COMMERCIAL APPLICATIONS OF MILITARY R&D:

U.S. AND E.U. PROGRAMS COMPARED

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In the peak years of defence spending, towards the end of the Cold War, global military R&D exceeded $120 billion annually with the U.S. at the forefront of the Western nations efforts in this field. Indeed, the U.S. contributed some 35% of the global total, creating a situation at the end of the Cold War where, for example, military R&D in the U.S. was approximately five times that devoted to health expenditure and twenty times that targeted on the environment. At the same time, the U.S. devoted 14% of its defense budget to military R&D while, in Europe, France committed almost 15%; Sweden just over 12% and the U.K. over 10%.

However, such official estimates rarely capture the true scale and scope of military R&D expenditure, even in those nations that choose to release reasonably accurate data. In the U.S., for example, during President Reagan's terms of office, it has been estimated that over 20% of the aggregate defence R&D budget was categorised as "black" (under which classification no data is revealed publicly) while, for the U.S. airforce R&D budget, the estimate was as much as 40%. Given the complexities and sometimes deliberate obfuscation by governments in defining terms such as "military", "research", and "development" and the variation in such definitions between countries and over time, the reality of this global resource commitment and its distribution remains a matter for conjecture.

Historical dimensions

Whatever its true scale, military R&D has played historically an indispensable part both in driving military capabilities and, more important to this analysis, through technology transfer to the commercial sector, has enhanced industrial productivity and competitive edge for many companies and countries where such activity is concentrated. Examples include a remarkable series of inventions - polythene, radar, jet engines, antibiotics, computers and atomic energy - and analytical tools -for example, operations research - which originated in military research and development but were then transferred very successfully to civil applications.

Prior to World War I, the military budgets of governments funded the development of wireless, aviation and guidance and control systems. The Army and Navy provided support for the development of automatically piloted aerial torpedo prototypes and flying bombs. The US lacked advanced military aircraft in 1917 and possessed few modern aircraft engines. In contrast, in Europe, the German, French and British military had subsidised aircraft and aero-engine design and development.

The driving force of military expenditure behind technological advance - and the initial synergies between military and civil aerospace development - gathered pace after 1918. In particular "military-funded construction projects culminating in systems for the mass production of various military weapons also effected momentous technological changes" (Hughes 1994, p. 426). Between 1918 and 1939, US aviation technology began to develop rapidly. In the 1920's, Curtiss and Boeing built fighters and Boeing and Martin built bombers. Modern aero-engines were being developed in the US to complement the new aircraft. Furthermore:

"the growth of civil aviation in the US paced that of military developments... and the accomplishments of civilian aircraft were translated into superior military designs...By 1935, the absolute world domination of civil aircraft design by Lockheed, Boeing and Douglas kept US aeronautics in top competitive condition. By 1939, the US ranked perhaps fifth in air power, globally." (Ziemke and Souder, 1992).

By 1940, the best American prototype fighters could match the performance of British military aircraft and Britain had no bomber aircraft comparable to the US B-17, B-24, B-25 and B-26. At the same time, aero-engine technology transfer to the US from Britain occurred with the Rolls-Royce Merlin V-12 aero-engine. The decision by the RAF in 1942 to integrate a Merlin 61 engine in the US P-51 Mustang fighter not only created an American aircraft superior to European contemporaries but, by transferring British jet engine technology to American engine manufacturers, provided the initial impetus for later jet engine design by General Electric, Pratt and Whitney and Westinghouse.

After 1945, the massive, government-driven expansion of the U.S. aircraft and aero-engine industry that commenced during the war was extended by an unrivalled government commitment to R&D in high-performance aircraft, both military and civilian. This degree of government support inevitably generated a competitive leading edge in the burgeoning global market for commercial aircraft and the world's airlines were compelled to purchase aircraft such as the Lockheed Constellation and Boeing 707 and 747 if they wished to remain competitive. Similarly, in the military aircraft market, the dominance of the US was maintained through such high-performance aircraft as the F-4, F-5, F-15, F-16, F-111 and C-130J Hercules.

The intense demand pressures on technology during World War II proved a massive stimulus to post-1945 technological advance. During and after the Second World War, the U.S. military became one of the most important drivers of technology development in the world, both as sponsor of military R&D and as a customer for its high-technology products. One of the principal reason why U.S. industry prospered and became globally dominant immediately after the war was that military technologies were in some important cases transferable to the civil sector and could be readily exploited.. As a result, U.S. government support for military R&D came to be viewed as an important contributor to national economic growth and competitive edge through commercial spin-off.

In particular, wartime projects stimulated the development of three major technological systems that spread through the world in subsequent decades with profound consequences. These three critical technological systems involved computers, nuclear energy and aerospace. Direct technological benefits accrued to the US in the two decades after 1945 from the legacy of research at wartime laboratories located at MIT, including the development of SAGE, a digital computer and radar system employed to defend the US against possible Soviet missile attacks. As Hughes (1994) comments:

> "The Whirlwind digital computer developed by Jay Forrester and his MIT colleagues for SAGE proved a seminal device that opened the doors to military and commercial development of interactive, stored-memory digital computers".

Furthermore, IBM developed much of its commercial computer hardware, utilising the learning experience of working on the Whirlwind project. From 1968 until 1972, the Department of Defense (DoD) were responsible for the development and deployment of a national US computer network that formed the basis of what was to become the Internet.

During the 1970's, the global economy began to grow around the advent of new technologies and production processes in which the distinction between civil and military applications became less important. The rapid expansion of world trade was driven mainly by growth in civil markets and, increasingly, the demands of the military sector for leading-edge technical advance no longer dominated technological innovation itself. Both the U.S. and the U.K., however, still desired to retain independent capability in advanced technology development but chose to do so by different mechanisms. Europe has taken a primarily civil sector-based route to scientific progress through such intra-European initiatives as BRITE (Basic Research in Industrial Technologies for Europe); the Eureka program; ESPRIT (European Strategic Programmes for Research and Development in Information Technology) and RACE (Research in Advanced Communications and Electronics), supplemented by national technology strategies such as the Foresight initiative in the U.K. with its defence and aerospace panel. That is not to say that the issues of dual-use and military/civil symbiosis have been ignored by European governments. Rather they have chosen to view these issues in the context of defence conversion, with European programs such as KONVER I and II, designed to facilitate resource transfer in the defence sector generally from military to civil application. In the U.K., this has been carried a stage further with the plans to establish a Defence Diversification Agency.

The U.S., on the other hand, has relied principally upon government-funded military programmes through NASA and the Department of Defense to support and facilitate the R&D and technology development effort, keeping it separate as far as possible from civil industry. However, increasingly over the last two decades, the symbiosis and synergy between scientific progress in military and civil sectors of aerospace in terms of dual-use applications has become more powerful and increasingly obvious.

Some analysts have suggested that the efficacy of such military-to-civil technology transfer is no longer what it once was, although the evidence for this assertion is somewhat questionable, particularly as Boeing in 1999 prepares to launch the F17 freighter, a derivative of the C17 military transport inherited from McDonnell Douglas. The principal reasons proposed for the apprent reduction in the effectiveness of military technology in transferring beneficially to the commercial sector are argued to be (a) the fact that the key technological requirements for some civil goods (particularly in electronics) have now outstripped those of the military sector (so that, in fact, a reverse technology `spin-on' is actually occurring) and (b) that a significant proportion of military R&D is now involved with such highly specific and specialised capabilities, delivered at very substantial cost, that applicability to the civil sector is extremely limited.

Also, and more generally, critics have maintained that the diversion of such an enormous share of national resources into the defence sector effectively "crowds out" crucial investment capital from the commercial sector of the economy and, ultimately, erodes a nation's competitive edge. For decades, there has been a widespread conviction among some economists that the share of national research and development (R&D) resources being devoted to military aims in those countries with a significant defence industrial base was too high in relation to the share being devoted to civil objectives with damaging economic consequences, particularly in terms of consumer goods market competitiveness. (For fuller discussion of these issues, see, for example, Buck, Hartley and Hooper, 1993; UNIDIR, 1993).

Although the effectiveness of technology transfer from military to civil use may have lost some of its earlier potency in recent years, it remains the case that in the aerospace sector at least, military and space-related R&D, historically and currently, have been paramount in stimulating new technological advance on the civil side (see, for example, Alic et al, 1992).

The Dual-Use Approach

In this context, the recent development of - and emphasis given by the U.S. government to - dual-use technology enables further gains to be made from closer integration of military and civil sectors of the aerospace industry. Importantly, the technology flow from such closer integration in two-way and offers a crucial way out of the dilemma posed by declining military budgets, increasing development costs and intense global competition in civilian markets.

The military technology base can benefit from the remarkable scientific advances made in civilian technology - particularly in the sphere of information technology - where today civilian technology is often more advanced than military technology. At the same time, there is scope for the civilian sector to be enhanced technologically by improved access to innovations in the military technology base. To the extent that technologies developed in the military sector can be identified as dual use, they provide the opportunity for genuine diversification and conversion of military R&D from strictly military ends. It is scarcely surprising that the pursuit of civil/military integration through the development of dual-use technology currently attracts the interest of political decision-makers who envisage its development providing a solution to many of their urgent problems. Gansler (1998), for example, has presented the argument particularly strongly in the U.S.:

> "Perhaps most essential for the transformation of our defence acquisition practices and industrial structures is the need to bring about far greater civilian/military industrial integration. In many respects, the advanced technology and the production and support processes to meet our defence needs can be better satisfied by commercial capability...The natural trend toward globalisation must be accommodated by greater civil/military integration on an international scale."

The objective, as Gansler (1998) made clear is to create:

> "a new civil/military partnership, not one in which we become simply the purchasers of commercial products and processes, but a dynamic and vigorous engagement that, through R&D, creates advanced products and systems with common technological bases and that, through the use of flexible manufacturing, allows production of our low-volume defence -unique items on the same lines with high-volume commercial items."

In general, dual-use technologies refer to those technical advances which can be utilised as successfully in the civil as in military sector. It is generally agreed that the potential for dual-use is most likely in `generic' technology areas such as information technology, new materials science and process technology where there is frequently little fundamental difference observed between civil and military focused R&D.

In the US, the Department of Defense has publicly encouraged the development of a dual-use R&D policy in recent years. The Department has started to reduce the number of precise and restrictive military specifications which manufacturers are obliged to meet, a measure now being adopted more widely in the UK under the `smart procurement' strategy. Maintaining superiority in military R&D remains at the heart of US military strategy in the late 1990's but is now also perceived to be central to a much broader economic strategy for global market dominance. Within the aerospace sector, while there are clear benefits to be derived from dual-use technologies on aircraft and space vehicles, there has been a much longer-term dependence on military R&D funding for its own sake (and, in the US, direct government-financed R&D initiatives).

In the US, in particular, much attention has been given to identifying the critical technologies necessary to maintain both military **and** economic power. A list of such critical technologies would include: materials synthesis and processing; electronic and photonic materials; ceramics and composites, computer-integrated flexible manufacturing, systems management technologies, micro- and nano-fabrication, software, microelectronics and opto-electronics, high-performance computing and networking, high-definition imaging and displays, sensors and signal processing, data storage and computer simulation, aeronautics and transportation technologies, applied molecular biology and energy technology. Most of these critical technologies have clear dual-use applications and are seen by key agencies in the US as crucial to the preservation of national economic and military strength. For example, the Office of Technology Assessment has depicted the relationship between the technology base and national economic and military power as a tree, where the roots represent generic technologies, the trunk of the tree the critical technology base and the branches are seen as specific military or civil applications of that technology (POST, 1991).

In the UK, the Ministry of Defence in 1986 identified a number of important spin-offs from defence research establishments into civil applications. These included: new aluminium-lithium alloys, aircraft noise reduction systems and helicopter rotor systems (House of Lords, 1986). A UK industrial survey in 1986 indicated that 37 out of 142 defence supply companies questioned had achieved civil spin-off from military R&D work (Select Committee on Science and Technology, 1986). In 1989, a study by the Department of Trade and Industry in the UK found that in 40 defence companies (receiving between them over half of the UK's defence procurement budget), 160 product lines had been developed for civil markets, generating a turnover of some £3.2 billion per year and representing about 20% of their civil sales (DTI/MoD, 1989). On the other hand, in 1989, a report by the UK Cabinet's Advisory Council for Science and Technology (ACOST) found that less than 20% of the UK government's military R&D was at that time targeted at technologies where civil spin-off was likely to occur (ACOST, 1989).

However, while in the U.S. the Department of Defense has given its support to a dual-use strategy and has taken practical steps to support such a strategy (i.e. cutting the number of military specifications required in defence goods), Congress has reduced its support for dual-use programs and demanded that the Defense Department justify their dual-use expenditure only on the basis of **military** need.

Military/Civil R&D Synergies

It is recognised within the aerospace industry that military programs subsidise civilian ones in a variety of ways. This is especially significant regarding the steady stream of financing provided by military contracts, which help to fund the long and risky development of civil aerospace products. In general, over many decades, it can be argued that the U.S. has gained enhanced global competitive advantage in aerospace (and in critical supporting industries such as avionics and electronics) from a covert strategy of government-financed indirect industrial support. In particular, massive government funding of research and development in the military aerospace sector has been implemented through the procurement decisions of the Department of Defense (through, for example, the Defence Advanced Research Projects Agency), the Department of Commerce (through, for example, the Advanced Technology Programme) and NASA (through, for example, the aeronautical research and development programme).

The U.S. aerospace industry, in particular, has gained much from these military/civil technology synergies where, often, whole systems developed for the military were `spun-off' to civil applications, reducing costs and risks for commercial users and providing a steady stream of finance for them which helped to fund long and often risky development of civil aircraft.(Thornton, 1995). Again, in many instances, products and technologies designed for commercial application have also been able to achieve `spin-on', that is, higher and longer production runs due to the procurement of large military orders, reducing commercial costs and enhancing competitiveness. Commercial gains here have frequently been at the sub-systems level in materials or in manufacturing process technology, broadening the relevance of, and benefits to be derived from, military-funded research and development expenditure.

The symbiosis between military and civil aircraft development in the US has been crucial in both fuelling and sustaining its leading edge in technology development. In avionics, for example, military technology continues to migrate to civil aircraft design and production including, for example, data and signal processors, data buses, software elements such as operating systems, and sensors such as infra-red and millimeter wave imagers. All of these, arguably, had their origins in the military technology developed in the 1970's; for example, digital avionics systems for the F 15 and F 16 aircraft, reinforced in the 1980's and 1990's by Joint Service initiatives to upgrade avionics for the A 12, F 22 Tactical Aircraft and the RAH-66 Light Helicopter.

More recently, and of perhaps the greatest potential strategic and commercial significance, has been the development of satellite technology in the form of the US NAVSTAR Global Positioning System (GPS). From the US perspective, the commercial impact of GPS has been described by the Office of Technology Assessment as exceeding anything envisioned by the U.S. military with civil applications moving forward rapidly.

It is important to note that, increasingly, the technology flow has become not only two-way between military and civil sectors but that the flow from civil to military in the US has also increased sharply in recent years, strengthening the synergies between the two sectors. In the US, following the end of the Cold War, the defence industry has gradually dissolved into a range of high technology industries where global competitiveness is the over-riding goal.

As a result, the most promising route to commercial success in the aerospace industry now resides in the greater integration of civil and defence sectors. New over-arching systems integration skills and new integrated production technologies allow civil users enhanced access to leading edge defence research and development while providing the military sector with access to path-breaking civil advances in information technology and microelectronics to drive forward the trend towards `information-based warfare'. The commercial implications in terms of economies of scale and scope (Hannah and Williamson, 1990) are also considerable and, together with the benefits of enhanced technology diffusion, provide further reasons for government intervention in the aerospace industry.

Government support for aerospace R&D

The direct and indirect involvement by governments in the aerospace industry offers a good example of how intervention can provide an important stimulus to business growth, technological advance and global competitive edge. In the US, Department of Defense research and development programmes, implemented principally through DARPA, while initially focused on military applications of new technology, frequently lead to technological developments that migrate to the civil aerospace sector.

Examples of civil aerospace projects deriving benefit from military aerospace developments in the US are numerous. For example, Boeing has been helped significantly in its design of large composite structures due to involvement in military programmes, particularly through its role as sub-contractor to Northrop-Grumman on the B-2 `Stealth' bomber programme. Boeing was entrusted with the development of the outboard and aft-centre sections of the B-2 using the latest in advanced composites technology. Similarly, fly-by-light/power-by-wire technology derives from military programmes, in particular that of the Sikorsky UH-60 Black Hawk programme in

1980. Through NASA's AST programme, Boeing received the fly-by-light technology and McDonnell Douglas the power-by-wire elements. The purpose of redirecting these technologies to the civil aerospace sector was to enable US commercial aircraft to access the benefits of full-authority digital computer control.

Unlike much of the European aerospace industry, US aerospace manufacturers are often involved in both military and commercial aircraft development and production simultaneously, allowing at least the potential for technology transfer within the organisation and offering the attractive prospect of significant scale and scope economies.. Indeed, at times, the inter-dependency goes even deeper. For example, it is alleged that, during the first 20 years of jet production, Boeing was kept economically viable by steady profits from its military business, especially the B-52 and Minutemen missile.

Many examples of such technology transfer can be identified in areas such as manufacturing technology, airframe development programmes and avionics. For example, in one particular instance work on commercial aircraft (such as the Boeing 737, 757,and 767) and on military aircraft (such as the Black Hawk helicopter and V-22 Osprey Tilt-wing transport) takes place within the same division and even the same engineering group. Again, in Wyman Gordon's forging and casting division, the same employees produce alloy castings for both commercial and military aircraft, the same manufacturing processes and the same equipment.

During the 1980's, the Department of Defense provided the stimulus for the development of advanced technologies and process techniques through its commitment of between $150 and $200 million annually to the Man-Tech programme. The Department of Defense throughout the decade 1982 to 1992 through the Industrial Modernisation and Incentives Programme (IMP) also provided support for sub-contractors in the aerospace industry.

U.S. Programs

The dramatic changes to defence strategy and operational requirements necessitated by the end of the Cold War encouraged the Department of Defense to radically restructure its procurement policy in 1993. Under President Clinton's Acquisition Reform proposals, future technology research contracts would be placed on a competitive basis with those producers dedicated to the pursuit of the applicability of that research to both commercial and military aircraft. The intention here was to initiate a new approach to the fostering of dual-use technology, thereby enabling the Department of Defense to gain access to lower cost, leading edge technology that resides in the civil sector of aerospace.

Declining global competitiveness in key industrial sectors encouraged President Clinton to initiate a new drive for U.S. global economic success in the 1990's. On October 28, 1993, Clinton spelt out the key role of technology policy in the new administration's economic strategy, outlining an array of devices to be employed in the future to support U.S. aerospace producers and ensure their competitiveness in the global market. These included: tax incentives for investment in R&D; switching of federal resources towards basic research and civilian technology; the promotion of defence conversion; direct expansion of Federal investment in basic research through agencies such as the National Science Foundation; and the strengthening of collaboration with industry through consortia.

A range of newly created or expanded technology support programmes was also announced including:

i) The Department of Defense's Technology Reinvestment Project (TRP)

ii) The Department of Commerce's Advanced Technology programme (ATP)

iii) The cross-departmental Co-operative Research and Development Agreements (CRADAs).

As U.S. Transportation Secretary, Frederico Pena, made clear in 1994: "while eschewing any return to regulation, we have defined a new role for government as an active player in aviation. One example of this philosophy in the Administration's initiative is the proposal to increase NASA's budget by 16% so that the agency can subsidize launches for private sector projects. The programs to receive the bulk of this funding are the Advanced Subsonic program and the High Speed Research Program." (Pena, 1994).

The critical point here is the long-term nature and multi-sectoral applicability of Federal support for R&D in manufacturing technology, a distinctive characteristic which is not replicated in Europe. For example, the US Department of Commerce has acknowledged that Federal R&D directed towards composite manufacturing research in the automobile industry has successfully migrated to the aerospace industry. Yet the US government, a frequent critic of the European's Airbus Industrie repayable launch aid programme, does not view this kind of state-funded technology migration as a form of indirect industrial support since the technology developed was not originally intended to be applicable to aerospace.

The Technology Reinvestment Project (TRP), formally controlled by DARPA, set out to achieve technically superior defence systems at reduced cost, while simultaneously strengthening the industrial base on which the Department of Defense depends. By 1995, however, critics in the U.S. Congress were seriously challenging the dual-use nature of TRP, since the technologies being developed seemed to be primarily commercial in application with few military spin-offs. Defence funding, therefore, it was alleged, was being diverted through TRP for commercial gain.

This criticism was responsible, in part, for TRP being revised and renamed the Dual-Use Application Programme (DUAP) with an enhanced focus on military applications and a halving of its budget in 1994-95. TRP and DUAP allow the Federal government to provide 50% of the funds required for a particular aerospace project with the remainder being provided by industry.

Listed below are several examples of important technology gains acquired by the US commercial aerospace industry from R&D initially funded by the Department of Defense for military purposes:

* FLASH - the fly-by-light advanced systems hardware project was a $43 millions programme over 2 years from 1993 to fund a McDonnell Douglas-led team which was developing components critical to making fly-by-light technology for both military and commercial aircraft. The lead company in this project has acknowledged that the TRP funding enabled it to accomplish the work twice as fast as it could have done without such support. DARPA estimate that FLASH could reduce aircraft weight, on average, by 2,700 kg which, in turn, could improve reliability and maintainability by some 10% while reducing wire count on aircraft by up to 80%.

* VITAL - the vehicle management system integration technology for affordable life-cycle cost project, again led by McDonnell Douglas, with a remit of developing components, interfaces, software and tools necessary to achieve affordable vehicle management systems. The objectives were to produce technology that would meet the requirements of both the military and commercial aerospace markets, extending the useful life of existing aircraft while setting the standard for the next generation. Tested on an F/A-18, VITAL technology has already migrated to commercial applications, playing a significant part in Boeing's Active Aerolastic Wing

programme which will probably be employed on three commercial aircraft, the MD-90-40X, the High Speed Civil Transport aircraft and the Future Thin-Winged aircraft. Among other US aerospace suppliers and manufacturers in the McDonnell Douglas team benefiting from VITAL technology are divisions of Allied Signal, Raytheon, Honeywell, Litton, United Technologies, Lear and Lockheed Martin.

Among many other examples of military-to-civil technology transfer are:

* ALGS - the autonomous landing guidance system, originally developed for the McDonnell Douglas F-15 STOL (Short Take-odd And Landing aircraft); and:

* PMMW - the passive millimeter wave camera project, under which McDonnell Douglas and TRW are developing a sensor that would enhance all-weather flight capabilities for both military and commercial aircraft.

It is important to note that schemes such as TRP and DUAP represent the formal and visible part of the US government's support programme for R&D in the military and commercial aerospace industry. Additionally, however, there are many other opportunities for US commercial aerospace to derive benefit from the fruits of military-funded R&D work, given the high degree to which these sectors are integrated in the US.

For example:

* the development of an Integrated Composites Centre (ICC) to electronically integrate the technical and management functions of planning, scheduling and controlling the fabrication of organic matrix composite aircraft components. This was developed by McDonnell Douglas for the F-15, F-18 and AV-8B military aircraft and then transferred to the commercial sector, saving an estimated $48 million over the period 1994 to 1999, according to the company.

* the development of the hybrid laminar flow control programme by the United States Air Force (USAF) and NASA in 1994 which was tested by Boeing on a modified commercial B-757 aircraft. The benefits to be expected here include much reduced wing drag, lower fuel requirements and a significant improvement in operational costs and range.

* the development of integrated controls and avionics by USAF to enhance fighter aircraft performance which has since been transferred to US commercial aircraft.

* the development of new wire insulation constructions for power and signal applications in aerospace vehicles by USAF for air force and navy aircraft and then applied by Boeing to some of its commercial aircraft.

A further way in which the Department of Defense provides support for the US aerospace industry, both military and commercial, is through the USAF Small Business Innovative Research programme (SBIR) and the Small Business Technology Transfer Research programme (STTR). Since 1995, small businesses have been actively encouraged to target rapid commercialisation of their innovative technologies under a Fast Track procedure, involving external funding from private investors. Under this scheme, the Department of Defense can match every $1 received from such investors with up to $4 of Department funds. Schemes such as the SBIR and STTR involve hundreds of small companies and injects several hundred million dollars into the US aerospace industry and its supply chain, which then does not need to invest itself in these technological developments.

Despite protestations by senior Department of Commerce leaders that the U.S. Government does not provide subsidies for the development and production of civil aircraft, it is clear from the evidence that civil aerospace does derive considerable benefits from military R&D, representing a kind of covert subsidy. An excellent example of this relates to the Boeing 777 which contains systems integration technology based upon that incorporated in previous military projects such as the Advanced Warning and Control System (AWACS) surveillance aircraft and fly-by-wire technology that was derived from the NASA F-8 programme in the 1970's. Another good example of technology transfer from military to civil aircraft of similar kind is the current migration of technologies from the V-22 Osprey to the Bell/Boeing 609 civil tiltrotor.

Further government support for US aerospace R&D comes from the Advanced Technology Programme (ATP) under which industry and government share the costs of project research and development equally and where small businesses and larger enterprises are encouraged to establish joint ventures to develop innovative technology. Estimates suggest that recently Boeing, for example, has received over $50 million annually from ATP support.

Under the Co-operative Research and Development Agreements (CRADAS) , a different kind of support is provided for US industry with distinct benefits accruing to aerospace manufacturers. A CRADA is a partnership between a private company and a government facility to research and develop a particular product or innovation through technology transfer to the private commercial sector. Among CRADAS awarded over the last few years are several which provide valuable technological developments for the US aerospace industry, including projects relating to electron beam processing (with Lockheed Martin, Boeing and Northrop Grumman involved in the partnership), enhanced alloys for aircraft parts (involving Boeing); and software development for application on massively parallel computers (involving Hughes, Olin Aerospace and Boeing, the latter employing these super-computer developments in the design of the HSCT aircraft.

Overall, the evidence from the US regarding government support for the enhancement of aerospace design, development and production technology appears to confirm the view of Albrecht et al (1994) that:

"There are indications that some US Defense contractors were able to use this lavish support of their defence contracts to pay the learning costs while they introduced CAD and CAM and then moved into the manufacture of high-quality components for civil aerospace."

In certain instances, however, evidence suggests that some NASA technology developments have migrated to competitor aircraft in Europe before being utilised on US aircraft, giving European aerospace manufacturers the possibility of a temporary and often brief competitive advantage. Examples of this include the development of winglets (used first on Airbus aircraft); the supercritical wing (first employed on the Airbus 320) and engine technology developments, emanating from NASA but utilised first by SNECMA in the high-pressure compressor for the GE-90 engine (Congress of the United States, 1994).

While the performance parameters and design characteristics of civil and military aircraft have long since diverged, what is often overlooked is that different engineering objectives can be achieved with generically related technologies. At the level of the whole airframe, fundamental synergies continue to exist between heavy-lift transports, tankers and civil jets. But even with modern fighters, potential spin-off exists from materials and avionics to civil applications. The avionics of a fighter aircraft are, necessarily, radically different from those of a large commercial aircraft but, today, both aircraft will share some generic technologies related to computer-controlled flight maintenance systems, constructed around an avionics architecture consisting of highly integrated modular components. For example, the Boeing 777 has a state-of-the-art avionics suite built around the Honeywell AIMS (Aircraft Information Management System), first pioneered by the digital avionics system for the F15 and F16 military aircraft.

European Programs

Within Europe, military and civil technology synergies have also been an important feature of the aerospace industry, although on a much smaller scale than in the U.S.. The early aero-engines developed by Rolls-Royce - the Avon, Olympus and Spey - all originated as military aero-engines, although more recent engines have been principally commercial in origin. In addition, SNECMA has benefited from combined civil and military sales of the CFM-56 while GEC of the United Kingdom has developed a heads-up display for use on commercial aircraft, with the required technology originating from military developments for night flying.

In Europe, however, governments have spent less overall on military aircraft than their US counterparts and military R&D has also taken a smaller proportion of overall procurement. As a result, there have been fewer opportunities to derive commercial spin-offs from military aircraft development. To some extent, reduced spin-off opportunities are attributable to the fragmented nature of European military procurement with already constrained national defence budgets often being deployed inefficiently on projects which effectively duplicate military R&D, reducing the potential for spin-offs from a more concerted, focused European military R&D strategy.

In France, the aerospace industry is financed primarily by the General Directorate for Armament (DGA) which provides the resources for two-thirds of the industry's research and development with a focus mainly on military aerospace. In the French context, it is important to recognise that the production of combat aircraft forms an essential part of France's military-industrial complex and has profoundly influenced its structure and modus operandi.

France commits a larger proportion of domestic R&D to its aerospace sector than the United Kingdom and much more than Japan and Germany, though significantly less than the United States and produces an extensive and expanding range of military and civil products. One important example is the French presence in the civil and military helicopter market. Aerospatiale effectively dominates 30% of the global civil helicopter market and also holds 60% of the capital in GIE Eurocopter, giving it a significant share of the global military helicopter market as well.

Basic research in French aerospace industry is controlled through the National Office for Aerospace Research (ONERA), created in 1946, which operates under the direct authority of the Defence Ministry. ONERA plays an important role in co-ordinating the research of all aerospace companies in the field, as well as conducting tests and simulations on their behalf. ONERA distributes the results of its advanced aerospace research freely to (*French*) businesses, and encourages them to undertake joint research projects. It is also the principal mechanism for the transfer of technology between the military and civil aircraft development.

Since the 1960's, the French government has given strong support to this process of technology transfer from military to civil aerospace, becoming directly involved as a result in major projects such as Concorde, the Airbus consortium and the Ariane space launch vehicle programme. As a result, civil aerospace activity has increased markedly over the years, influenced at government level principally by the National Centre for Space Studies (CNES). In the 1980's, under pressure from the French Defence Ministry, closer ties were established between DGA and CNES and, in 1991, the Delta Committee brought the two government agencies together to ensure close co-operation and technology transfer between military and civil space developments.

Although French aerospace is effectively divided between the military sector (Dassualt) and the civil sector (Aerospatiale), close military/civil links and synergies still exist. Aerospatiale is a significant sub-contractor for Dassault and, as long ago as the late 1970's, the two companies (with the support of the DGA) created a joint research programme to produce composite wings for the Falcon 100 executive transport aircraft.

At another level, the interdependency of military and civil technologies are also crucial for the survival of key French companies. For example, Snecma's role in the Rafale combat aircraft programme is vitally important to its long-term future. Snecma depends critically upon the civil aero-engine market for most of its income but, in doing so, works closely with General Electric in the CFM International consortium. The Rafale programme provides Snecma with leading edge technological developments with which to enhance its competence in key technology areas and prevents it becoming overwhelmed in the consortium by its US partner.

In United Kingdom, too, the government has played a prominent role in supporting the aerospace industry. The government retains a joint military and civil R&D base at the Royal Signals and Radar Establishment and at the Aerospace Division of the Defence Research Agency at Farnborough, as well as with many aerospace firms in the UK. A substantial proportion of the U.K.'s defence technology development takes place in the defence research establishments, created in 1991 from the amalgamation of four non-nuclear research establishments located in different parts of the country. From 1993, the DRA operated as a trading fund, enabling it to function in a contractor role with the government, conducting its business along commercial lines.

With Ministry of Defense funding in decline, DRA is working more with other clients and is strengthening its connections with industry generally and with the academic community. By the end of 1999, DRA plans to conduct some 15% of its annual turnover of business with clients from outside the MoD. This should help to increase significantly the proportion of U.K. R&D which has civil as well as military application, a figure estimated in 1986 by the Advisory Council on Science and Technology at about 20% of aggregate U.K. R&D.

The evidence for military-to-civil aerospace spin-off in the U.K., as in the U.S., tends to be anecdotal. A study by the U.K. Defense Manufacturers Association of their members in 1986 concluded that 37 out of 142 respondent companies had achieved spin-off from military to civil projects. Similarly, a study by General technology Systems Ltd for the U.K. government Department of Trade and Industry in 1986/7 found that in 40 U.K. defense contractors (together accounting for more than one-half of the U.K.'s defense procurement budget) some 160 civil products had been developed from defense-related technology, yielding a turnover in excess of £3 billion per annum, or about one-fifth of these companies combined civil sector earnings.

A 1989 report from the U.K. Cabinet's Advisory Council for Science and Technology (ACOST) ascertained that about one-fifth of the U.K.'s government-funded defense R&D budget was targeted on technologies which were likely to generate civil spin-off benefits, with a slightly lower estimate being produced by the German Ministry of Science and Technology in a similar study in 1990. In both cases, the main opportunities for successful spin-off were found to be in the aircraft industry in Europe, although limited by the differing requirements of military aircraft (maneuverability, speed and stealth) and civil aircraft (stability, affordable operating costs and radar visibility).

In 1994, increasingly conscious of the need to sharpen and enhance U.K. technological competitiveness, the Department of Trade and Industry established the Foresight Program with this precise remit. Among the sectoral panels established to focus attention on key sectors was one representing defence, aerospace and systems which should, in time, strengthen the potential for spin-off enhancement particularly in the aerospace sector.

Conclusion

At the end of the 1990's, the global economy is growing around new technologies and production processes that, in the main, no longer distinguish between military and civil applications. Global trade now reflects vigorous growth in civil markets and military markets no longer tend to dominate the innovation process behind technology advance as they once did. At the same time, particularly in the U.S., following the end of the Cold War, defense industries are gradually dissolving into a range of high-technology industries where global competitiveness is the over-riding goal (Scherpenberg, 1997). Defence industry mergers and rationalisation, particularly prominent in the U.S. aerospace sector, have created giant U.S. corporations far more advanced in the restructuring process than their European counterparts, with the potential to capitalise upon military/civil technological synergies in the immediate future.All the evidence suggests that, historically and currently, investment in R&D in the military sector, especially in aerospace, has paid significant dividends in terms of technology transfer to civil production and, as a result, has enhanced global competitiveness in commercial aeronautics.

As Jacobson (1990) commented:

"there has been very significant `fallout' in civilian sector industries from this large DoD investment. It has resulted in the generation and/or rapid stimulation of major commercial industries (jet aircraft, computers, communication satellites etc|).....stressing R&D has paid dividends not only for the DoD but also for the U.S. economy in general."

In the coming battle for global economic dominance in the 21st century, it would be unwise to ignore the potential that still remains in military-to-civil technological spin-off and important therefore to recognise the degree to which particular governments can and do, directly and indirectly, influence positively the global competitive edge of key industrial sectors such as civil aerospace.

References

ACOST (Advisory Council on Science and Technology), (1989), *Defence R&D; A National Resource,* HMSO, London.

Albrecht U, Lock P, and Cohen J., (1994), The Reluctant Eurofighter Partner, in Forsberg R. (ed) *The Arms Production Dilemma,* MIT Press, Cambridge, Mass., p. 188.

Alic J. et al (1992) B*eyond Spin-Off: Military and Commercial* Technologies *in a Changing World,* Harvard Business School Press, Boston.

Buck D., Hartley K, and Hooper N., (1993) Defence Research and Development, Crowding Out and the Peace Dividend, *Defence Economics,* Vol. 4., pp 161-178.

Congress of the United States (1994), Government Support of the Large Commercial Aircraft Industries of Japan, Europe and the United States, in *Competing Economies,* ch. 8, p. 344.

Department of Trade and Industry/Ministry of Defence, (1989), *The Potential for Civil Benefit from Defence Research and Development,* DTI Library, London, mimeograph.

Gansler J., (1998) *Military and Industrial Cooperation in a Transformed, NATO-Wide Competitive Market,* XVth International NATO Workshop on Political-Military Decisuion Making, Vienna, Austria, June 22nd.

Hannah L. and Williamson P., (1990) `Realising the Potential of Scale and Scope - A Review Article', *Business Strategy Review,* Autumn.

House of Lords, (1986). First Report of the Select Committee on Science and Technology, Session 1986-1987, *Civil Research and Development*, HMSO, london, HL 20-II, pp. 92-94.

Hughes T.P. (1994) Beyond the Economics of Technology, in Grandstrand O., *Economics of Technology,* Elsevier Science, ch.18, p. 426.

Jacobson C.G. (1990) (ed) *Strategic Power: USA/USSR*, Macmillan, p. 309.

Pena F., (1994) from a speech, Washington D.C., 6th January.

POST (Parliamentary Office of Science and Technology), 1991, *Relationships Between Defence and Civil Science and Technology,* POST, London, May, p. 9.

Select Committee on Science and Technology (1986), *Civil Research and Development,* pp 92-94.

Scherpenberg J.V., (1997) Transatlantic Competition and European Defence Industries: A New Look at the Trade-Defence Linkage, *International Affairs,* Vol. 73, 1, pp. 99-122.

Thornton D.W., (1995) *Airbus Industrie: The Politics of an International Industrial Collaboration,* Macmillan.

UNIDIR, (1993) *Economic Aspects of Disarmament,* United Nations, New York.

Ziemke M.C. and Souder W.E. (1992) Co-operative International weapons Development through echnology Transfer - From the Civil to the Gulf War" in McGovern J.F., Shapira P., and Ziemke M.C. (eds) *Proceedings of the Technology Transfer Society*, 17th Annual Meeting, *Atlanta, pp 165-172.*