bill. "Aircraft Rescue and Firefighting (ARFF) Vehicle Stability Study." August 1999. The report was a research project submitted to the American Association of Airport Executives. Wekenborg is a captain with the Dallas/Fort Worth (Texas, U.S.) International Airport Department of Public Safety.
3. Bagot, Keith. Telephone interview by Rosenkrans, Wayne. Alexandria, Virginia, U.S. Jan. 13, 2004. Flight Safety Foundation, Alexandria, Virginia, U.S.
4. Conroy, Mark. "NFPA 414 Is Being Revised to Reflect Advancing Technology." *NFPA Journal.* Volume 94 (January–June 2000).
5. NFPA International. *NFPA 414: Standard for Aircraft Rescue and Fire-Fighting Vehicles, 2001 Edition.* Aug. 2, 2001.
6. Conroy, Mark. Telephone interview by Rosenkrans, Wayne. Alexandria, Virginia, U.S. Feb. 12, 2004. Flight Safety Foundation, Alexandria, Virginia, U.S.
7. Valois, Bernard. Telephone interview by Rosenkrans, Wayne. Alexandria, Virginia, U.S. Jan. 28, 2004. Flight Safety Foundation, Alexandria, Virginia, U.S.
8. FAA. "A Message From the Manager, Airport Technology R&D Branch." *Federal Aviation Administration R&D Review.* Volume 1 (Spring 2002).
9. Centre for Surface Transportation Technology (CSTT), National Research Council Canada. "Driving Airport Rescue and Fire Fighting (ARFF) Vehicles." Feb. 14, 2003. <cstt-ctts.nrc-cnrc.gc.ca/en/course/course02.html>.
10. Sheaff, Jon. Telephone interview by Rosenkrans, Wayne. Alexandria, Virginia, U.S. Jan. 30, 2004. Flight Safety Foundation, Alexandria, Virginia, U.S.