Filling the Envelope

HOW RISKY ARE AVERAGE WEIGHTS?

BY PATRICK CHILES

The inaugural issue of *Aviation Safety World* carried an InSight column titled "One Size Fits All? The Danger of Average Weights" (July 2006, page 55). The author made a good case for requiring actual weights and seating control, but that solution would be impractical for many operators. While average weights may not reflect all passenger types, the risks of deviation were not considered in the proper context. There are methods by which we account for these variables, and they are described in the advisory circular cited by the author.[1]

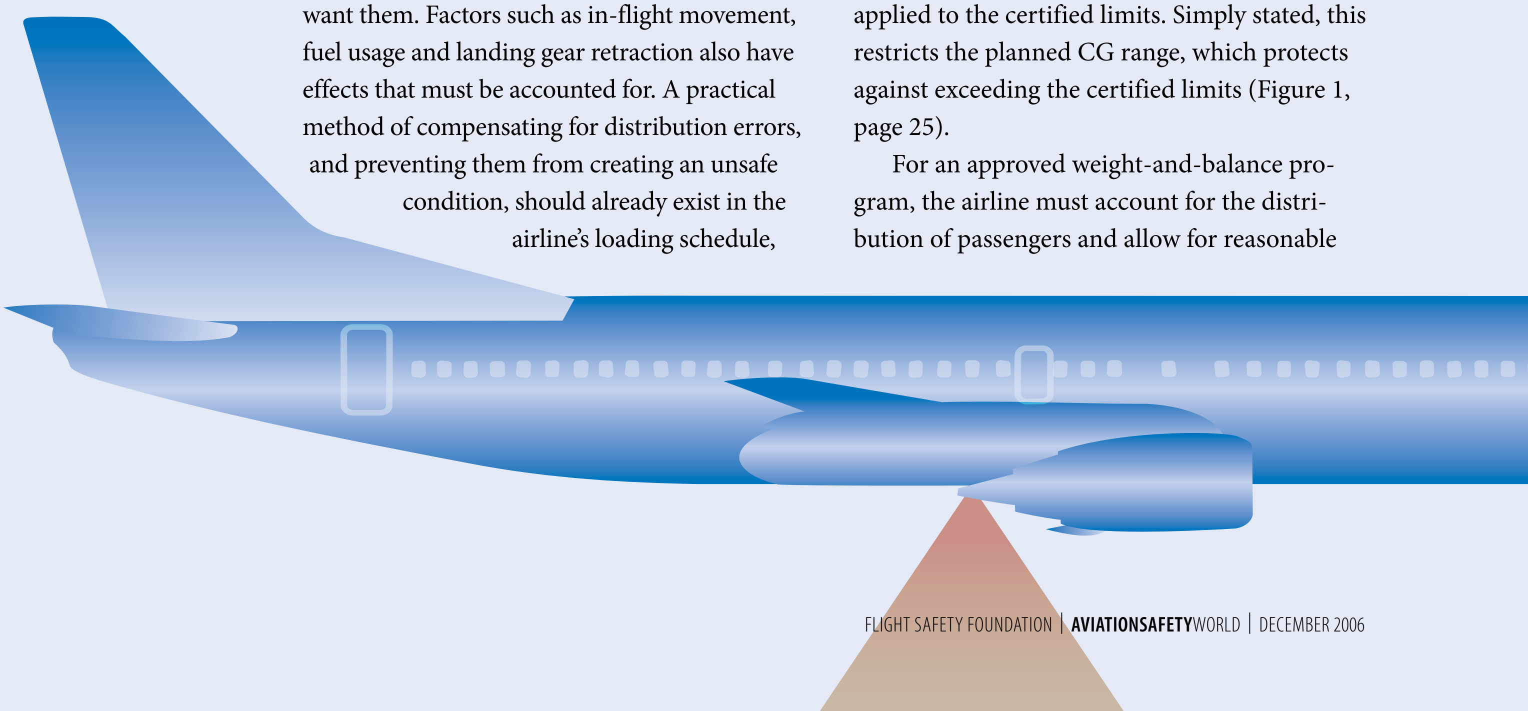
Potential errors in weight distribution are recognized and allowed for in a properly engineered loading envelope. It is not absolutely necessary to determine exact seating locations. Even when that's done, we can never be certain that people or their carry-ons will stay where we want them. Factors such as in-flight movement, fuel usage and landing gear retraction also have effects that must be accounted for. A practical method of compensating for distribution errors, and preventing them from creating an unsafe condition, should already exist in the airline's loading schedule, which typically includes a graphic depiction of the loading envelope and specific loading instructions.

Certified vs. Operational

It is important to recognize the fundamental difference between the manufacturer's certified limits and the airline's operating limits. The certified envelope provided in the aircraft flight manual (AFM) represents the approved safe limits for the airplane. However, it is not intended for use in actual load planning. The manufacturer's certified envelope by itself will not protect against center of gravity (CG) changes from inevitable loading variations. An operating envelope must be developed to account for this.

Probable deviations are accounted for by creating curtailments, or reductions, that are applied to the certified limits. Simply stated, this restricts the planned CG range, which protects against exceeding the certified limits (Figure 1, page 25).

For an approved weight-and-balance program, the airline must account for the distribution of passengers and allow for reasonable



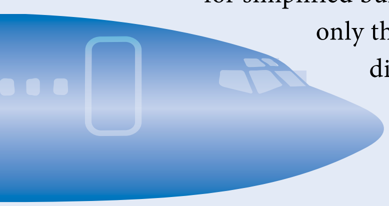
seating assumptions. One way of dealing with this is the "window-aisle-remaining" method. It assumes that window seats will be filled first, followed by aisle seats and middle seats, with worst-case moment changes calculated from the front and back. The potential variation from the cabin's centroid becomes the envelope curtailment and is subtracted from the certified forward and aft limits.[2] This protects against differences between planned and actual cabin centroids. Cabins frequently are subdivided into separate loading zones to further reduce potential error and to minimize reductions of the certified limits.

Curtailment for the in-flight movement of passengers and crewmembers depends on the same seating assumptions. The predicted magnitude of this movement places another limit on the loading envelope.

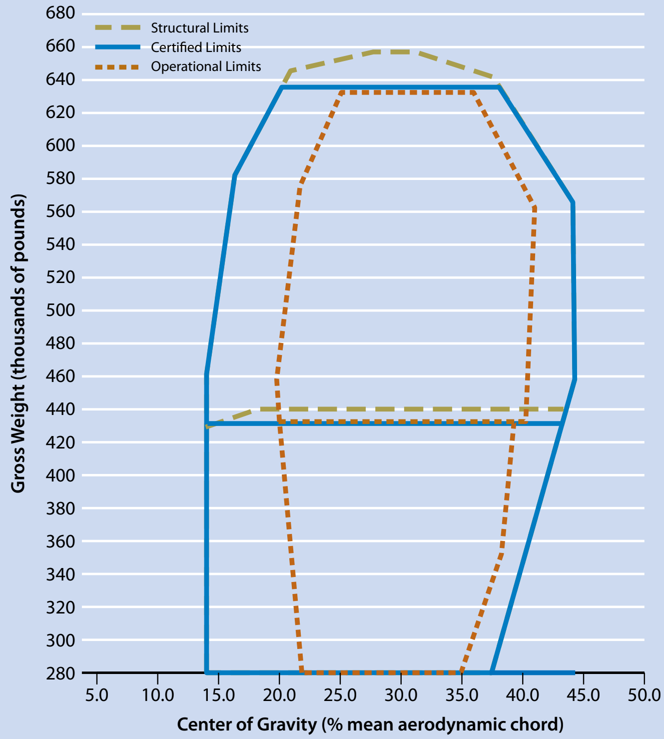
Cargo Loading Variation

The author's statement that "there are too many variables in how the baggage is loaded to allow for any reasonable predictions of probability" is inconsistent with common practice. Loading schedules account for the fact that baggage and cargo may not be distributed evenly. As with the cabin, cargo compartments can be subdivided into multiple zones with probable variations to each zone centroid applied to the new envelope.

Some curtailments are more complicated than others, and it is true that cargo variations are difficult to predict if the individual balance arms of each item are considered. The calculations must consider compartment design and other factors, such as whether the cargo is bulk-loaded or "containerized." For example, Boeing's single-aisle 737 and 757 are designed for simplified bulk-loading, requiring only that the bags are evenly distributed around the compartment centroid. Wide-body aircraft have more complex considerations for containerized loading and lateral imbalance.



Sample Certified vs. Operational Envelope



The horizontal lines at 430,000 to 440,000 lb gross weight are the zero fuel weight limits.

Source: Patrick Chiles

Figure 1

The Envelope, Please

Probable CG variations are determined by the airline's weight engineer and applied to the manufacturer's certified envelope. The resulting operational envelope will appear on the aircraft-specific weight-and-balance form, or loadsheet.

Loading schedules are commonly created by the manufacturers, airline engineering departments, or third-party vendors and completion centers. Pilots, dispatchers and load planners must be diligent to use a properly calculated loading schedule and operating envelope, and not confuse them with the manufacturer's certified envelope.

This does not relieve the operator of the responsibility to use the most realistic average weights available. For instance, while a 30-lb (14-kg) baggage allowance is "legal," an operator can use a higher weight allowance if it is believed to be more realistic. Likewise, the operator may

account for a higher ratio of male to female passengers and use the appropriate higher average weight. Operators should conduct their own passenger and baggage surveys if they believe the standard average weights are not appropriate.

With smaller aircraft, there are more opportunities for adverse effects from nonstandard weights. One solution is to use *segmented weights* as provided for in the advisory circular. This involves adding back part of the standard deviation to the average weight to improve the likelihood that actual weights won't exceed the new average.

Finally, average weights cannot be used when operating sports or military charters. Some type of actual-weight program must be used.

In Practice

The author's hypothetical airplane is similar to a 737-700 — 132 passengers, 200 bags, 118,000 lb (53,525 kg) zero fuel weight. Beginning with a fairly nose-heavy CG of 15 percent mean aerodynamic chord (MAC), the given worst-case forward passenger distribution would move the CG to 9.6 percent MAC. This is still within the airplane's certified limits.

Of greater concern are smaller operators that do not have engineering departments and mistakenly use the manufacturers' certified envelopes for load planning.

Of greater concern are smaller operators that do not have engineering departments and mistakenly use the manufacturers' certified envelopes for load planning. For example, consider a large airplane like a BBJ that has been loaded to within a few percent of the forward limit and has additional water tanks in the aft compartment that have not been filled or have faulty gauges. With 800–900 lb (363–408 kg) "missing" from the back end, the CG creeps forward. The airplane still is able to take off because AFM performance assumes the most forward limit. Soon, however, the CG will be pushed further forward when the landing gear and flaps are retracted. What happens then?

That's precisely why we have curtailments. Use of a good loading schedule helps prevent any of those variables from causing the airplane to exceed its envelope and become uncontrollable.

Magnitude of risk depends on the likelihood of a given event actually occurring. The author's probability model illustrates the intuitive notion that a particular error is less likely to occur as its severity increases. While it is possible that the worst-case distribution could happen, the given probability was 1 in 7.7×10^{160}. Those are astronomically high odds, much higher than the recently reported 1 in 5.3×10^{7} probability of being involved in an airline accident.[3]

For passenger carriers, mandating the use of actual weights and distribution probably is not necessary or even practical. It also would reduce the magnitude of the envelope curtailments commonly used as a safety margin. If certified envelopes were used in daily operations, with no accounting for probable errors, weight and distribution errors would be much more dangerous. But in current use, envelope curtailments mitigate the risks well enough to operate safely. If the loading schedule is properly constructed and adhered to, it then becomes a matter of training our personnel and being vigilant for extreme loading conditions. Mandating an actual-weight/distribution program won't change that. ●

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Notes

1. U.S. Federal Aviation Administration. Advisory Circular 120-27E, *Aircraft Weight and Balance Control*. June 10, 2005.
2. The centroid is the center of gravity of an aircraft section, such as the cabin, when passengers and/or baggage are distributed evenly in the section.
3. U.S. National Transportation Safety Board. Press release SB-06-14, "NTSB Reports Increase in Aviation Accidents in 2005." March 2006.

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.