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Responses to Citizen enquiry on the nature of contrail and contrail-induced cirrus clouds:

1. Could you please tell us a little about yourself, your qualifications, and your position at ACCRI.

I am a scientist / engineer working on problems related to atmospheric impact of aviation (among other things). I have a Ph. D. in Mechanical Aerospace Engineering from Cornell University and I have worked in the field of atmospheric science, atmospheric radiative transfer for over 30 years. I have published in many areas of atmospheric science and aviation. Between 2011 and 2013, I managed the Aviation Climate Change Research Initiative (ACCRI) program for the FAA. The program consisted of over 30 scientists, engineers from universities, industry and other government laboratories.

2. Online they call them chemtrails but scientists call them contrails, persistent contrails, aviation induced cloudiness (AIC), artificial clouds, cirrus homogenitus, or if you want to get real nerdy cirrus floccus homomutatus. For the sake and duration of this discussion, can you and I agree to refer to clouds made by jet aircraft as "contrail cirrus?"

There is a lot of misinformation regarding contrails among the general public. I will be perfectly happy to refer to them as "contrails" and "contrail-induced cirrus clouds".

3. What makes a contrail? (soot, sulfur dioxide/acid, WV)

When you burn any hydrocarbon fuel, such as kerosene or JP-8 (what the jet fuel is called), the products of combustion include water vapor, carbon dioxide, (for complete combustion), carbon monoxide, unburnt hydrocarbons, particulates such as soot, nitrates and sulfates and may include other impurities that the fuel may contain. The solid particulates have the water vapor condense on them and they grow in size. If the atmosphere at the cruise altitudes (about 30,000 feet above ground) contains naturally occurring water vapor, and if the atmospheric conditions are such that there is super-saturation with respect to ice (the relative humidity is greater than 100%), then the particles grow in size to form small liquid and subsequently solid (ice) particles, which are the constituents of contrails. Since the size of these particles is comparable to the wavelength of visible light or larger, they interact with sun light strongly thus becoming visible as a white streak against the backdrop of the blue sky.

4. What makes a contrail that normally should dissipate, persist? IE become contrail cirrus.

If the conditions in the atmosphere at cruise altitudes are such that a certain Schmidt – Appelman criterion is satisfied (the criterion refers to a minimum relative humidity and a low temperature), then the ice particles persist for long periods of time behind the jet engine, sometimes up to 15 – 30 minutes to even a few hours. If the atmosphere is too dry or too warm, then the ice particles evaporate thus dissipating the contrail. Because the aircraft exhaust contains small soot particles, perhaps intermixed with sulfates and nitrates, the wake expands behind the aircraft and the contrail also expands with it. Eventually, the contrails lose their pencil shape and appear quite diffuse, indistinguishable from a natural cirrus cloud, at which point we characterize them as contrail- induced cirrus clouds. These clouds will then be subject to the same type of evolution as natural cirrus clouds.

5. How does the FAA view contrail cirrus? A pollution problem that should be removed from the sky or a potential climate mitigation (IE geoengineering) option?

Contrail cirrus cloud, like its precursor, contrails, is made of ice particles which have small soot particles or other particles such as sulfates and nitrates at the core. The problem is not as much a pollution problem (due to the very small amount of these particles in a vast sky that too at high altitude away from people and much lower in density than on the ground next to a busy highway or a city road where the impact of ground vehicles are much more severe), as it is perhaps an aesthetic one, particularly in the West where the skies are otherwise pristine blue.

Climate mitigation using contrails or contrail-cirrus is not possible as they are both positive forcers – in other words, they increase warming. Even though these appear "white" indicating that they reflect solar energy back to space thus cooling the atmosphere, in the infrared they increase absorption of the ground- atmospheric system. The latter mechanism is operating even when the Sun is not around, at night. Geo-engineering is thought about, as a concept, within the context of injecting sulfate or other small particles into the stratosphere to reflect solar energy back into space. This has nothing to do with combustion in aviation or of contrails.

6. It is my understanding that contrail cirrus is a "hot topic" these days following the two research papers by Minis and Lee (9/11 contrail diurnal temperature range and 2008 Iceland volcano flight grounding). Could you please explain where we are in understanding how much contrail cirrus traps heat vs CO2?

As I mentioned before, contrails and contrail-cirrus are produced from aviation exhaust and are quite distinct from volcanic eruptions. The contrails and CICs are essentially clouds that the aircraft can fly through without damage to engines, unlike the Icelandic volcano plume which consisted of abrasive particles including dust at flight altitudes. Yes we did estimate the effect of contrail-cirrus in ACCRI. The uncertainties are huge mainly because of difficulty in the proper identification of contrail-cirrus as an entity separate from natural cirrus clouds. In ACCRI we estimate the radiative forcing from contrails as 2.9 – 11.3 mWm^{-2} and contrail-induced cirrus as 12.4 – 51.3 mWm^{-2}. These are comparable to the magnitude of carbon dioxide emissions, 28 mWm^{-2} (Lee et al; estimated for a slightly higher fuel consumption 232 4 vs 188 Tg yr^{-1} in ACCRI) which of course has a much longer time scale.

7. It seems that the general understanding was “contrails are cooling the planet” until these two studies, would you agree?

The reason we did ACCRI was that we did not know what the sign of the contrail and CIC impacts were. Our understanding was characterized as “very poor”. We have improved to “poor” category! Overall we expect high altitude cirrus clouds, which is what contrails and CICs are, to have positive forcing (which means they heat the atmosphere; negative forcing = cooling) even though they reflect sun light during day when the sun is shining, because they trap the infrared emissions (heat waves) from the ground to space during night and day.

8. Does the aviation industry face potential carbon taxes or other climate related fees due to the massive (negative, heat trapping) influence of contrail cirrus? (referring to EU legislation on GHG emissions from jets and the recent ICAO agreement to limit GHG)

Aviation industry, like any other industry has a global warming component and is therefore subject to eventual carbon regulation, even though the recent Paris agreement (2016) left out aviation. I would take exception to the characterization of the influence of contrail cirrus as “massive”. As outlined before it is of the order of at most 100 mWm^{-2} which when compared with other sources is miniscule. Just to give you an idea, the amount of solar energy falling on the top of the atmosphere (averaged over the sphere on the day and night side) is about 1360/4 W m^{-2} (the solar constant) = 340 W m^{-2} or 340000 m W m^{-2}! It is not negligible though and FAA (and other international agencies – ICAO) is doing all it can to minimize even this impact. Also of note is the total increase in anthropogenic effect from all sources is of the order of 2 W m^{-2}, which is sufficient to increase the surface temperature by a couple of degrees Celsius (see the latest IPCC reports).

9. Could you please explain the ACCESS-I and II flights, their purpose, and summarize some of your results.

ACCESS I and II refer to NASA field experiments involving sampling of exhaust from large, multi-engine airplanes in flight using smaller, well instrumented airplanes from USA, Canada and Germany. The idea was to fly these planes with regular and alternative fuels to minimize particle emissions and to study the formation of contrails and its properties and to see how contrail formation could be minimized. In ACCESS I, measurements showed that soot levels were 40 – 60 percent lower while burning blended fuels than those that burnt pure JP-8. The connection between the use of blended JP-8 fuel with renewable alternative fuel of hydro processed esters and fatty acids produced from camelina plant oil with reductions in soot emissions, could not be conclusively made[1]. For this reason, a follow-on field experiment – called ACCESSII was carried out in 2014 from the Armstrong Aircraft Operations Facility in Palmdale, California. During ACCESS II, only a few days were encountered when contrails formed, but they did not persist long enough to make comprehensive measurements. FAA funded three teams to look into analyzing data from ACCESS II. We realized that the effort required is a lot more than what was contemplated and we intend to pursue it in the future with hopefully, more resources.

[1] See: https://www.nasa.gov/centers/armstrong/Features/leaptech.html

10. Do you think biofuels can get rid of contrail cirrus. Is that even the plan?

One of ACCESS II goals was to use alternative fuels to minimize contrail formation. These could include bio-fuels but we are not sure at this time how these fuels could stop the formation of contrails. One way to minimize contrail formation is to minimize soot emissions. In principle, this is achievable with alternative fuels since they burn more completely.

11. What do you think Ulrich Schumann meant when he said "less warming, more cooling contrails; predictable for operational control?"

Not sure where he says this and in what context. Contrails during day cause cooling because of reflecting of sunlight back into space. During night, they trap infrared heat causing heating. So it is a balance between the two time intervals. We would like to have more CICs during day and none during night.

12. What are your thoughts on solar radiation management and the (potential) use of fuel sulfur content geoengineering?

We are in an era of increasing carbon dioxide whose concentration has gone up from 300 ppm to 400 ppm in a relatively short time of ~50 years. This is due to anthropogenic activities. We know CO2 is a greenhouse gas and the temperature will therefore increase unless we reduce CO2 in the atmosphere. Another way to control this effect of global warming is to decrease solar energy falling on the earth. All mechanisms to reduce the sunlight falling on the earth – reflecting sunlight back into space by sulfates in the stratosphere, mirrors in space, increasing albedo of the earth's surface – have advantages and disadvantages. Increasing sulfates in the stratosphere where its lifetime is a maximum of a couple of years requires constant replenishment. We do not know what the chemical consequences of such an effort are, even if it is possible to disperse vast quantities of sulfates in the stratosphere. Sulfates will eventually turn into sulfuric acid and fall on the ground. What are the consequences of such a phenomenon? Acid rain was studied comprehensively in the 70s and 80s. So, any action to 'manage' solar radiation has to include a comprehensive study that addresses subsequent environmental consequences that include impacts on human health. Installing large mirrors in space by rockets has its own problems – including cost of installation, producing very large reflective shields and deploying them, have technical challenges and unforeseen ecological effects here on earth.

13. It is my understanding that you tested a JP8 fuel doped with sulfur during the ACCESS-II flights. Could you explain the purpose of that fuel?

The fuel tested (by NASA) was a 50 – 50 blend of synthetic fuel with JP-8 (see above). The former had many desirable characteristics including zero sulfur and zero carbon (soot) emissions. By reducing soot, we were hoping to see a reduction in contrail and CIC formation.

14. I read a paper that suggested using biofuels on takeoff and sulfur doped fuel at altitude to kill less people around airports (from soot pollution) and cool the contrail cirrus created. Could you explain how this would even be possible? Two fuel tanks?

I am not aware of this paper or the idea it discusses. And of course, any action that deals with human mortality, has to be taken very seriously. Folks can come up with a number of scenarios by which GHG mitigation can be achieved while at the same time minimizing immediate impacts on human health. One way to do this is to minimize carbon/soot emissions using alternative (synthetic – not bio) fuels. The reduction in mortality is a statistical calculation based on the rates of mortality for a particular action – in this case the emission of carbon or soot and other particulates characterized as PM2.5. It is known that particulates cause health effects by penetrating lungs and cause pulmonary symptoms. Aviation is hardly a major source of this effect (other transportation modes and other industries are far more important; for example burning gasoline in cars, coal mining etc.). Surface transportation, in particular automobiles, statistically cause thousands of mortalities due to pulmonary effects, particularly in vulnerable groups – such as the aged and infirm, because of their proximity. Efforts are made in those industries to minimize particulate emissions as well.

As I mentioned, injecting sulfate into the high altitude parts of an aircraft trajectory during cruise, is an idea that has been discussed but not implemented because of various issues including the health issue you have outlined.

15. Would you please explain cirrus cloud seeding (Trude Storelvmo) and blasting contrail cirrus with lasers?

I am not aware of either of these mechanisms. I don't see how they can aid in global warming mitigation. Cirrus clouds are natural and have been around since time immemorial. On the second point, a scientific case has not been made to take such a drastic action of blasting contrails with lasers. (I don't even know how one can go about doing this).

16. If one wanted to go ahead with any of these geoengineering proposals using jet fuel or altering contrail cirrus, what would that legal process look like and how would the FAA and ACCRI be involved?

A benign way to avoid forming contrails and associated contrail-induced cirrus is to avoid flying in regions where the Schmidt – Appelman criterion is satisfied. For example, one could fly a little bit lower in the atmosphere where it is warmer so that ice particles comprising of contrails are never formed. So a legal process (I am no expert on this) might just be a pilot radioing in a request to the control tower to alter the flight path. Use of alternative fuels – those that do not emit soot when burnt – will require a more elaborate approval process. The manufacturers of engines and associated aircraft will have to obtain permission during the approval process to burn alternative fuels. Such mechanisms are in place already.

17. Thank you so much…

    You are welcome. Check out the picture below.

NASA's DC-8 research aircraft leads one of the ACCESS II sampler aircraft across the early morning California sky.
Credits: NASA / ORAU Richard Moore