

wanted and agree to pay for some of the R&D which might be required while allowing them much more room for manoeuvre when it came to choosing technologies and making trade-offs in design.

That approach opened the door for companies beyond the established military-industrial complex—including SpaceX, a firm founded in 2002 by Elon Musk in order to further his dream of establishing a civilisation beyond the Earth. When Dr Griffin left NASA in 2009, SpaceX had launched just one small payload into orbit. But it had also become part of NASA's Commercial Orbital Transportation Services programme. By 2012 money from NASA, some earned by meeting specified R&D milestones, had allowed it to use a new rocket, the Falcon 9, to launch a new cargo spacecraft, the Dragon, to the space station. The investment by NASA had not only given SpaceX new capabilities, it had also helped build up a truly innovative company in an area sorely bereft of innovation.

Rewriting the rocket equation

A spacecraft for humans was the next step. Not everything went to plan. The crewed version of Dragon was supposed to fly in 2015 but was delayed by technical problems and funding constraints. But NASA's new, cost-saving approach now has a human-rated spaceship to add to its list of accomplishments. It should soon add a second. The programme which saw SpaceX develop Crew Dragon has seen Boeing, a giant defence contractor, develop something similar, the Starliner. But a test flight last December went badly, and no crewed flight is expected until 2021. The next Crew Dragon flight—the first of six routine crewed flights that NASA has signed contracts for—is due in August.

Now NASA is applying a similar approach to its lunar ambitions. In April it announced it was spending \$1bn with three industry groups to develop the capacity to take humans from lunar orbit down to the surface. One group is led by Blue Origin, owned by Jeff Bezos, the founder of Ama-

zon. Blue Origin has yet to fly a rocket to orbit, but its technology appears first-rate. Mr Bezos, like Mr Musk, thinks that developing a human presence in space will assure him a place in the history books of a civilisation too grand for a single planet.

The second recipient of funds was a consortium led by Dynetics, a subsidiary of Leidos, a defence contractor formerly known as SAIC. The third was SpaceX, which offered a version of Starship, a new spacecraft it is developing off its own bat. The Starship and its booster are designed to be as capable as the SLS and also fully reusable. Things have not, so far, gone smoothly: four test vehicles have blown themselves apart, the most recent on May 29th.

None of these three lunar-lander options requires the SLS to get into orbit. Starship would be launched with a new booster SpaceX is designing for exactly that. The Blue Origin lander could be launched on the company's New Glenn rocket, somewhat more powerful than the Falcon 9, or on Vulcan, a similarly sized booster made by Boeing and Lockheed which is Dynetics's ride of choice: both launchers are due to make their debuts next year. But the SLS and its Orion capsule are still integral to NASA's Moon plans. They will fly the astronauts to lunar orbit before the new spacecraft takes them to the surface.

This looks even less sensible now than it ever did. With a big SpaceX rocket—the Falcon Heavy—already available, two new big boosters due to debut next year and Starship being developed, American industry offers a number of options for getting astronauts up to the Moon. A programme truly aimed at improving the state of the spacefaring art, demonstrating a unique national capability or providing a shared experience around which Americans could, in principle, unite needs no more. And it would cost much less. The idea that a trip to the Moon might heal national wounds looks even less likely now than it did half a century ago. But it could at least take less of the money that Scott-Heron's heirs earned last year. ■



Archaeology

Taking soundings in Teotihuacan

An ancient city may soon hear again the music of long-lost instruments

ONE AFTERNOON last December Arnd Adje Both, a researcher at Huddersfield University, in Britain, stood on top of the Pyramid of the Moon at Teotihuacan, in Mexico, and blew into a conch-shell trumpet, sounding a note that echoed in the plaza far below. Later this year—COVID-19 permitting—he hopes to return with a group of colleagues to conduct an aural examination of the site using replicas of the ancient instruments dug up there.

Teotihuacan is a mysterious place. Once home to more than 100,000 people, at its zenith around 1,500 years ago it was among the biggest cities in the world. Its inhabitants, though, had no known system of writing. Even the city's original name is unknown. "Teotihuacan", meaning "birth-place of the gods", is what the deserted settlement was called by the Aztecs, who took over control of what is now central Mexico in about 1300AD, some 650 years after the city was abandoned. All that is known about Teotihuacan's inhabitants and their culture is what archaeologists have pieced together from the remaining buildings and other artefacts.

Dr Both's curiosity about the music-making of these elusive people goes back to the 1990s. He took part in one of his first excavations at Teotihuacan. While doing so he got to know a group of Mexican musical-instrument makers and became interested in crafting replicas of the site's double-chambered water-sounding vessels (pictured above), which whistle when water moves from one chamber to the other, qua- ▶▶

The big-money seats

Costs of crewed space vehicles

Vehicle	Operator	Years of operation	Maximum crew capacity	Spacecraft development costs, 2019 \$m	Cost per seat to low-Earth orbit 2019 \$m
Mercury	NASA	1961-63	1	2,660	142
Gemini	NASA	1964-66	2	7,590	117
Apollo CSM	NASA	1968-75	3	30,890	390
Soyuz	Various	1967-	3	not known	80-90†
Space shuttle	NASA	1981-2011*	7	27,400	170
Crew Dragon	SpaceX	2020-	7	1,730	55
Starliner	Boeing	2021†	7	2,800	90
Orion	NASA	2021†	6	23,662	291

Sources: NASA; Planetary Society

*Except 1986-88 and 2003-05 †Planned ‡As charged to NASA

►druple flute pipes and other strange instruments. He has since spent many months in the collections of the National Anthropology Museum in Mexico City, and other institutes, plotting the dimensions and workings of these finds.

Since the genuine articles are too delicate and valuable to play, he has teamed up with Osvaldo Padrón, an instrument-maker in Amsterdam, to create replicas. He is not looking to reproduce pre-Columbian tunes on these facsimiles. The inhabitants' apparent societal aliteracy extended to musical notation, so there are no scores to interpret. But by recording the replicas being played in their native site he nevertheless hopes to gain a better purchase on how sound moved around the ancient city.

Creating such "soundscapes" is a trendy if somewhat esoteric idea in archaeology at the moment. Kristy Primeau and David Witt of the State University of New York, for example, have mapped the spread of the sound of voices and conch-shell trumpets around the ancient Puebloan dwelling-sites of Chaco Canyon, New Mexico. To do so they modified programs employed for environmental-impact studies—specifically, for the modelling of levels of noise from vehicle engines that might be perceived in a wilderness area as a result of economic development. Using this software they have shown that the sites of platform mounds built in the canyon were not chosen accidentally. Rather, they are well placed to propagate sound through the area's now-abandoned settlements.

Similarly, a team led by Margarita Díaz-Andreu of the Catalan Institution for Research and Advanced Studies has discovered that spaces in rock shelters in western Spain that are decorated with prehistoric art also have striking acoustic properties of reverb and echo—whereas undecorated areas used for shelter at the same time did not. And Miriam Kolar of Amherst College, in Massachusetts, has shown that the top of a towering central platform in the Inca city of Huánuco Pampa was not just a place from which to address the masses. It also had excellent internal acoustic properties. It would have made a good private venue for the local elite.

When Dr Both returns to Teotihuacan, he and his colleagues will play their replicas from spots on the Sun and Moon pyramids, and from other places among the palaces and temples that line the city's main thoroughfare, the Avenue of the Dead. Rupert Till, Huddersfield's professor of music, who is also a recording engineer, will record these from various places and attempt to build a model showing how sounds change in the city as the listener moves from one place to another. Or the listener can stop this virtual tour, turn off the sound of the instrument and hear the breeze blowing over the stones. ■

Climate feedbacks

Fire down below

A smouldering spring in the Arctic

SEEN FROM the sky, the northern stretches of Siberia in early May were a splotchy white, their thinning winter snow cover interrupted by the brown veins of meandering rivers. Nestled within some of these curves, though, satellites picked up patches of soil warmer than the ground around them. The patches grew and multiplied as the month went on. Before it was over, some were visibly ablaze.

Fires are not unheard of in the Arctic, even at this time of year. But the extraordinary fires seen last summer have put researchers on high alert for oddities. In June, July and August 2019 fires within the Arctic Circle pumped 173m tonnes of carbon dioxide into the atmosphere. The 182m tonnes emitted over the year as a whole smashed the previous record of 110m tonnes, set in 2004. Dense clouds of smoke smothered Siberian cities. The fires consumed not just trees and grasses but also peat which would normally have been frozen. Alaska experienced an unusually active fire season, too.

Last year's inferno makes this year's early-season hotspots and blazes particularly interesting. Fires can overwinter underground, particularly if they find their way to pockets of peat which offer the fire just enough oxygen for slow smouldering beneath the snow. After a wildfire singes a network of submerged layers of peat its descendant embers can pop up months later: though purists frown on the term, they have become known as "zombie fires".

A recent Dutch study of overwintering-fire data, presented at a meeting of the

European Geosciences Union held the same week that the satellites were seeing hotspots in Siberia, suggests that they are more likely to happen in years after large burns. Though such fires can travel some distance under the surface, and so do not have to reappear where last seen, most stay put. The fact that some of this May's flames were in areas that burned last year and are rich in peat is thus suggestive. On-the-ground observations will be required to settle the matter, though.

If the fires did overwinter, that is not in itself a bad omen; the Dutch study did not find that overwintering fires make a new year particularly fire-prone. Exceptional fire seasons are normally preceded by hot, dry early summers, as last year's was. Happily, the ground around the Arctic Ocean currently appears wetter than average, except in the north-eastern-most reaches of Siberia. That said, in Siberia and Greenland April's temperatures were well above the 1981-2010 average—in places by more than 10°C. A warm, damp spring could yet become a hot, dry summer.

Arctic fires garner less attention than those in Brazil, which the world has been worrying about for decades, or California, Australia and the Mediterranean, which are more densely populated. But regional and global feedbacks make them peculiarly alarming. By leaving dark scars on the land they burn and spreading soot much farther afield they increase the land's capacity to soak up summer sun, thus making the region warmer still. The warmer it gets, the more flammable it is—and the more carbon dioxide and methane get emitted.

On the scale of what humans do, last year's 173m tonnes of carbon dioxide is appreciable—about 30 big coal-fired power stations working flat out for a year—but not overwhelming. There are, though, hundreds of billions of tonnes of carbon stored up in the Arctic, a region already warming at twice the global rate. It is a tipping point to watch. ■



Siberian zombies?