Manufacturing for Space from a Small Company's Point of View
a case study

Helmut Kessler, Ph.D.
Managing Director, CVI Technical Optics Ltd.

The Commercial Space Environment

Historical Development

Rockets first saw use in military applications in ancient China in the 13th century, and they saw intermittent development thereafter in China and then with greater focus in Europe. It was, however, only in the late 19th and early 20th century that the 'Father of Russian cosmonautics,' the Russian Constantin Tsiolkovsky, developed the theoretical basis for rockets as means to escape the Earth's gravity and explore space. Further groundbreaking work was undertaken by the American Robert H Goddard and the German Herman Oberth.

The Second World War saw the first use of rockets as ballistic missiles with the German V2 rocket designed by Wernher von Braun. Von Braun had been an active member of one of the German rocket societies founded as a result of general enthusiasm for rocketry kindled by Oberth's work. Eventually von Braun's work culminated in the design of the Saturn V rocket that enabled the Moon landing.

Following the Second World War and the resulting Cold War, the main emphasis of rocket development was on national security rather than space exploration. With the USA confident of its technological supremacy, astronomy and space exploration were pushed into the background until the Soviet Union launched Sputnik, the world's first satellite, in October 1957.

Shocked by this development, the 'space race' began with both the USA and the Soviet Union applying considerable funds and resources to their space programs. While the political system in the Soviet Union did not allow private enterprise, the USA's political system encouraged it, though initially all use of space was scientifically oriented.

The 10th of July 1963 saw the launch of the first communications satellite, Telstar, built by AT&T's Bell Laboratories on behalf of the USA's NASA, the UK's General Post Office and the French National Post, Telegraph and Telecom Office. The first publicly available television broadcast was undertaken on the 23rd July 1962.

Following this milestone, the April 1965 launch of 'Early Bird,' the world's first commercial communications satellite, marked the beginning of a new era. It was built by built by Hughes Aircraft Company and used by a commercial company, Communication Satellite Corporation (COMSAT) (now Boeing Satellite Systems) and marked the beginning of the commercial use of space, driven by private entrepreneurship.[1]

Private Sector Activities in Space

The main private sector activity in space, and so far the most profitable, is telecommunications. Since the second half of the 1990s, however, several other space-related, private sectors have developed:

1. Commercial launch services
2. Satellite navigation
3. Remote sensing
4. Telemetry, tracking, control monitoring and data collection
5. Space tourism

While these sectors are making an increasing contribution to the space industry, the majority share of activity is still provided by government driven investments. However, especially in the telecommunications sector it has become clear that governments are moving more and more to a regulatory role, dealing with international treaty provisions and safety aspects, rather than the direct finance of space activities.

At the same time, governments are still one of the main drivers for space use for national security and space exploration, areas where private activity is either unwanted for security reasons, or where it does not make commercial sense.[2]

Overview of Space Industries

In terms of its historical development, the space industry must still be considered very new. The participating companies are a mix of large corporations with a space industry division as well as many smaller and medium-sized companies involved in space related activities to different degrees, depending on the sector.

Generally, the large firms are the main contractors to government-operated space programs as a result of their extensive experience in government contracting, while the smaller and medium-sized companies are sub-contractors and suppliers.

The breadth of technology required for space commerce and exploration gives rise to a large variety of typical products and services offered by these subcontractors. Some examples are:

1. Specialized electronic components
2. Specialized mechanical solutions
3. Optical systems and components
4. Software development
5. Finance for private space ventures
6. Space-related insurance brokerage
7. Technology brokerage
8. Legal advice for space-related activities

While private enterprise is seeing growth in all these areas and is thereby gaining economic importance, it is nevertheless still the case that there is still a very strong inter-dependency between private enterprise and governments.[2]

Case Study: CVI Technical Optics Ltd.

Company Overview and Product Portfolio

Founded in 1972, CVI Technical Optics Ltd. is part of the global CVI Melles Griot Group headquartered in New Mexico and operating in the US, Europe, and Asia. CVI Technical Optics became part of the CVI Melles Griot Group in 2000, and has benefitted from substantial capital investment, enabling the company to expand both sales and product range. With a headcount of approximately 50 employees in the Isle of Man, CVI Technical Optics is a typical small to medium-sized enterprise (SME), but with the backing of a large parent company. The Isle of Man itself is an environment that strongly embraces and encourages space-related business.

Within the CVI group of companies, CVI Technical Optics Ltd. specializes in the manufacture of high quality, high laser damage threshold (LDT) components that are applied in a large variety of applications such as:

1. Industrial applications such as laser cutting, marking, and welding
2. Medical applications including tattoo and hair removal
3. Aerospace, defense and space applications
4. Research and development applications
5. Semiconductor applications.

An example of a CVI innovation in a space application is a vacuum compatible coating that can also withstand large temperature swings. The demand for such coating is growing due to the increased use of optical components in satellites, which requires them to be able to withstand use in the space environment, in a vacuum and under circumstances that very often involve large temperature swings as a result of the satellite facing towards the sun or away during its orbit.

Figure 1
Substrate inspection under halogen light.

The risk for an optical device under these circumstances is that the optical coating can craze, or develop small surface cracks, and thereby render the component useless. On a slightly less dramatic scale, the optical flatness of the component changes, resulting in the instrument's precision bring compromised.

Use of optics in space thus requires these issues to be solved, necessitating an improvement in optical surface polishing and coating processes that provide better adhesion of the optical coating to the substrate.

The developed process is now also being used in Earth-bound applications, as it offers the same advantages (vacuum compatibility combined with resistance to large temperature swings) for large optical components as they are being used in the world's most powerful laser systems, those involved in high laser power research.

CVI Technical Optics benefits from an experienced and long-standing workforce with many staff members having worked for the company for more than 10 years, and an annual staff turnover of less than 4%. This, combined with customer requirements that constantly push component specifications to the technologically possible limits, has over the years enabled the company to become a world leader in the manufacture of some specific components such as Fabry-Perot etalons and optically contacted polarization cubes.

Continued capital investment has at the same time enabled the company to remain competitive in its core markets through both innovation and introduction of lean manufacturing techniques.

For many SMEs, this is an important balancing act, as the 'bread-and butter' business needs to be maintained in a profitable fashion to provide the funds for development of new products and production methods, not all of which are initially customer funded.

Manufacturing for Space: Benefits and challenges

Space is a hostile environment and hence all equipment manufactured for space is required to meet demanding specifications. Apart from the hostility of the space environment itself, the remoteness of the location where the equipment is going to be used makes reliability paramount. Once a piece of equipment has been launched – an expensive undertaking in itself – it is expected and required to work because any exchange of components is generally not possible.

CVI Technical Optics Ltd. manufactures components for the space industry, such as optical mirrors, windows, lenses and polarizers. These optical components are supplied to contractors or sub-contractors who then integrate the components into a system or sub-system for the payload of a spacecraft.

Optical components used for space applications can range from almost standard components to very specific components designed and manufactured to extremely tight tolerances, which depends on the system or sub-system they are being used in. During the development phase of spacecraft bus or payload systems or sub-systems, it frequently occurs that specifications are assigned to components without any further thought, the system or sub-system designer simply assuming the manufacturability of the given part.

Only when manufacturers are being contacted regarding procurement of the component does it then emerge that certain aspects of the specifications are unachievable, even in some rare cases to the point where the specification contravenes the laws of physics. In such cases, a cost-efficient solution must be found. Cost efficient here means both with a view to the manufacture of the component itself, and also with a view to a potential re-design of the system or sub-system, and the consequent cost involved with that.

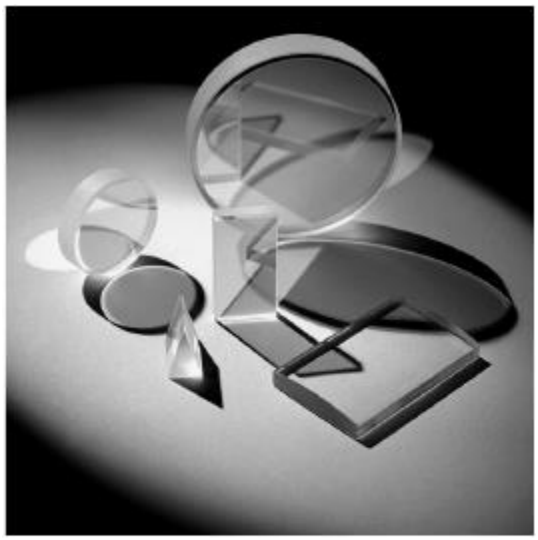

Figure 2
Various Laser Optics.

In these situations, SME-sized component manufacturers can have a distinct advantage over their larger competitors because many of the people in the firm have the detailed technical knowledge of what is and is not possible. In the case of CVI Technical Optics Ltd., most of the senior staff have risen through the company's ranks through in-house promotion, they are also often the ones who negotiate with the customer and are very familiar with the manufacturing process and its limits and cost-drivers. This means that they can contribute significantly in the design/negotiation process of looking for a new solution when the original design has been found to be unfeasible.

As a result, negotiations about the manufacturability of certain specifications and possible alternatives can be held very efficiently. The manufacturer of the system or sub-system can gather the relevant staff from their side, while two or three members of staff from CVI Technical Optics Ltd. are generally able to assess all requirements and answer all possible questions. Hence, even after the first meeting the achievable specifications are generally clear, and a way forward has been established.

This solution is generally either the manufacture of a component with altered, yet acceptable specifications, or a substantial re-design of the system or sub-system on the basis of the discussion and the decisions taken.

Hierarchies in SMEs are generally very flat and the ways of communication are direct, so decisions can be taken quickly, thereby speeding up the decision-making process, especially when time is short.

Often the changed specifications that move a component into the realm of manufacturability are generally at the leading edge of what is technologically possible. As a result, an SME like CVI Technical Optics Ltd. will generally benefit from the manufacture of such a component, as new avenues of manufacturing in both materials and process will more often than not have to be taken. After the successful manufacture of the relevant component, many of the new techniques learnt will be applied to the every-day manufacturing of other components, thereby increasing the technical capabilities and efficiency of processes of the company overall.

More often than not, terrestrial market applications for components or derivatives thereof can be found. This will then make a good case for further capital investment, allowing the company to take another step forward. As a result, even a small quantity of components manufactured for space applications will generally have a significant impact on the overall technological advancement of the product portfolio and, through improved efficiency of processes, will also reap financial benefits.

An example of a process developed for space-related optics that was then transferred with great success to Earth bound applications was mentioned above regarding the vacuum and large temperature swing compatibility of optical components.

Another example comes from a project where a high extinction ration optical polarizer was required, which again had to work in the space environment. Traditionally, optical cue polarizers consist of two prisms, where the prism of one hypotenuse of the prism is coated and then cemented to the hypotenuse of the other prism using optical cement. Once light passes through this component, the vertically and horizontally polarized components of the light are separated.

Unfortunately, conventional optical cement is not able to withstand high laser power or cosmic radiation. While it would survive cosmic radiation for a limited amount of time, on longer missions the optical cement would discolour and drastically reduce the functionality of the polarizer, jeopardizing the instrument.

To find a solution for this requirement, CVI Technical Optics developed optically contacted polarization cubes, in which the prisms are coated as before, but the surfaces are kept so flat that the two hypotenuses can be contacted together simply by molecular (van-der Waals) adhesion, thereby eliminating the use of optical cement. This makes the component stable even for prolonged use in the space environment.

At the same time, elimination of the optical cement also means that the cube polarizer can withstand high laser power, making it a useful alternative to plate polarizers traditionally used for high power applications. Especially when used in the field, the cube has the advantage of being much easier to align, saving service time and thereby maintenance costs. As a result of these advances, optically contacted cubes are now widely used within the laser industry.

Optical components manufactured for space applications generally require much more rigorous testing than Earth-bound components for the above-mentioned reasons. While the tests are generally harder, there is also often greater variation in the tests required..

While many defense-related optics require salt-spray testing to ensure that the component can cope with use in a marine environment, this is rarely required of optics destined for space. On the other hand, many Earth-bound industrial applications do not require any components to be radiation resistant, something that is of paramount importance in the space environment.

Use of non-radiation resistant optical windows in space applications, for example, will create color-centers in the component substrate and cause it to become non-transparent, so the system or subsystem it is being used in will most likely fail to function properly.

Component testing is a challenge that many SMEs face.. In fact, the testing requirements are often the biggest challenge SMEs manufacturing for space application face. Since SMEs generally have limited test equipment, both in terms of the type of specification that can tested as well as the number of test bays available, the required certification of a component can often be more costly and difficult to achieve than its actual manufacture because this must be paid for outside.

Not only does much of the testing tie up valuable metrology equipment for considerable amounts of time, but the necessary documentation in itself is very often extensive. The size of the company more often than not does not warrant the employment of a specific member of staff for such tasks, but the function of ensuring proper documentation will generally fall on the quality assurance manager, who will also deal with all other aspects of quality within the company.

Hence it is the case that not only is testing equipment used for long periods, but also manpower to monitor and record test results. This is not always reflected in the achievable sale price of the component, and can hurt the SME when the final delivery and invoicing are completed, and total costs are aggregated.

The QA documentation issue is part of a wider documentation issue associated mainly with the space industry. In most cases the documentation required when tendering for space-related work is rather extensive and requires a significant amount of time to be spent on it.

Especially in an SME, this means that manpower is diverted from other sales and technical areas of the company to enable the tender paperwork to be compiled properly as per the customer's requirement.

Using the relevant manpower naturally has a monetary cost side, but especially for an SME, where key people very often 'multi-task', there is a significant opportunity cost associated with such work. In fact, this is often the biggest hurdle in the way of 'the next step up' for an SME.

As the components will be used in space, a meticulous record of manufacturing and testing needs to be maintained. The scope of the required documentation in most cases far exceeds the scope required under standard requirements for Earth applications. For example, while the optical surfaces of standard components generally have to meet standard cleanliness ('scratch-dig') criteria, the customer will in most cases accept a report that simply states whether or not the component passes the requirement.

For space applications, a map of the surface, generated by inspection under a microscope, is generally required. As a result, the per–surface inspection time can easily increase from 10 minutes to around 30-45 minutes, depending on the level of accuracy.

Further, the nature of much of the additional documentation such as surface mapping requires the work to be carried out by a senior member of staff, but only when the volume of work in this area grows above a certain level can it be justified to employ a specific member of staff for such tasks. Expanding the workforce is a financial expense and by committing to this expansion, the SME needs to be certain that the required revenue can be generated. Especially when the staff headcount is very low, each additionally employed member of staff, especially when in a more senior position, adds noticeable percentage increases to monthly overhead.

Being prepared to take this risk, and knowing when to take it, depends on the forecast of future revenues and relates directly to the degree of risk that the owners of the company are prepared to take.

Manufacturing for Space: The Future

It is clear that space-related industries are not only here to stay, but that the commercial use of space is constantly expanding. With it goes the need for systems and sub-systems for spacecraft bus and payloads, which themselves are made up of individual components.

From this point of view, there will be significant growth in the opportunities for SMEs to get involved in the manufacture of components for space applications. CVI Technical Optics Ltd. is firmly committed to manufacturing components for space applications due to the synergies for the overall product portfolio, discussed above, which far outweigh the challenges.

Further, many components required for space applications have stringent requirements combined with generally low production quantities, and are hence less and less suited for manufacture by large companies with established and hard to change manufacturing processes. This is where the SMEs benefit from their higher agility and decision-making processes. The coming years should therefore see an increase in the number of space-related components manufactured by SMEs.

The challenge for most of them, including CVI Technical Optics Ltd. will be to move to the next step and become a manufacturer of sub-systems. Under most of the current tender procedures this will be a difficult and risky step, so only a few companies will be likely to take the step in the first place, or achieve this transition. In many cases, change will be initiated from potential customers and will ultimately be driven by their willingness to increase purchasing risk while lowering costs. This tradeoff shows a significant change from the days when government agencies were the only one procuring these components and systems; the logic of the competitive marketplace is progressively coming into space commerce as well.

Furthermore, with cost pressures running through all parts of the manufacturing sector, it has to be emphasized that an early involvement of component manufacturers will reduce design cost due to reducing the cost of potential re-design of parts of a system or sub-system. Dialogue at the earliest stages between all parties involved in a potential project will be beneficial.

Since the exchange of data is cheaper and easier than it has ever been, many hurdles that in the past prevented a closer collaboration from day one have been overcome. One can therefore only hope that improvements in this area will be made over the coming years as the needs for close collaboration in the development of new generations of commercial space hardware expand as the overall industry of space commerce also expands.

•••

Dr. Helmut Kessler

Dr. Helmut Kessler lives in the Isle of Man where he is the Managing Director of CVI Technical Optics Ltd. a company belonging to the CVI Melles Group. He was born in Hannover, Germany and it was there that he also went to school, which was followed by National Service in the German army. Following that, he studied physics at the University of Hannover. His diploma thesis investigated optical coatings for the UV and VUV light range. Having obtained his diploma, Dr Kessler went on to study for a PhD, which he completed in 1995 with a thesis on laser spectroscopy of molecules.

Dr. Kessler then moved to the Isle of Man to work for the company that is now CVI Technical Optics Ltd. where he progressed to become Managing Director.

Apart from his interest in optics, Dr Kessler has a strong interest in space research and exploration and enjoys finding engineering solutions for space related applications of optical components. He is currently studying for an executive MBA with the International Space University.

Dr Kessler is married with one child, and in addition to spending time with his family, his hobbies include classic cars and photography.

References

1. http://www.boeing.com/defensespace/space/bss/factsheets/376/earlybird/ebird.html
2. W. Peeters, *Keys to Space*, McGraw-Hill Inc, US 1999, ISBN 0070294380