Flights from sense: how space tourism could alter the climate

Philip Chapman investigates the potential environmental impacts should space tourism recover from its recent setbacks and become a thriving global industry.

It is over a year since the high altitude disintegration of Virgin Galactic's SpaceShipTwo (SS2) – which caused the tragic death of pilot Mike Alsbury. The mission had been a test flight of what Virgin still hopes will become regularly scheduled tourist trips into space. While the cause of the crash has now been established as pilot error, made possible by the failure of the contractor responsible to safeguard against its occurrence,[1] immediate media coverage of the crash did include voices calling for Virgin to quit the space business because of alleged incompetence.[2] However, none of the coverage has mentioned the impact that the industry would have on the global climate were this type of spacecraft ever to make frequent space tourism a reality. The particular concern is due to a new dirtier type of rocket engine, the 'hybrid', which, if deployed on a large-scale, would soon start polluting the stratosphere and creating a low density cloud of soot that would span the globe. Establishing exactly how this stratospheric 'black carbon' will affect the climate system will require further investigation, but the sole scientific study to do so thus far has given alarming results.

Space tourism using conventional rockets

American multi-millionaire Dennis Tito became the first space tourist when he flew to the International Space Station (ISS) aboard a Russian Soyuz-TM spacecraft in 2001. His flight was organised through a US company called Space Adventures, the only company to have sent tourists into space thus far and sending only seven in total before the Russians suspended the use of its spacecraft for tourists. Space Adventures continues however to promise a return of tourists to the ISS using another variant of the Soyuz spacecraft and using Boeing's Commercial Space Transportation-100 craft.[3]

This venture represents part of the consequences of NASA's boost to the commercial sector by retiring the Space Shuttle and concentrating its vessel development on deeper space. Accordingly, the NASA Authorization Act of 2010 provided $1.6 billion for private companies to develop human spaceflight capabilities, under which NASA has drawn up an 'Integrated Design Contract' (IDC). This means that multiple companies will be developing 'end-to-end' capabilities, i.e. spacecraft, launch vehicles, ground control, recovery capacity and all the services and add-ons necessary for sending people into low earth orbit. And just as Boeing has done, other commercial ventures should be expected to solicit private as well as state customers in the future. There are also a number of companies promising to send tourists into orbit independent of any funding from NASA.[4]

Sub-orbital space tourism

It is other types of space tourism however that (at least until the recent crash) have had a greater immediate prospect of expanding rapidly, largely because they do not depend upon low earth orbit infrastructure, such as the ISS, in order to operate.

Suborbital flights technically enter outer space because they cross the Kármán line, defined as above 100km above the Earth's surface. It is this sector of the industry that has been set for imminent expansion. There are a number of companies presently developing craft capable of suborbital flight and promising to take tourists on flights in the coming years. One of these, XCOR, based in California, is developing the Lynx suborbital spacecraft with a single passenger seat. The craft will take off and land horizontally, and the company plans that it would eventually make several suborbital flights per day.[5] Enabling this relative simplicity in turnaround is the fact that, like most other rocket engines, including the Soyuz, the Lynx craft will burn a mixture of liquid oxygen and kerosene.

In contrast to this 'typical' engine is that of the spacecraft belonging to the most widely publicised space tourism venture – the one emblazoned with the Virgin brand. Virgin Galactic's SpaceShipTwo is equipped with a single hybrid rocket motor. In the world of rocket engines however, 'hybrid' does not mean that its hydrocarbon-fuelled propulsion system is supplemented by an electric motor, as in a hybrid car. Rather hybrid here describes the use of fuel in different states of matter. Until mid-2014 that meant for SS2's engine the fuel was solid synthetic hydroxyl-terminated polybutadiene and liquid nitrous oxide (basically, rubber and laughing gas). This engine had a number of problems during tests and was deemed unable to provide sufficient power to take the craft to the desired height. The subcontractor responsible suggested reducing the number of passengers on SS2 to four, but Virgin apparently determined that it could not make money under such circumstances.[6] They decided instead to use a different hybrid engine developed by the principal contractor, Scaled Composites, which burns a thermoplastic rather than rubber.

Unlike the Lynx craft, SS2 is air-launched, meaning it is dependent upon a mothership, in this case a cargo vessel called WhiteKnightTwo (WK2). SS2 launches from WK2 at 15.5km before firing its engine for approximately 70 seconds and attaining speeds of close to 4,000km/h. The plan is that it will then coast up to 110km where it will spend 5 minutes in the weightlessness of space before beginning to descend. SS2 thus launches from its mothership close to the tropopause (the top of the troposhere) before flying through the stratosphere and mesosphere and will just cross the Kármán line into outer space. Its engine will therefore burn within the stratosphere and it is here that its emission of black carbon will provide the most atmospheric altering effects of the entire endeavour.

Impacts on the atmosphere and climate

The stratosphere is the section of the atmosphere where the ozone layer resides and it is this layer that causes the effects that creates the zone. Whereas below the tropopause (from the Earth's surface up to the bottom of the stratosphere) temperature falls with increasing altitude, above it there is an inversion; in the stratosphere temperature increases with altitude because ozone absorbs shortwave radiation from the sun. The temperature inversion creates a stable density structure in the stratosphere and the overturning circulation that occurs here is therefore slow (see Figure 1). Coupled with low moisture content this means that no clouds form and there is therefore no rain. These factors, along with the low density that reduces coagulation, mean that particles emitted here have a residence time of years, rather than the weeks they would have in the troposphere.[7]

This in large part is why Darin Toohey, professor of atmospheric and ocean sciences at the University of Colorado, says "there's one issue and it's simple: you don't want to put black carbon in the stratosphere. Period."[9]

The results of the 2010 modelling study that Toohey co-authored showed a non-uniform effect over the globe of sustained regular launches of these spacecraft.[10] Assuming a launch site at a latitude of

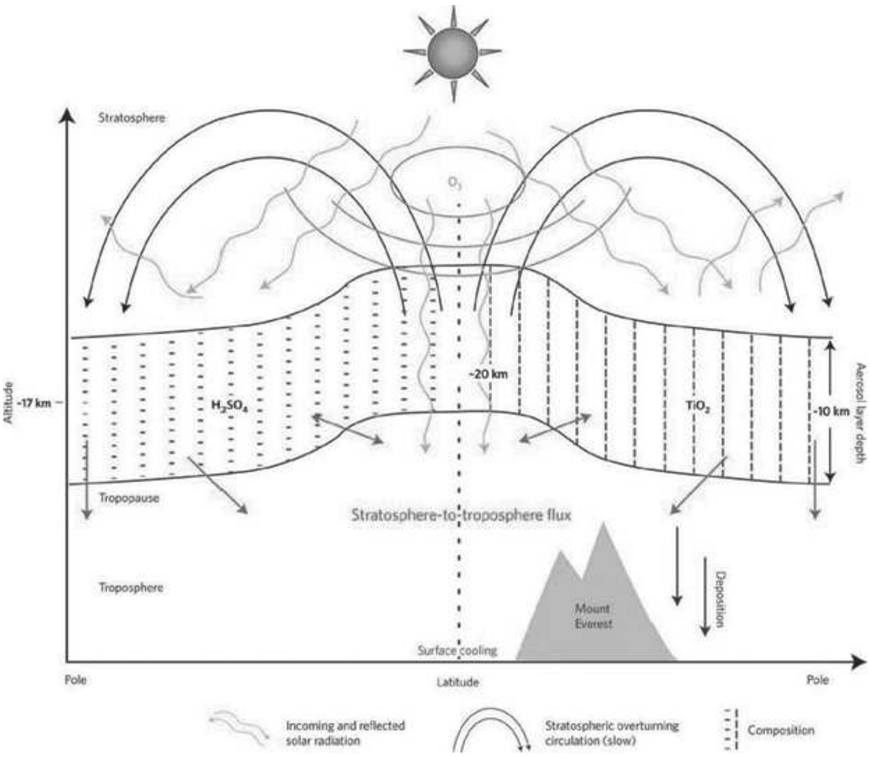

Figure 1. The slow overturning circulation in the stratosphere that covers the globe.[8]

about 33°N (in line with where Virgin Galactic's Spaceport America has been built), the majority of the black carbon (BC) was constrained between 25°N and 45°N and only about 20% of the pollutant travelled into the southern hemisphere. This asymmetry could be the driver of the resultant modelled decrease of ozone at the tropics and sub-tropics but an increase at the poles. This altered distribution of ozone has been attributed to greater stratospheric overturning circulation in previous studies, which has been shown to be produced by relatively small differential heating effects in the stratosphere. Within the northern hemisphere stratospheric zone, where most of the BC was distributed, temperature increased by approximately 0.2°C whereas, because very little BC went into the southern hemisphere, there was no heating there. This suggests that the latitude of the launch site may play an important role in the effect on ozone distribution, which was found to reduce ozone in the tropics by the same amount as CFCs have caused. The increase in the stratospheric circulation caused by the BC load is found to be roughly equivalent to the changes induced in this circulation due to modelled greenhouse gas emissions.

Modelled temperature changes at the surface also differed regionally and seasonally, with up to a 1°C increase at the poles,[11] but taken together show BC from 1,000 launches per year would influence global climate by about the same amount as the entire current global aviation industry, with a radiative forcing effect of $43mW/m^2$. Also of note is that the climate change effect of the emitted BC exceeds the climate change effect of the emitted carbon dioxide by a factor of about 100,000. When Virgin Galactic boast about the low CO_2 emissions from SS2 in comparison to other air travel,[12] they are missing the most significant climate impact their new fleet of machines is likely to have.

The University of Colorado study was the first to model the global climate impacts of the particle emissions by rockets and as a single study with many parameters only loosely constrained it is far from the final word on the subject. However, despite the money being poured into these high profile ventures and the scale of the impact they could have on the atmosphere, the calls of the authors for their work to be built upon and extended remain largely unanswered.

Time for more caution

Current knowledge of the atmosphere, coupled with the University of Colorado's recent modelling work, should be considered sufficient to suggest a course of considerable caution for space tourism, especially considering the huge greenhouse gas forcing that humans are already responsible for. It is only with the benefit of hindsight that the other global environmental impacts of many applications of the technological innovations of the industrial age are now known. But we can no longer claim to be ignorant of the risks of a free-for-all in the stratosphere. The current plans for space tourism look much more like a demonstration of reckless disregard for the future.

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Update

Since this article was written, there have been significant test flights of Blue Origin's New Shepard rocket and SpaceX's Falcon rocket, which indicate that these corporations may be gaining the upper hand in the space tourism industry. Although they do not use the more polluting engines favoured by Virgin Galactic, there nevertheless remains a question over their environmental credentials.