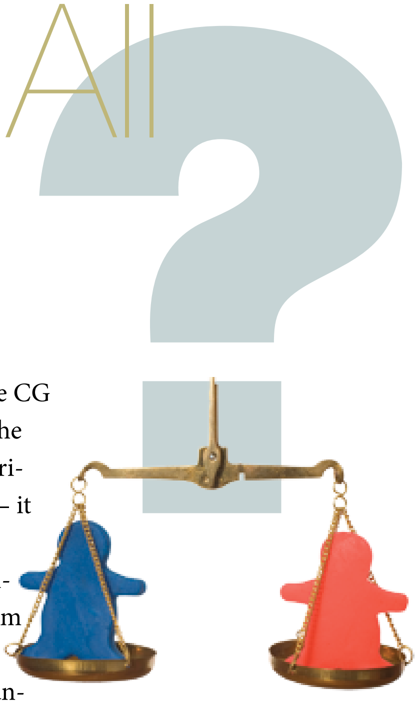
One Size Fits All?

The Danger of Average Weights

BY KEITH GLASSCOCK



Look around any airport terminal and you'll see that few passengers, or their bags, meet the average weights prescribed under current weight-and-balance programs. The differences between the prescribed average weights and the actual weights of passengers and their baggage — and variations in their distributions throughout the airplane — can lead to significant errors in weight-and-balance calculations.

Weight-and-balance errors have been involved in accidents and incidents. While civil aviation authorities, including the U.S. Federal Aviation Administration (FAA), have attempted to lessen the danger by increasing the prescribed average weights, the underlying causes of errors remain.[1]

A study conducted by the author, using computer-aided data modeling, shows that a center of gravity (CG) calculated from average weights is more often erroneous than not. The study used a hypothetical airplane with 132 passenger seats arranged in 22 rows with three seats on each side of the aisle. Zero fuel weight is 118,000 lb (53,525 kg). The body weights of the hypothetical adult passengers were created from an analysis of data from the National Health and Nutrition Examination Survey conducted in 2000 by the U.S. Department of Health and Human Services.

With many different ways — approximately 1.5×10^{161} — to distribute the 132 passengers in the cabin, the first phase of the study examined the worst case of distributing the passengers by weight, with the heaviest at one end of the cabin and the lightest at the other end. With this distribution, the resulting change in moment would cause an overall difference in airplane CG of 8.4 in (21.3 cm) at 118,000 lb. Although the probability of this worst-case passenger distribution is extremely small — 1 in 7.7×10^{160} — it could happen.

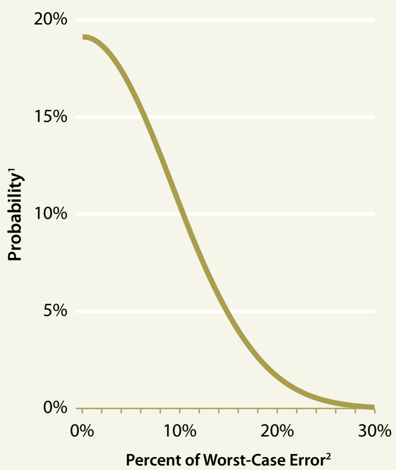
For the second phase of the study, a computer was used to generate 10 million random passenger distributions and to calculate the resulting CGs. Comparing the mean and standard deviations of these CGs to CGs calculated using FAA's average passenger weight — 169 lb (77 kg), not including allowances for carry-on baggage or clothing— produced a calculation of error probabilities.[2]

Figure 1 (page 56) shows the probability of errors between CGs calculated from the hypothetical passenger weights and CGs calculated from average weights as a percentage of the worst-case error (8.4 in). Figure 1 shows, for example, the probability that 2 percent of the random passenger loadings will result in an error approximating 18.5 percent of the worst-case error. Thus, for the hypothetical airplane, there is a 1 in 50 chance that the CG error caused by the passengers will be approximately 1.6 in (4.1 cm) at 118,000 lb. The data show that as the probability decreases, the magnitude of the error increases until the worst-case error is reached.

Baggage, especially checked baggage, also has a significant effect on CG location. Carry-on baggage is a very small portion of total airplane weight. Calculations using FAA survey results for carry-on baggage show that the effect of a worst-case distribution — heaviest baggage at the front or at the rear of the cabin — is approximately 1.7 in (4.3 cm) at 118,000 lb.

Calculations for checked baggage are far more complex than for carry-on baggage.

Probability of CG Error Caused by Random Seating of Passengers



Notes

1. Probability is the sum of forward and aft error probabilities.
2. Chart excludes zero error. Worst-case CG error for hypothetical airplane and 132 adult passengers is 8.4 in (21.3 cm) at 118,000 lb (53,525 kg).

Source: Keith Glasscock

Figure 1

However, some estimates can be made, using FAA survey results for checked baggage and the following assumptions:

- There are 200 checked bags for the flight.
- None of the bags is classified as heavy.
- The baggage is distributed evenly below the entire length of the cabin.

The worst-case effect of checked baggage on overall airplane CG is approximately 3.0 in (7.6 cm) at 118,000 lb. Like the worst-case passenger distribution, the probability of such an arrangement is exceedingly small. Unfortunately, the probabilities of errors less than worst-case are indeterminable; there are too many variables in how the baggage is loaded to allow for any reasonable predictions of probability.

Children can exacerbate CG error. Many airlines have weight-and-balance programs that allow the difference between the prescribed average weights of adults and children to be applied as a weight credit; the weight credit is calculated at the cabin centroid, the CG of the cabin if all seats are loaded equally, instead of the child's actual seat position.

Moreover, in the hypothetical airplane, the effect of a single child seated in the first or the last row is significant. The FAA-prescribed average weight for children, aged two through 12, is 82 lb (37 kg). If a child seated in the first or last row actually weighed only 40 lb (18 kg), the CG error would be approximately 1.0 in (2.5 cm). Obviously, several children seated at the extreme front or rear of the cabin could create a large CG error.

Calculations using only the effects of passengers and baggage indicate that a total worst-case CG error of approximately 13.1 in (33.3 cm) is possible for the hypothetical airplane. The effects of crewmembers and children easily could increase that amount by one inch.

The significance of such an error depends on the approved CG range. For example, the McDonnell Douglas MD-81 has an approved CG range at zero fuel weight of approximately 53 in (135 cm). If the hypothetical airplane had that CG range, the total error caused by passengers and baggage alone would be equal to approximately 25 percent of the available CG range.

Accident reports continue to show the risk of operating overweight and/or out-of-balance aircraft. While ongoing mitigation efforts will reduce the risk, the only way to eliminate the risk is with accurate CG determination based on the actual weights of passengers and all items placed aboard the aircraft and their actual locations within the aircraft. Electronic scales and computer programs can be used to accomplish this. In addition, several companies are certifying or marketing systems that compute weight and balance by weighing the entire airplane before departure. A concerted effort by commercial aircraft operators and regulators must be made to place these technologies in service. ●

Keith Glasscock recently was graduated summa cum laude by Embry-Riddle Aeronautical University with a bachelor of science degree in professional aeronautics. He has been employed since 2001 as a pilot for a large regional airline and has provided classroom instruction to fellow pilots on a variety of safety topics. Glasscock also has 15 years of experience in aircraft maintenance.

Notes

1. The U.S. Federal Aviation Administration (FAA) increased the prescribed average weights of passengers and pilots by 10 lb, flight attendants by 30 lb and checked baggage by five lb. A new category called "heavy checked baggage" was created for bags with actual weights between 50 and 100 lb; the prescribed average weight is 60 lb.
2. FAA Advisory Circular 120-27E, *Aircraft Weight and Balance Control.* June 10, 2005.

InSight is a forum for expressing personal opinions about issues of importance to aviation safety and for stimulating constructive discussion, pro and con, about the expressed opinions. Send your comments about the author's call for computing aircraft CG based on the actual weights and distributions of passengers and baggage to J.A. Donoghue, director of publications, Flight Safety Foundation, 601 Madison St., Suite 300, Alexandria VA 22314-1756 USA.