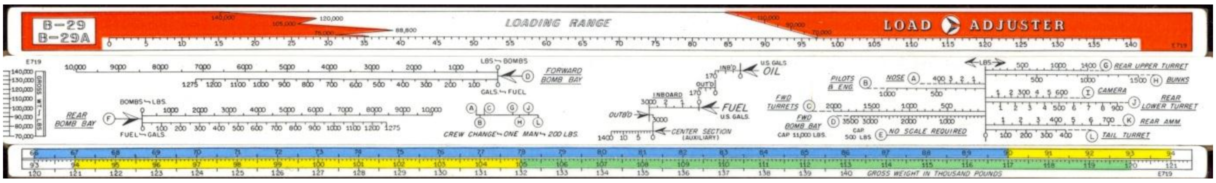
Aircraft Load Adjusters
And other slide rules for weight & Balance

Ronald van Riet

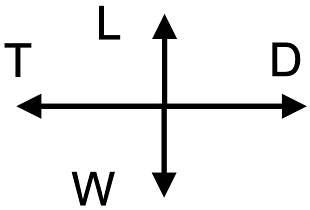


Introduction

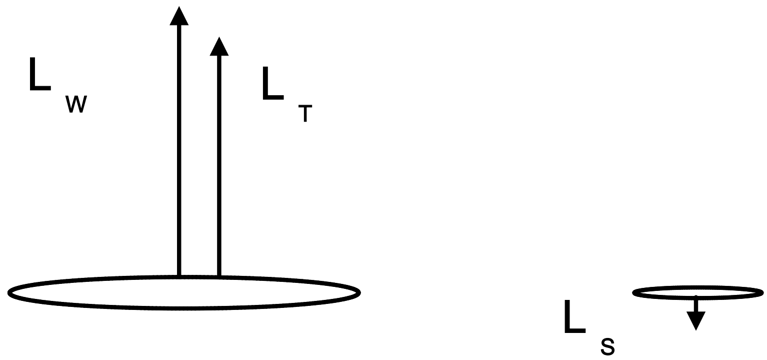
Load adjusters are well known, even though in general, little is actually known ***about*** them. They are a bit of an odd guy out in the slide rule community, in fact whether or not they ***are*** slide rules has been debated and if part of the definition of a slide rule would be the existence of a logarithmic scale, then they definitely wouldn't qualify. But according to the adage about ducks, if it has a rule, it has a slide and it has a cursor, it is hard to deny that there is something slide ruleish about them. Whatever you feel about load adjusters, with their often colorful appearance and the wide range of types available on eBay and elsewhere, they do make an interesting addition to any collection.

Application Background

For an aircraft to fly properly, i.e. it can be safely and comfortably controlled along all three axes, it is necessary that its overall weight and its center of gravity fall within limits that have been initially calculated and then confirmed by flight tests. Overall weight is largely determined by structural and power limitations: increasing the overall weight means building a stronger and therefore heavier airframe, requiring more power, which in turn is heavier and so on. The center of gravity has to coincide with the center of lift, which needs a bit more of an explanation to see why an aircraft doesn't become unstable when a passenger walks from the front to the back, effectively moving the center of gravity.



When an aircraft is in stable horizontal flight, the overall forces acting on it are in balance (a flight from right to left is assumed in the drawing): thrust T is balanced by drag D (or resistance), lift L is balanced by weight W. Lateral weight distribution will not be taken into account: most of the weight is concentrated in the fuselage and it is good practice to switch fuel tanks (normally situated in the wings) regularly between the port and starboard tanks to keep lateral weight more or less in balance. Moreover, slight lateral imbalances can easily be compensated with the ailerons.



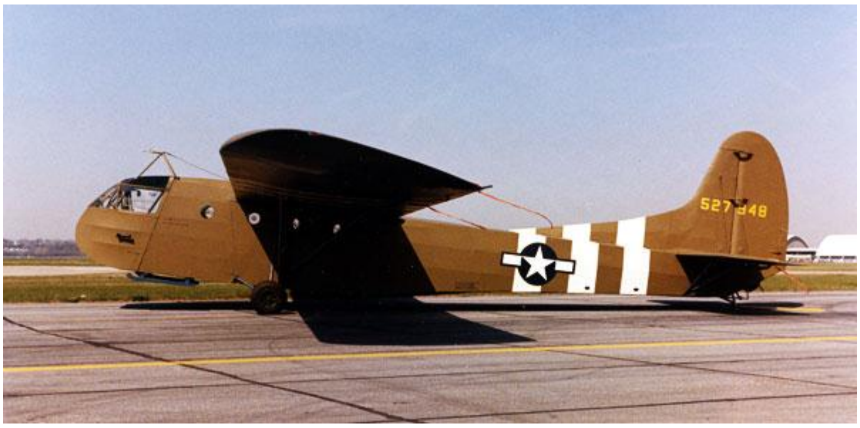
Lift is generated by the movement of air over the (curved) wing surface, and it is the combination of air speed, angle of incidence (the angle between the wing and the air stream) and parameters determined by the wing profile used, that determine how much lift is generated and where its center of lift is located along the wing cord. Now, how do we control the center of lift to cater for a changing center of gravity (like that passenger moving along)? In fact, the picture is slightly more complicated. Total lift L_T is a vector resulting from the addition of two separate lift vectors: a positive one (upward) on the wing L_W and a negative one (downward) on the horizontal stabilizer L_S.

By controlling the angle of incidence of the horizontal stabilizer, the amount of downward lift is controlled and thus the net lift vector and its center of lift. And as the negative lift from the stabilizer changes, not only does the total lift change in size, but also in its point of impact and thus it can be moved forward or backward (within limits) by changing the angle of incidence of the horizontal stabilizer. The change in total lift can be compensated by slight changes in power settings (but is often negligible).

If the angle of incidence of an aerofoil increases, lift increases, but only up to a certain point, after which the lift drops dramatically, this is called stalling the wing, and it means that there is a limit to the angle of incidence in a practical situation, effectively limiting the travel of the horizontal stabilizer. Throw in a safety margin or two and we have the practical limits that directly set the fore and aft limits of the center of lift and thus of the center of gravity. Moving the center of gravity beyond these limits means there is a risk of not being able to adjust the center of lift sufficiently and the aircraft could get out of control. In practice, the situation is a little more complex, an additional margin of safety has to be kept for turbulent weather etc. but these are the principles for all normal aircraft (tailless aircraft obviously work slightly differently).

Examples of air crashes caused by improper loading

So how dangerous is it in practice if an aircraft is not properly loaded? Let me give two examples separated in time and space.



During the D-Day landings in Normandy in June 1944, Waco CG-4 transport gliders were used to transport troops and material (howitzers, jeeps etc.) behind the enemy lines. These were rather flimsy, wood-and-fabric airplanes that were built to be used once and crash landings were more the rule than the exception. But one of these dove straight into the ground after being released from its tug plane, killing all on board, including a US Army general riding in the co-pilot's seat. Post-crash investigation showed the following: the general was afraid of anti-aircraft fire and had asked one of the mechanics to install a large steel plate below his seat. The loadmaster in charge of loading the glider didn't know about this and so to the best of his knowledge, he loaded the plane to its maximum weight with troops and equipment. But, with the steel plate, the plane was not only overweight, the center of gravity was too far forward. Now, while it took off and flew towards Normandy behind its tug plane, no serious problems arose: the tug line held the nose up without problems, but as soon as the line was cast off, the plane tipped over and bore straight down. Glider pilots didn't have much experience and even with experience, there probably wasn't much the pilot could have done to correct the situation. So a general afraid to have his crown jewels shot off, effectively caused not only his own death, but the death of all on board as well.

A second example, which made the headlines all over the world, occurred on December 12, 1985 with Arrow Air Flight 285, a commercial DC-8-63 transporting U.S. 101st Airborne troops back home from the Middle East for the holidays. It made several stopovers on the way, the last one in Gander, Newfoundland. On take-off it briefly seemed to get airborne but then crashed just after having left the runway. All 256 on board were killed. The investigation concentrated on icing and the official cause was declared to be icing, even though no other plane taking off before or after had had any serious problem due to icing. However, a few facts about this crash lead to other possibilities. First of all, the aircraft was a stretched version of the standard DC-8, actually the ultimate stretch. Stretching an aircraft means it can carry more passengers but its maximum take-off weight doesn't change by the same amount, so if you take a full load of passengers on board, you should carry less fuel. It is interesting to note that all reports about the crash mention that the flight took on fuel at Gander. Also, since this airplane was operated by a civil company, it is more than likely that the weight and balance was based on the average of 75 kg per passenger that many civil operators calculate with. The average airborne trooper is larger and heavier than that, and many of them would have bought Christmas presents which, added to their normal heavy gear, would increase the weight per person even more. So, a full load of heavier-than-average passengers and a full load of fuel could well have meant the airplane was grossly overweight and I am convinced that this is the true cause of the crash.

Read on

If the above has whetted your appetite to know more about load adjusters and see how load adjusters like the one depicted at the start of this article were used and learn about the history of the load adjusters and about the devices shown below, please visit the website https://sites.google.com/site/sliderulesite/load-adjusters where the full IM2011 version of this paper is available for download, as are the papers I have presented at earlier IMs.