Episode Book

EPISODE #5561

Fog, Light, and the Limits of Sight

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SYNOPSIS

Daniel grew up watching planes emerge from the murk at Cork Airport, and he wrote in with four questions about fog: how it forms so suddenly, what it does to light, what the realistic minimum is for driving, and how it affects airport operations and ILS approaches. This episode works through all four, starting with the physics of saturation and temperature inversions, then Koschmieder's law and the theoretical limit of sight in the cleanest possible air. Along the way: why fog makes things flatter rather than darker, why a foggy morning sounds like a low-pass filter, and why "what's the minimum visibility for driving" is a malformed question.

TRANSCRIPT



Corn

Daniel grew up near Cork Airport, and he spent a lot of childhood afternoons out watching the planes come out of the murk on the ILS. He wrote in this week with something he remembers from the road rather than the apron. Driving around the airport when visibility just collapsed, dropping so fast you could barely make out the car in front of you.



Herman

Which is the thing that gets people. Not the fog itself, the speed of it.



Corn

Right, and he's got four questions stacked up. How fog forms and why it sets in so suddenly in a place like Cork. How fog physically degrades visibility, and what the theoretical limit of sight actually is. What the realistic minimum is for driving a car safely. And how all of it affects ground operations and landings at airports, including ILS approaches and ceiling and fog minima.



Herman

Four questions, and they're all the same question wearing different hats.



Corn

So let's start with the mechanism, because the reason it feels sudden is baked into the physics.



Herman

Fog is a cloud. That's the first thing to get straight, and it's the thing most people never quite internalize. It's a visible aerosol of tiny water droplets suspended near the surface, effectively a low-lying stratus deck that happens to be sitting where you're driving. The international definition is a visibility reduction below one kilometer. Mist is one to two kilometers. Haze is two to five.



Corn

So the line between fog and mist is a kilometer.



Herman

By convention, yes. And it's a convention, not a physical cliff. Nothing changes in the air at nine hundred and ninety-nine meters.



Corn

It just becomes somebody's problem at a thousand.



Herman

The mechanism underneath is saturation. Fog forms when the air temperature and the dew point differ by less than about two and a half degrees Celsius. The air is nearly saturated, and once it crosses that line, water vapor condenses onto condensation nuclei. Dust, salt, ice crystals, whatever's floating around. What you get is a stable cloud deck trapped beneath warmer air.



Corn

Trapped is doing work in that sentence.



Herman

It is. A temperature inversion is what holds it down. Warmer air above, cooler air below, and the two don't want to mix. That's why fog sits there instead of just rising away like a normal cloud.



Corn

And there are different routes to that same endpoint.



Herman

Four that matter here. Radiation fog, which forms after sunset under clear, calm skies as the ground radiates its heat away. Advection fog, where moist air moves horizontally over a cooler surface and gets chilled from below. Up-slope fog, or hill fog, where wind pushes air up a slope and it cools adiabatically until the moisture condenses. And valley fog, which is really a special case of radiation fog where cold air drains downhill and pools in low ground.



Corn

Cork gets all four.



Herman

Cork gets all four, and that's not an accident. The airport sits at a hundred and fifty-three meters, five hundred and two feet, on high ground south of the city. It's exposed to Atlantic moisture on one side and hilly terrain on the other. The airport's own documentation describes it as sometimes prone to fog and a low cloud ceiling. That's a polite way of saying it's a fog magnet.



Corn

Let's take radiation fog first, because that's the one that ambushes drivers.



Herman

It's the classic sudden fog. After sunset, clear skies, no wind. The ground radiates heat away into space, and the air immediately above it cools by conduction. You get a temperature inversion forming right at the surface, and once the temperature hits the dew point, you have fog. It can go from nothing to dense in minutes.



Corn

Minutes.



Herman

The counterintuitive part is when it's thickest. Not at midnight. Shortly after sunrise.



Corn

That seems backwards.



Herman

It's the turbulence. The sun comes up and starts heating the ground, which starts stirring the air, which mixes the fog layer upward before there's enough energy to actually evaporate the droplets. So you get this window right after dawn where the fog is at its worst. It's also most common in late autumn and winter, when the nights are long enough for the ground to cool properly.



Corn

So the fog that catches the morning commute is the fog that's been forming all night and peaks right when everyone's on the road.



Herman

And it pools. Cold air drains into low ground, so a valley or a hollow will have fog when the ridge above it is clear. Which is why a driver can be on a perfectly clear stretch of road and then drop into a hollow and be in soup.



Corn

That's Daniel's memory exactly. You're driving along, and then you're not.



Herman

Advection fog is the second mechanism, and it behaves completely differently. Moist air moves horizontally over a cooler surface and gets cooled from below. This is the dominant mechanism for coastal fog. The Irish Sea haar, the fret off the south coast. And critically, advection fog doesn't need calm conditions. It can persist with wind.



Corn

Which makes it harder to shift.



Herman

Much harder. Radiation fog burns off when the sun gets high enough. Advection fog can sit there for days if the wind keeps feeding moist air over cold water or cold ground.



Corn

And then up-slope fog is the one that's specifically Cork's problem.



Herman

That's the orographic piece. Wind blows air up a slope, the air expands and cools adiabatically, and once it hits saturation, the moisture condenses. That's the mechanism that turns a hill into a fog factory. Cork Airport's elevation means it's catching air that's been lifted over terrain, and the terrain around it is exactly the kind that produces cold-air drainage into the valleys below.



Corn

So you've got the airport up on the hill in the fog, and the roads below it in the valleys, also in the fog, for different reasons.



Herman

Same fog, two mechanisms. Which is why the area around Cork is so consistently bad. You've got Atlantic moisture, you've got hilly terrain producing orographic lift, you've got cold-air drainage into low ground, and you've got an exposed airport at a hundred and fifty-three meters sitting in the middle of it.



Corn

And that's why the airport has spent money on it.



Herman

The ILS has been upgraded to Category II, and the main runway was extended by three hundred and five meters. The airport's own account is that this significantly reduced the number of diversions. But in severe weather it still diverts to Shannon, Dublin, or Kerry. The upgrade bought margin, not immunity.



Corn

So that's how the fog gets there. What does it actually do to the light?



Herman

This is where it gets elegant, and it comes down to one equation. Visibility in fog is governed by the Beer-Lambert law applied to visual contrast. For a perfectly black object against a bright background, the contrast decays exponentially with distance.



Corn

Exponential.



Herman

The contrast at distance x is e to the minus b-ext times x, where b-ext is the extinction coefficient. That's the total attenuation from scattering plus absorption. Everything else in this episode falls out of that one number.



Corn

So the question becomes, at what contrast does the eye give up?



Herman

Lab experiments put the human contrast detection threshold between about zero point zero one eight and zero point zero three under typical daylight. The standard convention uses two percent. So you set the contrast to zero point zero two and solve.



Corn

And that gives you the constant.



Herman

Three point nine one two divided by b-ext. The three point nine one two is just minus the natural log of zero point zero two. That's Koschmieder's law, and it's the theoretical limit of sight in any given fog.



Corn

So visibility isn't a property of the fog in some vague sense. It's a specific number you can calculate from the extinction coefficient.



Herman

And it lets you ask the question Daniel actually asked, which is what the theoretical limit of sight is. Not in fog. In the cleanest air possible.



Corn

Which is a real number.



Herman

It is. At sea level, a pure Rayleigh atmosphere, which is just molecular scattering with nothing else in it, has an extinction coefficient of about thirteen point two times ten to the minus six per meter at five hundred and twenty nanometers. Plug that in and you get roughly two hundred and ninety-six kilometers. About a hundred and eighty-four miles.



Corn

So even in a perfectly clean atmosphere, you can't see past about three hundred kilometers.



Herman

That's the ceiling. The atmosphere itself eats the contrast. In practice, extremely clean Arctic air gets you to about two hundred and forty kilometers, a hundred and fifty miles, and that's about as good as it ever gets on this planet.



Corn

Which means the horizon you can see is never the horizon.



Herman

The planet curves away before the air does, in most cases. But the point stands. There's a hard limit, and it's set by the same physics that sets the limit in fog. Just with a much smaller extinction coefficient.



Corn

Now, why is fog so much more effective at killing visibility than the numbers might suggest?



Herman

Droplet size. Fog droplets run from about one to a hundred micrometers in diameter. That's comparable to or larger than the wavelength of visible light, which puts you squarely in Mie scattering territory. And Mie scattering is brutal compared to Rayleigh scattering.



Corn

What does that mean in practice?



Herman

It means the droplets do two things at once. They scatter light out of your line of sight, which dims the object. And they scatter ambient light into your line of sight, which adds a grey wash on top of everything. So you're losing contrast from both directions at the same time.



Corn

That's why fog doesn't just make things darker.



Herman

It makes them flatter. A black car in fog doesn't look like a black car that's been dimmed. It looks like a slightly darker grey patch against a slightly lighter grey background, and the difference between the two shrinks with every meter. That's what destroys visibility. The loss of contrast.



Corn

Which is why the eye gives up long before the object is actually invisible.



Herman

Right. The object is still there, still reflecting photons. Your visual system just can't tell it apart from the background anymore.



Corn

There's a side effect here that I want to get into, because it's the part of fog that people notice without knowing why.



Herman

Sound.



Corn

Fog sounds different.



Herman

It does, and there are two mechanisms. The small droplets damp high-pitched sounds, which is why foghorns use low tones. Low frequencies punch through the droplet field; high frequencies get absorbed. And then the temperature inversion reflects sound back toward the ground, which extends how far low-frequency sound carries.



Corn

So in fog, you lose the treble and you gain range on the bass.



Herman

Which is why a foggy morning sounds like the world has been put through a low-pass filter. It's not your imagination. The physics is doing it.



Corn

Okay. So we know what fog does to a photon. What does it do to a driver?



Herman

The blunt answer, and I want to be careful here because this is the question people get wrong, is that there is no safe minimum visibility. There's only a speed at which you can stop within the distance you can see.



Corn

Say that again, because I think that's the whole thing.



Herman

The governing principle is stopping sight distance. You have to be able to stop before you reach an obstacle you can just barely see. That's it. That's the rule. Everything else is a consequence.



Corn

So the question "what's the minimum visibility for driving" is malformed.



Herman

It's malformed because it's missing a variable. Visibility tells you how far you can see. It doesn't tell you how fast you should be going, because that depends on your brakes, your tires, the road surface, the grade, the curve. Two drivers in the same fog at the same speed are not in the same situation.



Corn

And there's a practical floor anyway.



Herman

Below a hundred meters, meteorological convention treats visibility as effectively zero. Roads get closed. Automatic warning signs activate. Dense fog advisories from the National Weather Service in the US advise motorists to avoid travel entirely until the fog dissipates. That's the point where the correct answer stops being "slow down" and becomes "get off the road."



Corn

There's actual research on the speed question.



Herman

There is, and it's more interesting than you'd expect. A driving simulator study published in Traffic Injury Prevention in twenty twenty, Wang and colleagues, thirty participants, five simulator trials each, varying visibility, curve radius, and gradient. They measured normalized heart rate as a proxy for driver workload.



Corn

And what moved the needle?



Herman

All four variables. Speed, visibility, curve radius, gradient. Higher speed raised heart rate. Steeper grade raised it. Tighter curves raised it. Reduced visibility raised it. And the study built a model of maximum acceptable speed as a function of visibility and road geometry.



Corn

So the safe speed isn't a number. It's a surface.



Herman

It's a surface over three axes. Visibility, curvature, gradient. And the practical implication is that the driver who's doing forty in fog on a straight flat road and the driver doing forty in fog on a curving downhill are not making the same decision, even though the speedometer reads the same.



Corn

Which brings us to the thing that actually kills people.



Herman

The perceptual trap. Fog removes the peripheral visual flow that drivers use to gauge speed. You know how you can feel your speed from the way the roadside moves past you? Fog deletes that. So drivers under-estimate their speed and over-estimate how far they can see.



Corn

Both errors point the same direction.



Herman

Both errors push you faster than you should be going. And that's why fog produces the pile-up. The chain-reaction crash where dozens of cars pile into a fog bank. It's not that any one driver is being reckless. It's that every driver in the chain is running on corrupted speed information.



Corn

The fog doesn't just hide the hazard. It hides the fact that you're approaching the hazard too fast.



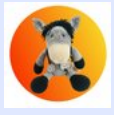
Herman

And that's the single most important safety point in this whole segment. Fog doesn't reduce sight. It corrupts the driver's sense of speed and distance. Those are different failures, and the second one is worse.



Corn

Practical guidance, then.



Herman

The safe speed in fog is the speed at which you can stop within your visible distance. In dense fog that's often well under thirty kilometers an hour, twenty miles an hour. Low beams or fog lights, never high beams, because high beams reflect back off the droplets and make things worse. Following distance goes up dramatically. And below a hundred meters of visibility, the correct answer is to get off the road entirely.



Corn

The driver's problem is the pilot's problem, just with more instruments and a longer stopping distance.



Herman

And a different vocabulary. Aviation uses runway visual range, RVR. The definition is the distance over which a pilot on the runway centerline can see the runway surface markings or the lights that delineate the runway or identify its centerline. Measured in meters or feet.



Corn

How is it actually measured?



Herman

Instrumented RVR, IRVR. Traditionally transmissometers, three per runway, one at each end and one at the midpoint. Forward scatterometers are replacing them in the US. About two hundred and forty-two of two hundred and seventy-nine American RVR systems are now forward-scatter. The values get reported in METARs and relayed by air traffic control.



Corn

And here's where it gets good, because there's a flaw in that setup.



Herman

There's a flaw, and it's a beautiful one. Because IRVR is measured at discrete points, the values can be mutually inconsistent. A two thousand meter runway might report touchdown, midpoint, and rollout RVR of seven hundred meters, four hundred meters, and nine hundred meters.



Corn

Walk me through why that's a contradiction.



Herman

A pilot at the touchdown point should be able to see a light seven hundred meters away, at the midpoint. That's what the touchdown RVR is telling you. But the midpoint RVR says four hundred meters, which means a light seven hundred meters away should be invisible



Herman (continued)

from there. The same air mass is giving contradictory answers depending on where you stand.



Corn

So the number isn't a property of the fog.



Herman

The number is a property of the fog at a specific point, measured by a specific instrument, and then reported as if it were a single fact about the runway. And the fog is spatially patchy, so the two things don't reconcile.



Corn

That's the RVR fallacy.



Herman

That's it. And it's not a criticism of the instruments. The instruments are doing exactly what they're designed to do. It's a reminder that visibility is observer-dependent. It's not a scalar field you can just sample.



Corn

Which is the same thing Koschmieder's law was telling us. Visibility is a contrast threshold. It depends on who's looking and from where.



Herman

And that's why the ILS categories exist, because the certification framework has to turn a slippery quantity into a decision rule.



Corn

Give me the ladder.



Herman

Category I is a decision height of two hundred feet or more, RVR of five hundred and fifty meters or more. Category II is a decision height between a hundred and two hundred feet, RVR of three hundred meters or more. Category IIIa is a decision height below a hundred feet or none at all, RVR of two hundred meters or more. Category IIIb is below fifty feet or none, RVR between fifty and two hundred meters. Category IIIc is no decision height and no RVR.



Corn

And the decision height is where the pilot has to see something or go around.



Herman

It's the point at which the pilot must have the required visual reference to continue. Category I relies only on the altimeter for that decision height. Category II and III use a radio altimeter, because the barometric altimeter isn't precise enough at those heights.



Corn

And Category III requires autoland.



Herman

Category III requires autoland, because the minima give insufficient visual reference for a manual landing. Some operators use a head-up display to hand-fly Category III, but that's the exception.



Corn

So the aircraft is doing the landing.



Herman

The aircraft is doing the landing. And the equipment has to be faster to fail safe. A Category I localizer has to shut down within ten seconds of a fault. Category III is two seconds. Because at two hundred meters of RVR, ten seconds of a bad signal is a long time.



Corn

What about the lights? The approach lighting.



Herman

Approach lighting systems extend the runway environment out toward the aircraft, which lets you certify lower minima. A Category I ILS with a fourteen hundred to three thousand foot approach lighting system can get down to half a mile, twenty-four hundred feet RVR. Add high-intensity edge lights, touchdown zone and centerline lights, and a two thousand four hundred foot or longer approach lighting system, and you can get to three-eighths of a mile, eighteen hundred feet RVR.



Corn

So the lights are doing certification work.



Herman

The lights are part of the certified system. You can't separate the avionics from the visual aids. They're one machine.



Corn

And Cork's on Category II.



Herman

Cork's on Category II. Which is why the airport can operate in much worse fog than a Category I field. But not in the very worst conditions, which is why diversions to Shannon, Dublin, and Kerry still happen. The three hundred and five meter runway extension helped



Herman (continued)

too, by giving more margin on the stop.



Corn

There's a specific accident tied to this.



Herman

Manx2 Flight 7100. February tenth, twenty eleven. A Fairchild SA two twenty-seven BC Metro Three operating Belfast City to Cork. It crashed on its third attempt to land at Cork in low visibility. Control was lost, the aircraft impacted the runway and came to rest inverted. Six people died, including both pilots. Four passengers were seriously injured.



Corn

Third attempt.



Herman

Third attempt in marginal visibility. And that's the human factors piece. The decision to continue isn't made in isolation. It's made after two previous approaches, with fuel burning down, with passengers waiting, with a crew that's already been working the problem for longer than anyone planned.



Corn

The minima exist precisely because that pressure is real.



Herman

The minima exist because human judgment degrades in exactly the conditions where it's most needed. The rule is there to protect the crew from themselves.



Corn

And even when the landing works, the airport around it stops.



Herman

That's the part people miss. Autoland solves the approach. It doesn't solve the ground. Control towers have to visually confirm aircraft on the runway. Below six hundred feet RVR, you need surface movement guidance and control systems, taxiway centerline lights, red stop bars. ILS critical areas have to be kept clear of aircraft and vehicles to avoid signal reflections.



Corn

Signal reflections.



Herman

The ILS beam is a radio signal. A vehicle parked in the wrong place reflects it, and the aircraft on final sees a distorted glide path. So the critical area is protected, which means taxiway restrictions, which means delays, which means aircraft holding on the ground while the fog sits there.



Corn

The landing is automated and the airport grinds to a crawl anyway.



Herman

The landing is automated and the airport grinds to a crawl anyway. The bottleneck moves from the approach to the taxiway. Which is the thing to watch as airports push toward Category IIIc and zero-zero operations. The approach is nearly solved. The ground is not.



Corn

There's a historical footnote here that I love.



Herman

FIDO. Fog Investigation and Dispersal Operation. World War Two. They burned enormous quantities of fuel alongside runways to literally evaporate the fog and give returning bomber crews visual cues to land.



Corn

They heated the sky.



Herman

It worked. It was so energy-hungry it was never viable for routine use. But the fact that the solution they reached for was to set the air on fire is a pretty good indication of how badly fog was hurting them.



Corn

I once watched a hawk pace an aircraft on a parallel taxiway for a full minute at Denver. Same problem, different scale. Everything on the ground moves at the speed of the slowest thing, and in fog the slowest thing is the tower's ability to see.



Herman

The tower's ability to see is the constraint. Which is why the RVR number and the human eye disagree, and the eye is what's actually running the airport.



Hilbert

The eye is what's driving the van, too. I did a stint as a ground handler at a regional airport. Different field, same problem. On foggy mornings my job was to take the follow-me car out and meet inbound aircraft and lead them in along the taxiways when the tower couldn't see them.



Corn

How bad was it?



Hilbert

Worse than you described. The RVR patchiness you were talking about, the follow-me driver is the one person on the airfield who experiences it directly. I'd drive out to the holding point and watch the visibility go from four hundred meters to eighty and back again over a few hundred meters of taxiway. The tower would read me an RVR that bore no relationship to what I could see out the windscreen.



Herman

The instrumented number and your actual view were just two different things.



Hilbert

Two different things. And the van had a heater that didn't work, so on foggy mornings the inside of the windscreen fogged up as badly as the outside. I was driving in fog, looking through fog, with a fogged windscreen. The only thing I could reliably see was the yellow beacon on the roof reflecting off the droplets in front of me.



Corn

You were following your own light.



Hilbert

I followed it in a circle once. I don't know how long I did that. Nobody said anything on the radio, so I assume nobody noticed.



Herman

What did you do when you figured it out?



Hilbert

Stopped. Listened. Found the taxiway edge lights. Went back to the follow-me car's actual job, which is to be a thing the aircraft can see, not a thing that can see. That's the part the numbers don't tell you. The beacon isn't for me. It's for them.



Corn

The number and the eye disagree, and the eye is the one that has to make the decision.



Hilbert

The eye is the one that has to make the decision. I'm due at the post office. There's a queue and I'd rather be at the front of it than the back.



Herman

The number and the eye disagree. And that might be the whole story, because the same extinction coefficient governs a driver's eye on the road into Cork and a pilot's decision height on a Category II ILS.



Corn

It doesn't care what you're operating. A photon scattered by a fog droplet doesn't know if it's scattering off a windscreen or a cockpit.



Herman

Which means the question "what's the visibility" is always partly a question about who's asking. The RVR says four hundred meters. The follow-me driver's windscreen says eighty. Both are true, and they're describing the same air.



Corn

Visibility is a physical quantity and a negotiated one at the same time.



Herman

I think that's the thing to hold onto. As airports push toward zero-zero operations, the landing gets solved and the ground operation becomes the bottleneck. The next frontier isn't the approach. It's the taxiway.



Corn

Here's the thing from the research that didn't make it into the main discussion, and it's a good one. Fog droplets are between one and a hundred micrometers across, which puts them in the same size range as the wavelength of visible light. That's why the scattering is Mie scattering rather than Rayleigh. It's the reason fog flattens contrast instead of just dimming it. If the droplets were much smaller, fog would look completely different.



Herman

Smaller droplets would scatter more selectively by wavelength, which would tint the fog. Bigger droplets would just be rain. The one to a hundred micrometer range is the sweet spot for maximum visual damage.



Corn

That's the cutting room floor. If you've ever driven into a fog bank and felt the world dissolve, you now know exactly what's happening to the light. And why the number on the sign and the view out your windscreen will never quite agree.



Herman

Thanks to Hilbert Flumingtop, our producer.



Corn

This has been My Weird Prompts. If you've got a question like Daniel's, email us at show at my weird prompts dot com. We'll be back soon.