

# Technical Comments

## Comment on "Aerodynamic Penalties of Heavy Rain on Landing Airplanes"

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**I**N an interesting paper,<sup>1</sup> Haines and Luers have discussed the aerodynamic penalties of heavy rain on aircraft. However, they have not mentioned one possible beneficial effect of rain: the ingestion of rain by the aircraft engines, leading to thrust augmentation. Of course, rain on the inlet aerodynamic surfaces within the engine may well lead to penalties similar to those on the wing, fuselage, etc., that is, an increase in roughness due to the water film's waviness and water drops' impact. However, water addition to the hot gases within the engine for thrust augmentation is a well-established procedure (either at intake or in the combustion chamber)<sup>2</sup>; and the ingested rain could act in a similar manner. Its effect should be estimated to obtain a total picture of the effect of rain on the aircraft's performance.

For a rainfall rate of 500 mm/h, Haines and Luers estimate a liquid water content of 15.3 g/m<sup>3</sup>. With a mass flow rate of 20 kg/s (representative value), this would mean an excess thrust (through greater density of airflow) of about 1.5%, at landing conditions. Momentum losses (estimated around 1%) by the raindrops hitting the aircraft should therefore easily be compensated.

Depending on the control system of the engine, cooling of the hot gases within the engine by the rain ingestion could also lead to greater fuel addition and larger possible thrusts.

The net effect of rain ingestion on aircraft engines needs further careful study; it seems, however, to be significant. Another interesting study would be that of the aerodynamic penalties of rain on high-speed ground transport; for which, penalties of increased drag and greater fuel consumption are to be expected.

### References

<sup>1</sup>Haines, P. and Luers, J., "Aerodynamic Penalties of Heavy Rain on Landing Airplanes," *Journal of Aircraft*, Vol. 20, Feb. 1983, pp. 111-119.

<sup>2</sup>Schlottel, R. H., "The Aircraft Applications," *Gas Turbine Principles and Practices*, edited by H. R. Cox, George Newnes Limited, London, 1955, pp. 86-88.

## Reply by Authors to G. Rajen

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**R**AJEN has introduced an interesting aspect of heavy rain that was not considered in our work on the aerodynamic penalties of heavy rain on aircraft. We do consider rain ingestion as an important topic, especially in regard to its effect on aircraft engine thrust. Rajen's comment implies that rain will always augment engine thrust. In talking with propulsion experts,<sup>1</sup> the advantages of water ingestion derive from deliberate design of the engine. Jet engines usually are not designed for thrust augmentation from heavy rain, and a mismatch in the compressor stators due to the effects of heavy rain could actually lead to decreased engine performance or even to engine stall. In addition, ingested rain contributes to the so-called ram drag, which would not be the case for engines designed for water ingestion using water stored in the vehicle. It is therefore very difficult to assign any figure to a possible thrust augmentation from rain ingestion by jet aircraft engines, and, in fact, there may be a net decrease in engine performance.

The momentum losses estimated for a rainfall rate of 500 mm/h are about 2.25% of maximum thrust. This estimate did not incorporate leading-edge slats or extended flaps, which should increase the water catch rate and momentum loss of the aircraft. In addition, an aircraft in the landing configuration expends only about one-half of maximum thrust with a spoolup time to maximum thrust of several seconds. The relevant momentum loss percentage is therefore about 5% or greater. Finally, it should be remembered that we consider the most important effect of the rain to be the aerodynamic roughness, and any change of engine performance ought to be compared to the aerodynamic effects as well.

### Reference

<sup>1</sup>Von Ohain, H., University of Dayton Research Institute, Dayton, Ohio, personal communication, 1983.