Docket No. **SA-509**

Exhibit No. 2E

NATIONAL TRANSPORTATION SAFETY BOARD

WASHINGTON, D.C.

USAIR DC-9 PILOT'S HANDBOOK
SEVERE PRECIPITATION

SEVERE PRECIPITATION

AVOIDANCE

Flight crews should carefully evaluate all available weather information for the purpose of avoiding unusually severe storms with extreme precipitation. Avoidance of these severe storms is the only measure assured to be effective in preventing exposure to multiple engine damage.

During an unavoidable encounter with severe rain or ice in flight, the following procedure should be used:

— IGNITION — OVRD.

— ENGINE ANTI-ICE — ON.

— AIRFOIL ANTI-ICE — ON.

— APU — START.

— COMMUNICATIONS — USE #1 VHF TRANSCEIVER.

Slow to turbulence penetration speed, using speedbrakes as necessary. Use smooth power changes, maintain thrust as high as possible.

In extremely heavy precipitation, try not to make throttle changes, trade altitude for airspeed if possible. If thrust must be changed, move throttle slowly. Do not reverse direction of throttle movement until RPM stabilizes.

If throttles are at IDLE when extreme precipitation is encountered, wait for N_2 spool-down. Delay advancing throttles for as long as possible, then advance throttles one at a time. If no N_2 response is seen, return throttles to IDLE until N_2 RPM is normal idle.

ICE AND WATER INGESTION BY TURBINE ENGINES

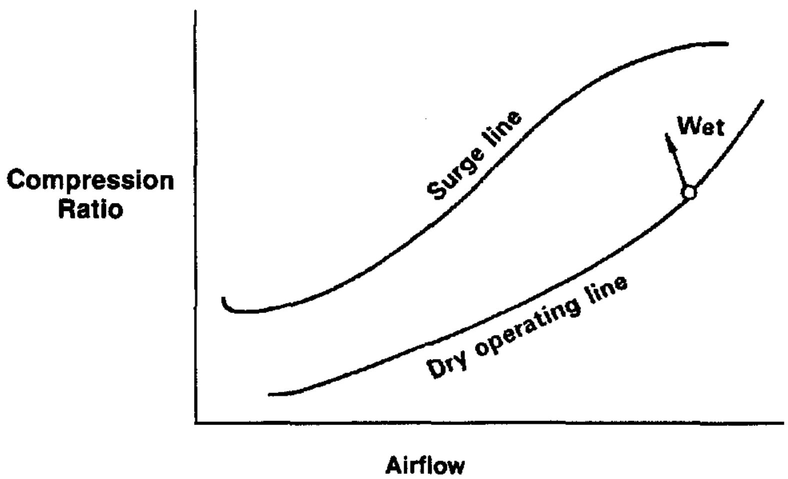
Recent incidents have raised questions concerning the ingestion of water and ice particles by turbine engines. The following will explain the effects of this ingestion on engine operation and offer techniques to reduce its impact.

The complicated and varied interactions that determine the effects of water ingestion on turbine engine operation preclude detailed quantitative engine module by module analysis. The magnitude of the shifts in gas generator performance will vary depending on the particular circumstances. However, the overall qualitative changes in engine operation resulting from the ingestion of water through the engine are listed below for a constant throttle position.

ICE AND WATER INGESTION BY TURBINE ENGINES (cont'd.)

— N_1 & N_2:	May or may not be affected — Depends on engine control mode and amount of water ingested.
— EGT:	Decreases
— Fuel Flow:	Increases
— Surge:	Increased possibility
— Flameout:	Increased possibility

Ingestion of water in liquid or solid form will affect engine operation because of the higher specific heat of water and the latent heat of vaporization associated with evaporation. When flying through heavy rain storms, the compressors of a dual compressor engine are "rematched" by the water ingested. The reason for this is that when the water is vaporized within the engine, it absorbs about 1,000 BTU per pound of water from the air passing through the engine, effectively reducing the air temperature in the downstream stages of the compressor and in the combustion chamber. The ingestion of ice further increases the cooling in the compressors as it absorbs heat while melting into water and then more heat as it evaporates. The degree of rematch is, of course, proportional to the water/air ratio and the compressor design. The compressor rematch moves the high pressure compressor operating line toward the surge line, thus causing the compressor to be more susceptible to surge (see the following illustration).

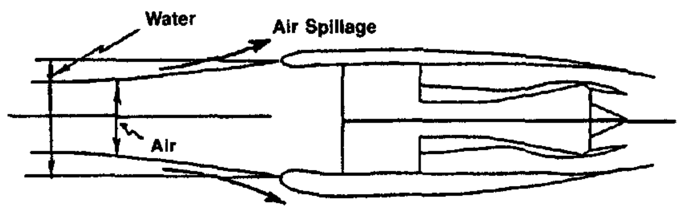


(High Pressure Compressor)

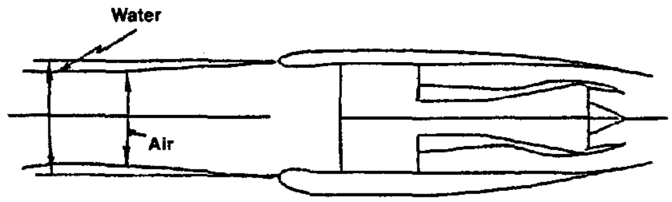
ICE AND WATER INGESTION BY TURBINE ENGINES (cont'd.)

In addition, the compressor and engine response may be affected by the water as the aerodynamics, tip clearance and sensed control parameters become modified. If sufficient water is ingested, compressor surge or engine flameout may occur.

The engine inlet size basically determines the capture area for water ingestion. However, the amount of air ingested depends upon aircraft and engine speed. At high aircraft speeds and low engine RPM more air is being forced into the inlet than the engine requires. Thus, air is spilled out of the inlet which effectively reduces the size of the column of air being ingested. The water droplets, being heavy, are not ejected and the result is an increased water/air ratio. On a typical high bypass ratio engine, this "scoop factor" during idle descent increases the water/air ratio by as much as 200%. Increasing engine RPM increases the airflow requirement while maintaining the same area for water ingestion. Reducing aircraft speed will also reduce air spillage around the inlet. This combination significantly reduces the water/air ratio as illustrated in the following diagram.



Inlet air spillage at low engine RPM/high aircraft speed increases engine face water/air ratio.



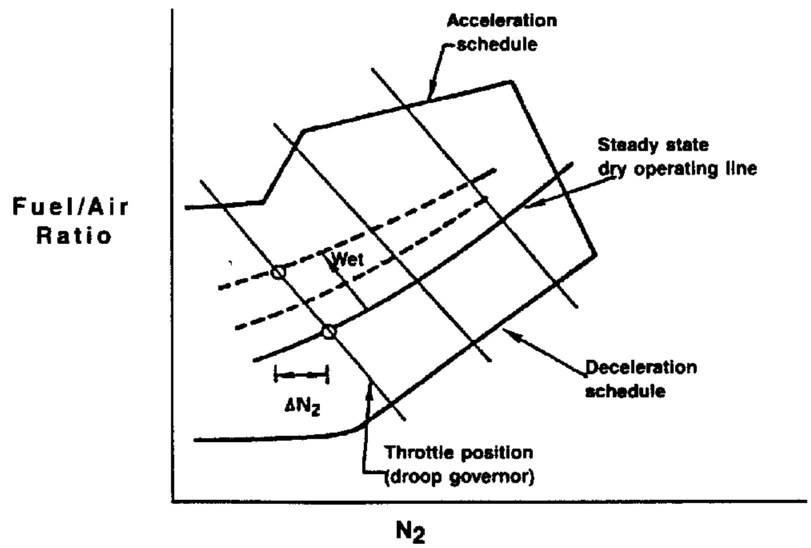
High engine RPM/low aircraft speed decreases engine face water/air ratio by reducing air spillage.

(Scoop Factor)

ICE AND WATER INGESTION BY TURBINE ENGINES (cont'd.)

The effect of water ingestion on the engine response varies depending on the type of fuel control installed on the engine. Earlier model engines, such as the JT8D and JT9D, use a control with a droop governing mode.

The following diagram illustrates the effect of water ingestion on the fuel control schedules for engines which use droop governing controls. The dashed lines represent fuel required (operating) lines for various rates of water ingestion. As the water/air ratio is increased the operating line moves upwards toward the acceleration schedule. The higher the operating line the more fuel is required to run steady-state. It is apparent from the slope of the lines of constant throttle position on the diagram that a rise in the operating line results in a loss in N_2 speed when throttle position remains fixed. The acceleration schedule represents the maximum fuel/air ratio available to the engine. As the operating line rises, it can, under the most severe situation, reach the accel schedule, at which point the fuel control would be unable to deliver additional fuel to accommodate the increasing water ingestion. Under this condition, the engine would spool down to the point where the maximum fuel flow available was sufficient to operate the engine steady state. This would eventually result in spool down below idle, loss of the throttle response and loss of aircraft electrical power if the generator drops off the line. As the aircraft leaves the area of heavy precipitation, the water/air ratio would decrease and the fuel required line would lower, allowing the engine to re-accelerate to the original set speed providing surge or flameout has not occurred as a result of the water ingestion.



N_2 decay due to water ingestion at constant throttle position

(Typical Engine Control Characteristics)

ICE AND WATER INGESTION BY TURBINE ENGINES (cont'd.)

The engine response to throttle movement varies depending on the direction the throttle is moved.

THROTTLE ADVANCE — As the fuel control operating line rises due to the increasing water ingestion, the margin between the operating line and the acceleration schedule is reduced. The engine will respond sluggishly to an acceleration command from the throttle because of the reduced "overfueling" capability of the control.

THROTTLE RETARD — As the operating line rises, the margin between the operating line and the deceleration schedule is increased and the engine response to a throttle position decrease is more rapid than normal. This could result in a sub-idle condition and possible engine flameout.

In summary, the ingestion of water by a turbine engine results in the following:

— Reduced surge margin.

— Possible engine spooldown to sub-idle.

— Possible engine flameout.

— Sluggish response to throttle advance and rapid response to throttle retard.

Severe storms should be avoided. Typically the highest water concentration exists between 15,000 and 20,000 feet altitude. If flight must be made in extreme precipitation, the following techniques are recommended:

— Turn on ingestion system to protect against engine flameout.

— Turn autothrottles off to avoid rapid throttle movements and protect against engine spooldown.

— Reduce aircraft speed and increase engine RPM to reduce water/ice ratio, increase engine energy to deal with water evaporation and protect against spooldown. This condition is most prevalent when at low thrust during descent and holding operation.

— Avoid rapid throttle movements to reduce possibility of engine surge. If thrust changes are necessary move throttles very slowly and do not change throttle direction until the engine has stabilized.

These procedures are most effective if initiated prior to extreme precipitation.