Researchers worldwide are pioneering techniques for the continued advancement of space exploration. Dr Martin Cullum, Chair of the TECHBREAK Scientific Committee at the European Science Foundation, discusses their activities and the development of technologies to enable new missions.
Technological Breakthroughs for Scientific Progress (TECHBREAK) was launched in response to the identification of problems specific to the space field. Can you discuss the 'Overwhelming Drivers' developed by the Scientific Committee as long-term goals?

Firstly, let me emphasise that the Overwhelming Drivers do not correspond to any specific current or planned European Space Agency (ESA) projects. They represent realistic potential projects that could be undertaken in the coming 10-25 years, and illustrate the technical challenges many future space projects will face. The TECHBREAK Scientific Committee realised early on in the study that it was important for researchers outside the space industry to relate to the goals of the study in order to be able to assess the potential relevance of their own research to future space projects. The Overwhelming Drivers were primarily aimed at helping this dialogue by describing specific realistic examples rather than simply listing technical requirements for currently initiated or planned ESA projects.

The objective of Overwhelming Driver 5 is to enable humans to stay in space for more than two years. How close are scientists to making this a reality?

The background of the two-year space mission was the often-discussed idea of a manned round trip to Mars. In the last 10 years, much experience has been gained – for example, through the International Space Station – on the effects of long-duration spacelift on humans. However, there is a big difference between being in a close orbit around the Earth, where rescue and/or repair missions are realistic, and an autonomous trip into deep space. For a Mars trip, there are still many challenges to be overcome before such a trip would be technically, economically and even politically feasible. A number of these challenges have indeed been identified in the TECHBREAK Report. However, my personal guess is that a round trip to Mars could not feasibly take place before 2040.

Self-censorship due to the fear of adopting technologies that are not fully proven is one of the challenges inhibiting progress in the field. How is TECHBREAK encouraging departure from these traditional approaches?

It was not the purpose of TECHBREAK to challenge the way the ESA runs its programmes. What we did, however, is draw attention to the problem that ESA itself has also recognised. When missions are selected, the failure to make a new technology available in a timely manner results in cost and schedule overruns that can also impact follow-up missions. The technological risk analysis that is built into the project selection process tends to automatically penalise proposals that are based on new and untried technologies. As a result, ESA may select missions that are based on obsolete technologies in a fast developing field, thereby losing competitiveness and leadership.

There are ways in which ESA might address the risk of self-censorship. For example, instead of requesting a single competitive call for science proposals, it calls for a number of parallel study proposals to enable a better evaluation of the benefits and risks of new technologies before the final project is selected. What is important here is that ESA defines a transparent selection process in which the bidding firms and institutions do not feel that they will be prematurely disadvantaged by proposing avant-garde solutions.

What do Key Enabling Technologies (KETs) mean in the context of TECHBREAK?

KETs are technologies that are multidisciplinary in their nature and cut across many technology areas. They are seen by the European Commission (EC) as the route to new products, processes and services capable of generating economic growth and employment within Europe as well as contributing to strengthening and/or rejuvenating existing European sectors and improving competitiveness. KETs were therefore a useful starting point for defining the scope of the study. However, the EC KETs are quite broadly defined and, to be useful for TECHBREAK, they had to be refined and the granularity improved. In the end, a selection was made by the Scientific Committee of those technologies that seem most appropriate for future space projects, which were not already well known to ESA, and which could be realised within the planned time scale and with the resources available.

Could you outline the process involved in forecasting the development of technologies for the achievement of scientific breakthroughs that enable novel space missions in the 2030-50 timeframe?

The process was somewhat eclectic and evolved through the duration of the study. TECHBREAK initially obtained input from a study by the
European Science Policy Institute and then elaborated a foresight strategy and methodology for the project. The basis for the technologies investigated in the study were aligned to the EC’s KETs. A bibliographic study was carried out to identify key researchers and institutions within Europe and a meeting was held with the ESA Advanced Concepts Team (ACT) to clarify ESA requirements and boundary conditions.

Within ESA, the ACT has a somewhat similar function as TECHBREAK, but its approach is more mission orientated (technology pull) whereas TECHBREAK was specifically looking outside mainstream space science, and was therefore more orientated towards technology push. Some specific areas, such as lasers, propulsion systems and energy storage were excluded from the TECHBREAK study because ESA already had considerable experience in these fields. The KETs reviewed by the study comprised nanotechnology, advanced materials, photonics and metamaterials, micro and nano electronics, and biotechnology and medicine. Following these meetings, a series of multi-thematic workshops with invited experts were arranged. These were followed up towards the end of the study by interviews with selected key researchers and visits to various laboratories. For the final report, assessments were made for the various fields on technological readiness, likely timescales to reach maturity, level of research interest and funding as well as, of course, potential relevance to future space science missions.

Have you identified any fruitful partnerships with space and non-space specialists?

Yes, we have collaborated with a number of experts and institutions. One example is in the field of biomimetics. The Alfred Wegener Institute (AWI) in Bremerhaven has developed a mechanical design process based on plankton. These creatures have evolved into a vast array of different structural forms, but with the general criteria that they must be extremely robust to withstand the environment in the oceans, but also be light so they can float near the water surface. Unlike computer-aided designed structures, which are often based on cut-and-paste designs, natural structures are usually highly irregular. Selecting and adapting them has been shown to lead to considerable reduction in structural mass, higher stiffness and better damping. For example, an AWI design for an off-shore wind turbine base resulted in a weight reduction of almost 50 per cent without changing the construction material. Other examples of biomimetic design have been applied in the auto industry as well as in medicine. This technology is at a Technology Readiness Level (TRL) that could be readily applied to space and other projects.

TECHBREAK identified a range of technologies that are of potential interest to future space projects. One should bear in mind, though, that the scope of the TECHBREAK study did not allow for establishing partnerships. Rather, the purpose was to identify and to flag up promising technologies to ESA that could have potential application for future space missions. To this end, key European experts and institutions were identified in the final report, but the follow-up and establishing of partnerships is a matter for ESA itself.

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‘OVERWHELMING DRIVERS’ FOR SPACE RESEARCH AND EXPLORATION

1. Reduce mass, maintain stiffness
2. Build a spacecraft and space missions that can last 50 years
3. Deploy a 30m+ telescope into space
4. Autonomous geophysical survey of planets
5. Enable humans to stay in space for more than two years
Are there any successes to date that you would like to highlight?

It depends on what you mean by ‘successes’! In the TECHBREAK report, there are a number of cases where technologies – or, in several cases, a combination of technologies – under development outside the space sector, would appear highly interesting for future space missions. To give but one example: large telescopes, both ground-based and in space, have revolutionised our understanding of the universe in the last 20-30 years. However, it is a fact of life that the more we discover about the universe, the more questions are raised, and that usually means requiring even larger telescopes to provide the answers.

The reason for proposing a 30m space telescope as an Overwhelming Driver, was based on this premise. All current space telescopes have rigid mirrors – either monolithic or segmented – that can fit into a rocket fairing. As this will no longer be true for a 30m telescope, we need to adopt new approaches. Another challenge is that such mirrors not only need to be extremely smooth to reduce scattering, but also be diffraction limited. This becomes increasingly difficult with very large mirrors. The Hubble and James Webb Telescopes, along with all ground-based telescopes, have a mechanical structure to hold the telescope mirrors and instruments in strict alignment. This constraint leads to the requirement for a very fast primary focal ratio, which is not only difficult to manufacture, but could not simply be ‘rolled up’ for transport.

ESA has been intensively studying formation-flying concepts for space probes during the last few years. This would seem a highly attractive solution for the 30m telescope because it could release these constraints. A very large free-flying primary mirror can have a very long focal length, which would therefore be much easier to transport or even manufacture in situ, and much simpler to correct the optical aberration. The main disadvantage is that the optical field would be small, but nevertheless ideal for research into many hot topics in astronomy, such as extra-terrestrial planets. A further advantage of this concept is that instruments could be exchanged or juxtaposed relatively easily rather than with the complex manned repair missions required to exchange, for example, Hubble Space Telescope instruments.

**THE DEMANDS OF MODERN SCIENCE**

Thomas Edison is quoted as to have said: “To invent, you need a good imagination and a pile of junk”. Dr Martin Cullum explains to what extent he agrees with this statement.

I would not disagree with the first statement, but the ‘pile of junk’ really refers to a bygone age. Today, competition in science is so intense that even the smallest academic department has to operate in a highly professional way in order to survive. Moreover, inventing and demonstrating an idea in a laboratory is a far cry from developing a technology mature enough to work reliably in a space environment. Over the past 30 years, the concept of TRL, originally developed by NASA in the 1980s, has been an important tool for managing high tech development projects. A new technology not only has to be at the right stage of technological maturity, it also has to be available at the right time for a mission. There is no point in spending manifold resources to bring an interesting technology to a stage at which it can be deployed, if it arrives too late to be useful for the intended mission. In this sense, invention and development are far more goal orientated and less serendipitous than in the past. Nevertheless, over a longer time scale, such as that of TECHBREAK, we also had room for considering some more quirky long-shot ideas.