A balanced approach: How weight and loading are critical for takeoff

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News

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Last week, it was reported that the incorrect loading of a Prague-bound A321 out of London Luton Airport caused “takeoff issues” for the pilots. A last-minute change was made to the aircraft operating the service, from an A320 to a longer-bodied A321. However, the passenger seating was not changed, meaning that there were more people towards the front of the aircraft than the rear.

Reaching Vr, the speed at which the pilot pulls back on the controls to rotate the aircraft into the air, the first officer pulled back on the control stick but nothing happened. He pulled harder, almost to full deflection on the control stick. Still, nothing happened.

At this point, the captain pushed the thrust levers all the way forwards giving full takeoff power. With the extra thrust, the aircraft was able to climb safely away from the runway.

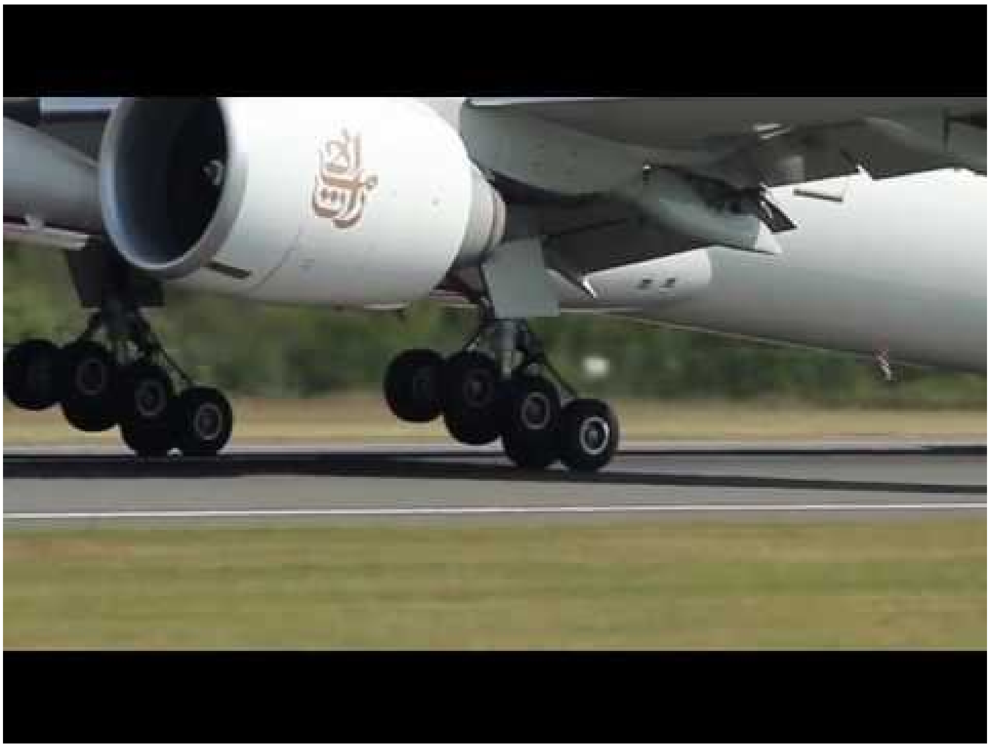
So why did this incident occur and why are the weight and balance of the aircraft so important?

Mass and balance

One of the 14 technical subjects pilots study as part of their air transport pilots licence is mass and balance. Knowing the weight of your aircraft, and critically, how it is balanced, is key to a safe flight.

When you watch an aircraft taking off, nothing really happens for the first 30 seconds or so. However, just before it gets airborne, something magical happens. The nose wheel of the aircraft lifts off the ground whilst at the same time, the tail sinks slightly lower.

However, if you look at the landing gear, there is no discernible movement. It's almost as if the aircraft is rocking back like a child's see-saw using the landing gear as the fulcrum.



Watch Video At: https://youtu.be/KFyAWHEwgVE

As the nose lifts off the ground, the tail sinks lower — just like a child's see-saw.

In the flight deck, this manoeuvre requires only gentle pressure on the controls — be it the control column on a Boeing or the side stick on an Airbus. Fly-by-wire aircraft such as these are designed so that every takeoff feels the same. If something isn't right, as the pilots out of London Luton discovered, we know about it pretty quickly.

However, the ease of the rotation doesn't happen by luck. Before every flight, careful consideration must be given to not only the total weight of the aircraft but also how the passengers, baggage and cargo are loaded.

Aircraft weight

The most obvious part of the mass and balance equation, it's important for us to know the weight of the aircraft when we take off. Not only do we use this to calculate our takeoff performance, but we also use it to work out our fuel burn for the flight and how high we can fly.

The takeoff weight of the aircraft is made up of three parts, one of them fixed and the other two variables. The basic empty weight is the fixed element, consisting of the aircraft itself, seats, engine fluids, etc. This weight remains the same for every flight.

Payload and fuel

The two variable elements are the payload (passengers, baggage and cargo) and the fuel. As these will be different for every flight, it's important that close attention is paid to them both.

If you've ever been on a small aircraft for a commercial flight, you may have had to step on a set of scales to measure your exact weight before boarding. The need for accuracy is important as the passenger weight as a percentage of the total aircraft weight is much greater than if it were on a jet airliner.

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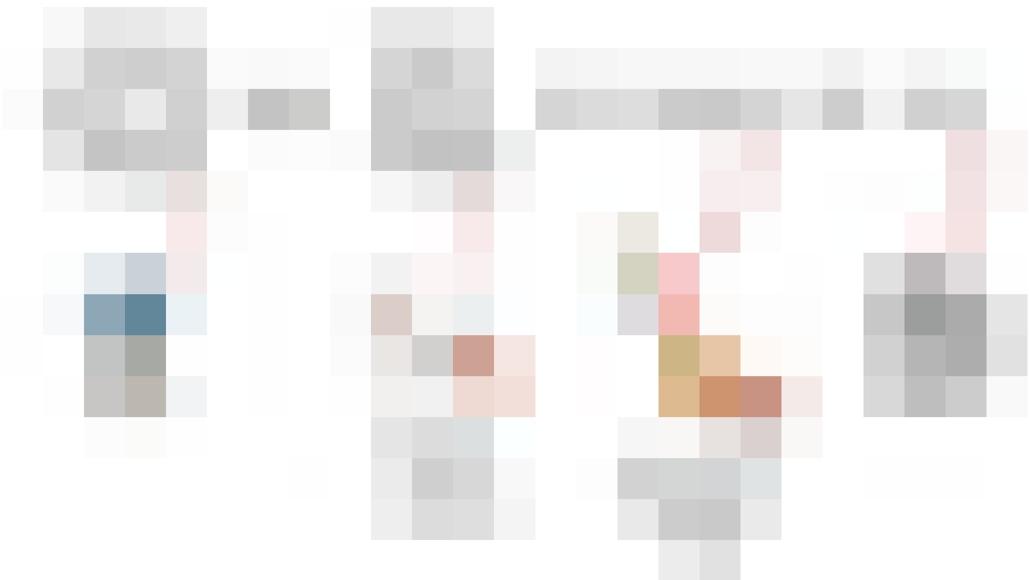

(Image by Charlie Page/The Points Guy)

In addition, attempting to weigh every single person who checks in for a flight on an aircraft such as the A380 would be time-consuming for passengers and staff alike. As a result, airlines use standard weights for adults and children, which also includes an allowance for hand baggage. Whilst not totally accurate individually, they are designed to average out to give a figure that is accurate for the total load.

The fuel required is also unique for every flight. Whatever figure the pilots chose to take must be accurately pumped into the fuel tanks

Centre of gravity

The centre of gravity (CoG) is “the point from which the weight of a body or system may be considered to act.”

For a uniform item such as a ruler, place the centre-point on your finger and it will balance. However, many other items are heavier at one end than the other. Table knives are a good example. To balance one of those on your finger, you may have to place it some distance towards one end.

When considering the three elements that make up the aircraft weight, the CoG of two of them is pretty much the same — that of the empty aircraft and the fuel in the tanks.

However, where the baggage and cargo are loaded and where the passengers are sat can have a massive effect on the position of the CoG.

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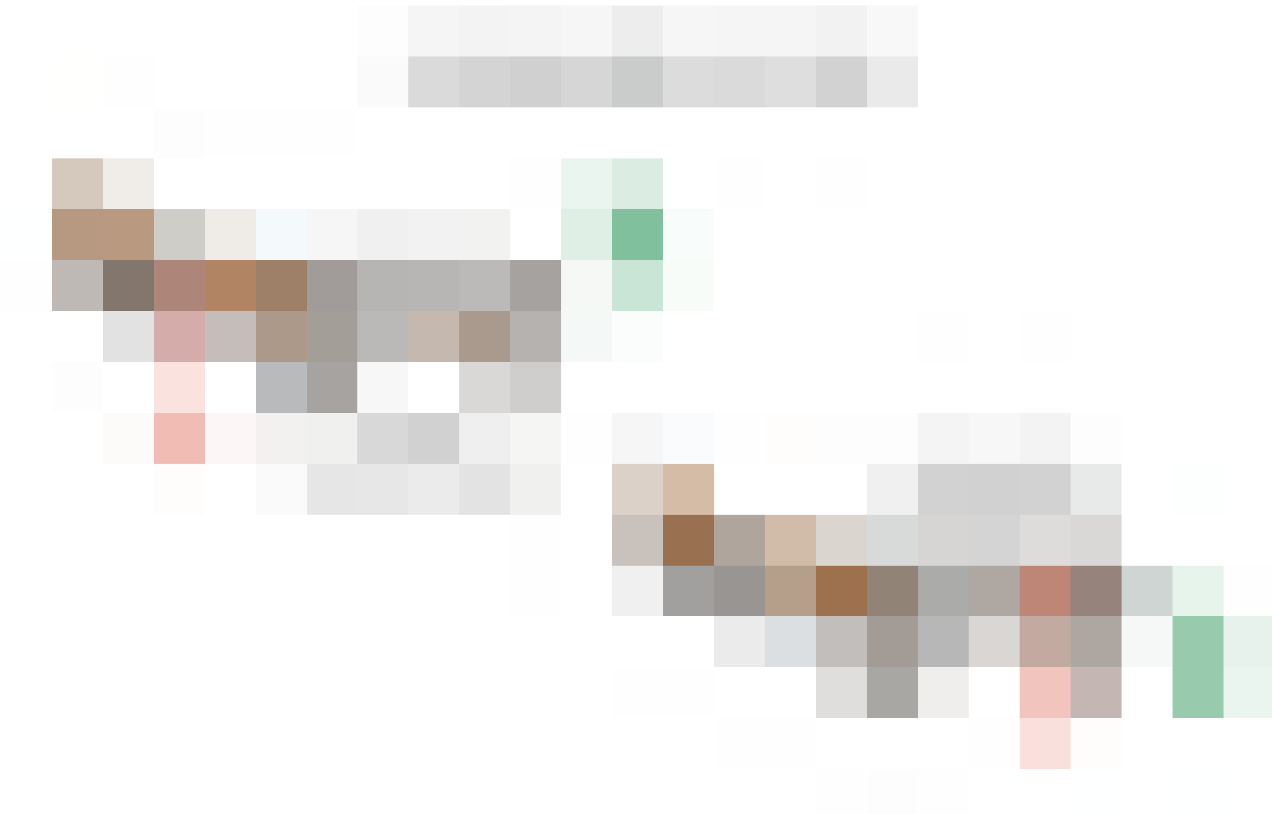


(Image by Charlie Page/The Points Guy)

Aerodynamically, airliners are most fuel-efficient with a slightly aft CoG. However, if the CoG is too far aft, there's a risk that the aircraft could tip back onto its tail. Too far forwards and you run the risk of having control issues — as the crew of this A321 found out.

As a result, the careful distribution of weight both in the cabin and in the cargo compartments is critical to a safe takeoff.

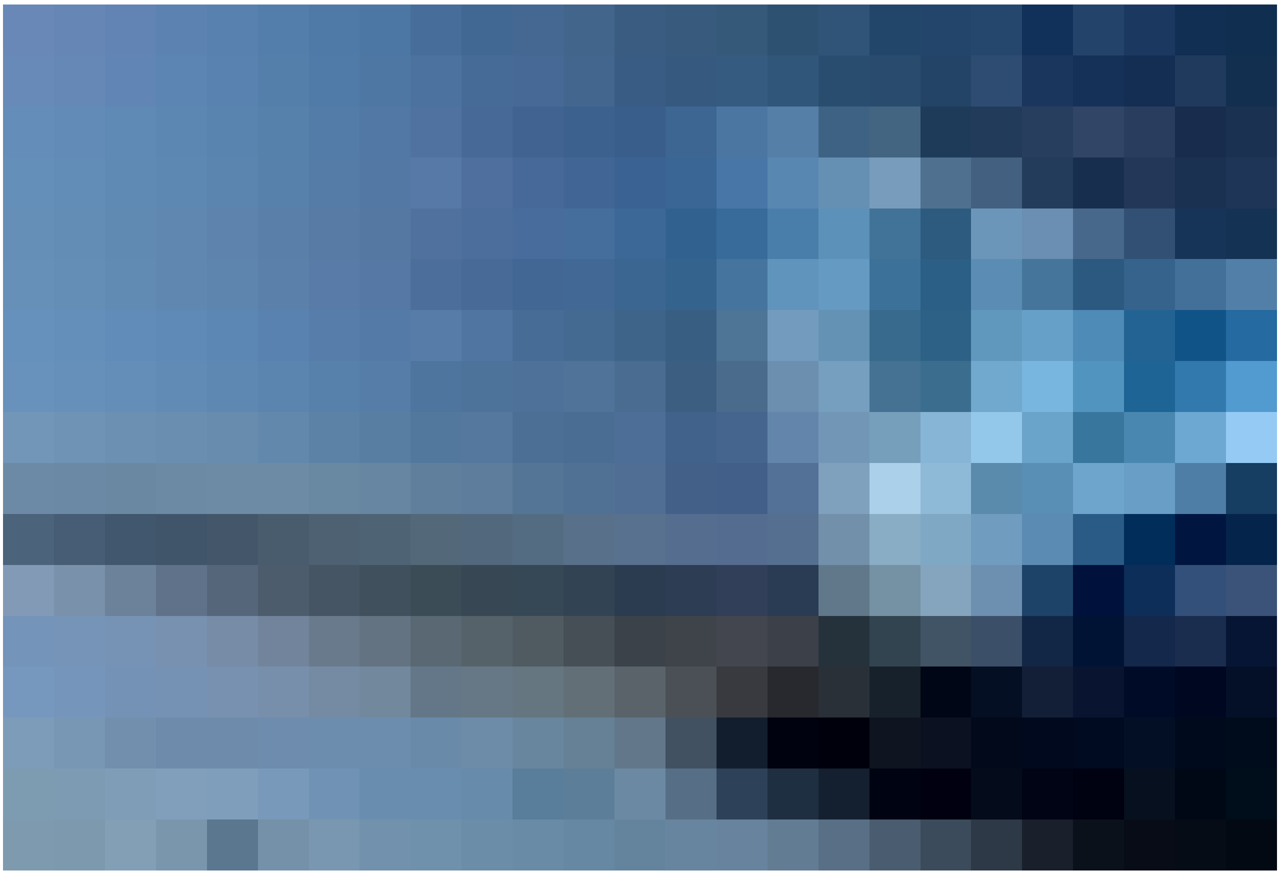
Load sheet

When flying a small single-engine propellor aircraft, it's pretty straightforward for the pilot to see how the aircraft has been loaded. However, for bigger airliners, it is not so easy.

The operations department of the airline take the passenger, baggage and cargo information and collate this with the basic empty weight of the aircraft and the fuel load as determined by the pilots.

They then feed this into a computer to calculate not only the gross weight of the aircraft but also the CoG at takeoff.

If there is an uneven distribution of passengers, for example, if the first- and business-class cabins at the front are full, but the economy section at the rear is empty, the CoG will be forwards. To counter this, baggage and cargo will be loaded into the rear cargo compartments to balance the aircraft out.



The horizontal stabiliser on the Boeing 787 Dreamliner is adjusted for each takeoff. (Photo by ERIC PIERMONT/AFP/Getty Images)

With this computer-generated plan, the baggage handlers can then load the cargo compartments accurately to ensure that an optimum CoG is achieved.

The final part of this is to let the pilots know exactly how the aircraft has been loaded by generating a load sheet. This details the aircraft registration, the flight number, date and all the relevant weights and location of the passengers and cargo.

The load sheet also indicates the location of the CoG. With this information, we then set the takeoff "trim". This changes the angle of the horizontal stabiliser at rear of the aircraft so that when we reach our Vr speed, the uniform backwards pressure we apply to the control column rotates the nose into the air as we would expect.

So how did the above incident still happen?

Incorrect trim setting

The load sheet that the operations department generated was for the correct A321 aircraft operating the flight, hence why the pilot's check would not have highlighted any discrepancies. However, the passengers had been seated as if it were an A320. This left the entire back section of the aircraft empty.

With more weight in the front of the aircraft than at the rear, the actual CoG was further forward than what the load sheet indicated. This caused the trim, which the pilots set correctly as far as they knew, to be insufficient for takeoff. As a result, when they reached Vr and pulled back on the control stick, nothing happened.

It was only the quick thinking of the captain that enabled the aircraft to get airborne before the end of the runway.

Why not just reject the takeoff?

Contrary to popular belief, aircraft very rarely use full power during takeoff. At 2.1 kilometres long, the runway at London Luton isn't the longest in the world, but still plenty long enough for an A321 to get airborne safely.

So why increase the strain on the engines when you can utilise the runway length by accelerating more slowly and still getting safely airborne by the end?

Manufacturers design the aircraft and engines to be able to get airborne using as little engine power as possible. This is known as a de-rated takeoff. Not only does it save on engine wear, but it also reduces the noise experienced by those who live and work near the airport.

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(Image by Charlie Page/ThePoints Guy)

However, this creates a trade-off. Get airborne too far down the runway and you run the risk of going off the end should something unexpected happen. Liftoff too soon and you're using more engine power than you need to be, increasing engine wear and fuel burn.

A sensible medium needs to be found between the two — a takeoff point which optimises engine power whilst leaving enough runway to stop if the need arises.

The critical speed: V1

V1 is the speed at which the aircraft can both reject the takeoff, stopping safely on the runway and also at which it can continue to takeoff safely. To put this into more practical terms, the European Aviation Safety Agency (EASA) and the Federal Aviation Administration (FAA) defines V1 as "the maximum speed during takeoff at which the pilot must take the first action to stop the aircraft."

It is often referred to as the "takeoff decision speed," but this isn't totally accurate. The actual decision to reject the takeoff must be made before V1 has been reached. This gives the pilot enough time to react and make the first action to reject the takeoff before the aircraft reaches the V1 speed. In the case of this Prague-bound A321, the V1 speed was 112 knots.

If the decision to stop is made at V1, by the time the first action is taken to stop, the aircraft will be travelling in excess of the V1 speed, putting it at risk of going off the end of the runway. Seeing as some runways finish in the sea or with steep embankments, as it does at London Luton, this is undesirable, to say the least.

The V1 for any departure will depend on a range of variables such as aircraft weight, runway length, air pressure, air temperature and wind speed and direction. It also varies with the runway condition. If a runway is dry, the stopping efficiency is much better than if the runway is wet or slippery. As a result, the V1 will be slower on a wet runway – as was the case in this example.

This means there will be more runway remaining on which to stop when the V1 speed is reached. If a problem occurs after V1, we must continue to get airborne. Even in the event of an engine failure, we can still climb away safely. The performance which we calculate before departure is based on this very event.

The rotation speed: Vr

The next critical speed after V1 is the speed at which the pilot flying pulls gently back on the control stick to rotate the aircraft nose into the air. This is known as Vr (rotate) and, by definition, must always be greater than or equal to V1. In the London Luton incident, the VR for that departure was 123 knots.

However, the pilots only realised that they had a problem once they had reached Vr — 11 knots beyond their V1 speed. As a result, they did not have the option to reject the takeoff. Had they done so, there was a very real risk that they would not stop before the end of the runway.

Bottom line

The way in which an aircraft is loaded is critical to the safety of the flight. Too heavy at the rear and it could tip onto its tail. Too heavy at the front and the pilots will struggle to get the aircraft airborne. As a result, cargo and baggage are loaded in a way in which they will balance out how passengers are sat in the cabin.

The load sheet provides the pilots with information as to how the aircraft has been loaded. From this, we are able to set the trim of the horizontal stabiliser to ensure that all takeoffs handle in the same way.

Featured photo by Pierre-Yves Babelon/Getty Images

Charlie Page Charlie Page is an airline pilot flying the Boeing 787 Dreamliner. Each Saturday he gives you a 'behind the cockpit door' insight to life in the flight deck.