Aircraft Vortices, Condensation and Contrails – an overview

Perhaps the most common view of an airliner flying overhead is of a cruising aircraft at altitude with white trails being left behind in the sky tracing its path.

These trails are known as contrails and are a result of water vapour, produced as a product of combustion, being ejected from the aircraft engines. This phenomena was first observed and widely commented on as a result of high altitude combat between fighters and bombers during the Second World War. This reflects that the conventional aircraft piston engine also produces water vapour in its exhaust and is equally capable of producing a contrail in high altitude flight.

When an aircraft flies, its wing supports the aircraft by creating a low pressure on the upper surface of the wing and an increased pressure on the lower surface. The difference between these forces produces an upward force, the lift, which supports the aircraft in flight and in manoeuvres.

At the wing tips, the high pressure below the wing and low pressure above the wing interact to produce a rapidly rotating vortex (the tip vortex) that trails behind the aircraft. This vortex is increased in strength at high aircraft weights and when the aircraft is manoeuvring or ‘pulling g’.

The pressure inside the rapidly-rotating vortex is reduced and, in humid conditions, may result in condensation making the tip vortex visible as a white trail from the wing tips. This is due to the local combination of temperature and pressure becoming lower than the ‘dew point’, resulting in visible condensation of water vapour from the atmosphere. This is visible in the photograph of the manoeuvring Hawker Hunter, above.

The tip vortex phenomena is not just restricted to the wing tip, but also occurs at the tips of heavily loaded propellers (and helicopter rotors) in suitable conditions, as illustrated below.


Above: Propeller tip vortices on a DC-3 and C-130 Hercules taking off

At high weights and when manoeuvring hard (pulling high-g) humid conditions may allow the general low pressure field above the wing to produce a visible ‘cloud’ of condensation above the wing. This is illustrated below with airshow pictures of a Hawker Sea Fury fighter and an Airbus A380 commercial transport aircraft.


Both aircraft are also trailing tip vortices and the Airbus also has vortices springing from small sharply swept plates fixed to the engine nacelles. These vortices help to maintain attached flow on the wing behind the engines, which would otherwise be disturbed at high incidence by the flows around the engine nacelles. Notice the condensation on the A380 trailing as a sheet behind the wing.

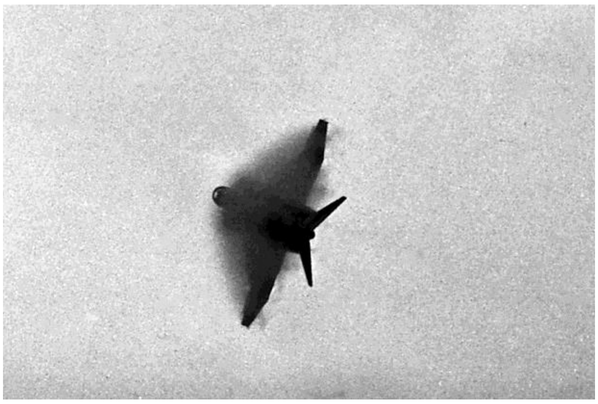
The two illustrations below show similar phenomena on modern jet fighters, the F-15 and F/A-18E.

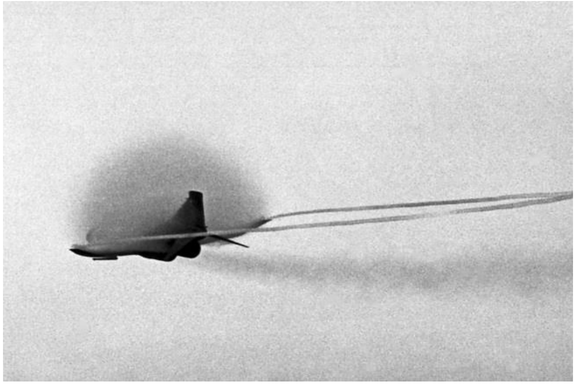
In the case of the F/A-18E (right), there is also a pair of very strong vortices sat above the aircraft wing roots. These are generated by a sharply-swept extension of the inboard wing leading edge (a strake), which produces this large vortex structure (with associated visible condensation) at high angles of attack. This is the same mechanism that is used to produce the vortices from the A380 engine nacelles.

The large vortex structure generates suction over the wing, allowing lift to be generated at high angles of attack at which the wing would normally stall and increasing the aircrafts manoeuvre capability. The same mechanism was used to provide the majority of the low speed lift for Concorde and resulted in the high nose up attitude of that aircraft when on the landing approach.

Both aircraft are trailing tip vortices, which are noticeably ‘wriggly’ behind the aircraft. This distortion is cause by a phenomenon known as the ‘Crow instability’, which I don’t propose to detail here (look it up on Wikipedia). Basically if one vortex is displaced up, or down it produces a lateral displacement of the other vortex and far behind the aircraft this may cause the vortices to meet in a series of loops that dissipate their strength. The photo below is an example of the Crow instability in the contrail of a Boeing 747, well behind the aircraft.

At very high transonic speeds, shock waves form around the body and wings off an aircraft. There is a sudden drop of pressure behind the shock wave, which may produce a further condensation cloud, as shown below in two impressive photographs of manoeuvring F-4 Phantom aircraft, again photographed at air shows.





The aircraft on the right, above, displays a very clear set of tip vortices in addition to the semi-circular condensation cloud due to the transonic shock wave.

My last example is a rather beautiful ‘rainbow’ contrail behind a British Airways Boeing 777-300 airliner. This photograph was taken at around 1300 local on 18 July 2015 at Henstridge, Somerset, UK. The aircraft was flying from East to West and, when first seen, was only producing an intermittent contrail.
As the aircraft started to fly pass over an area of cloud, it started to produce a visible condensation cloud trailing behind the whole wing – as with the A380 illustrated earlier.

On examining the image, it can be seen that the particles in this contrail wake are interacting with the sunlight that is illuminating the wake to produce a dramatic rainbow effect in the contrail.

One of nature’s works of art!

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