BERR | Department for Business Enterprise & Regulatory Reform

EVALUATION OF THE CIVIL AERONAUTICS RESEARCH AND TECHNOLOGY DEMONSTRATION (CARAD) PROGRAMME

MAY 2008

EXECUTIVE SUMMARY

1. This evaluation addressed the Civil Aeronautics Research and Technology Demonstration (CARAD) Programme, later known as the Civil Aeronautics Research and Demonstration Programme and then the Aeronautics Research Programme. It was initiated within the (then) Department of Trade and Industry (DTI) to support long-term pre-competitive research and demonstration. The evaluation covered the period 1990 to 2002 when the programme evolved to increase the number of small firm participants, and to include joint Calls with the Ministry of Defence (MoD), and joint projects with the Engineering and Physical Sciences Research Council (EPSRC).

2. From 1990 to 2002 programme expenditure was over £270 million (Annex A). Grant funding was open to businesses, universities and research organisations. The grant-aided work was the priority for this evaluation, as this mechanism has most relevance to future research support. Running costs (also in Annex A) equated to around 3% of the annual programme expenditure.

<u>Reason for the evaluation</u>

3. By 2002 the programme had run for 12 years with expenditure of £278 million in support of research and demonstration in a strategic sector of UK industry. Only partial evaluations had been possible since 1990, and a fuller assessment was required of the achievements in relation to the original rationale and objectives.

<u>Methodology</u>

4. Interviews with a selection of project grant recipients provided evidence for assessment of the achievements, benefits and outcomes since 1990. Structured interviews were held with research managers from 20 of the 39 organisations that each received over £500,000 of CARAD Programme funding. There was more than one interview at larger organisations in order to obtain views from managers of different projects. Feedback was sought from the programme management team within DTI.

5. In addition, views were sought about the value of CARAD support and its role in their organisational strategies from directors of companies that were major recipients of grants as well as from programme managers at the Engineering and Physical Sciences Research Council and Ministry of Defence.

<u>Rationale for government support</u>

6. In 1990 DTI Ministers agreed an overarching rationale that noted the high degree of technical and financial risk over timescales of 10-15 years or more in researching and developing new civil aircraft and associated equipment. A contributory factor was the reluctance of capital markets to invest in research where they lack understanding of high technology, the risk and the business operations.

7. The rationale recognised that aerospace has significant barriers to entry as the long product cycle makes returns uncertain, and it is difficult to acquire the technological expertise. It also took into account the need for aerospace companies to maintain a programme of technological innovation across the full range of inter-dependent

technologies to keep the sector as a whole competitive, to be attractive partners in collaborations nationally and internationally, and to compete with US firms.

8. In 1996, the sub-programmes were aerodynamics; advanced helicopters and rotorcraft; avionics and mechanical systems; materials and structures; and propulsion systems. Government priorities remained fuel saving and the environment (noise and emissions) in addition to cost reductions and shorter time to market. A consultation exercise involving industry, research organisations, the Defence Evaluation and Research Agency (DERA) and academia concluded:

   - There was continuing need for a spectrum of research, demonstration and development;
   - The CARAD-funded work at DERA required further transparency and accessibility to industry;
   - University work should be supported only where the proposals and funding were channelled through industry.

9. This led to a revised rationale and a reshaped third CARAD Programme in October 1996.

10. The rationale evolved further in 2001 as the fourth CARAD Programme moved towards support for competitiveness through knowledge transfer to other sectors.

11. The wider benefits to the UK economy that were presented in support of the programme included:
    - technology transfer to other sectors;
    - training and interchange of research staff;
    - sub-contract business and collaboration opportunities for small and medium sized firms (leading to improved competitiveness of the UK industrial base as a whole);
    - and support for international standards.

<u>Objectives</u>

12. The main objectives were:

    - To improve UK industry competitiveness and market share by developing world-class technology from which to launch successful ventures in world civil aerospace markets;

    - To make UK industry an attractive partner in civil collaborative projects in Europe and internationally;

    - To encourage longer term industrial investment in innovation without early prospect of commercial return;

    - To help maximise spin-off to civil aviation from military research and demonstration support;

- To increase collaboration with higher education institutions and promote maximum “pull through” of academic research;

- To help meet global standards e.g. for reduced emissions (aircraft & aeroengines);

- To study the scope and recommend ways of disseminating CARAD technology to non-aerospace sectors in UK, and other R&D programmes (1990-2000);

- To promote the participation of small and medium sized enterprises (SMEs) in collaborative ventures (1990-2000).

13. The review of projects for this evaluation demonstrated that the portfolio of CARAD research projects produced outcomes that met the stated objectives of the programme, although the extent of dissemination was limited. However, the programme objectives were qualitative not quantified. It was therefore very difficult to judge:

- how much contribution CARAD made to progress against each of these qualitative but directional objectives;
- the extent to which CARAD funding was essential in delivering these outcomes;
- whether projects funded by CARAD produced greater spillover benefits than other similar research & development funding programmes.

14. Nor did our interview schedule provide a direct test of whether the objectives were appropriate in the first place (or the balance of importance between them). Interview respondents recognised these objectives as desirable outcomes for the UK aerospace industry and for CARAD; but the deep stakeholder involvement in the design of the programme makes such a pattern of response almost inevitable.

Outcomes of the Programme

15. A majority of interviewees stated that they gained world-class technology, were able to develop new products or services, and had improved their market position. Almost all those interviewed said that participation raised the skill levels in their organisation.

16. CARAD research also helped them to meet, or have less chance of failing, regulatory standards, for example in aircraft systems components and processes and safety standards.

17. Expenditure on aerospace research rose by at least the amount of DTI funding and was more effective because of collaboration through pooling of skills and knowledge, greater cohesiveness of the UK knowledge base, and economies of scale. By spreading technological knowledge across a wider range of organisations there was greater chance of beneficial spin-off.

18. DERA could run civil and military programmes together, which gave extra leverage over either programme alone. DERA could therefore orchestrate technology research through the aerospace sector from the basic research stage through to its use in industry.

19. CARAD research collaborations played a role in building links within the aerospace sector and with universities, and the links continue on a project-by-project basis. Support from both EPSRC and DTI enabled synergy and some strategic coherence in the aerospace area.

20. The networking and knowledge transfer between companies and universities as project partners extended to the rest of the aerospace supply chains, and to other industry sectors with similar components, processes or services. Collaborations strengthened the technology base of UK companies and often remained beyond the original project, to pursue further research, disseminate results, and set up student placements.

21. Advances in technology were transferred to other businesses in the aerospace and related sectors (transport, power generation, engineering, specialist materials, and security) through the demands of the supply chain. However interviews showed that in practice there was a considerable gap between technology being considered applicable to other sectors and subsequent transfer taking place. Knowledge transferred through movement of staff to other employers and sectors, mainly through those with partnership or collaborative links to the researchers, however the interviews showed that there was relatively little movement of staff between the aerospace engineering companies.

22. Effort was made to encourage the direct dissemination to other sectors of technological knowledge generated by CARAD supported research. Technology dissemination and spin-offs have taken place by other routes such as the enhancement of the technological expertise of lower tier suppliers who also produce leading edge products, materials and software for other sectors;

23. One sixth of the businesses taking part in CARAD were small or medium-sized, and they gained in terms of technology, partners, skills and new contacts.

Conclusions

24. The CARAD Programme enabled DTI to take a strategic view of the coherence of research in the aerospace sector that no single player could achieve, and to focus discussions with the sector on long term development of strategic technologies. This facilitated a collective sense of direction and in particular it helped to remove a bias against high risk (high return) and/or longer-term research. The sector was then able to attract more investment from UK and overseas, and the scale of CARAD (at least £20 million annually) would have been a major factor in this.

25. DTI grant support was responsible for additional collaborative research that contributed to improvements in all the aspects addressed by the programme's objectives. The amount of aerospace-related research increased by at least the amount of Government funding.

26. The CARAD Programme added value by enabling leading edge research and demonstration, which supported competitiveness both for the aerospace sector and for related sectors. There was subsequent exploitation of new technology and processes,

although it was difficult for participants to quantify exploitation benefits from specific CARAD projects.

27. The aerospace sector gained benefits from a strengthened supply chain, and increased skills. It also gained synergy with MoD research, which enabled applications of advanced technology for civil aerospace. Without the CARAD Programme (and the European Framework programme) there would have been very little drive for civil research at DERA, and potential for defence/civil synergy would have been lost.

28. However interview evidence showed limited benefit through transfer of technology knowledge to other companies and sectors. Tacit knowledge, held in staff experience, is guarded within companies for their commercial advantage.

29. There was difficulty in identification and attribution of spillover benefits from the programme because:
    - CARAD technology is combined with technologies from other research sources into products and services;
    - There are multiple routes to product development using the methods and technologies from research projects;
    - Up to 10 years may have passed since project completion, and traceability is hindered by changes in company structures and staff;
    - Spin-off technologies, products and services may not be officially recognised by patents and licences.

30. Businesses, universities and research organisations with successful experience of project leadership and participation in the CARAD Programme were better able to win and lead European Framework research projects, with consequent gains in technology, funding, partners and access to potential new markets.

31. There were benefits to the public good in safety, security and environmental applications and standards that would probably not have taken place when they did without government steering and support.

32. The CARAD Programme provided a means by which small and medium-sized firms could play a greater part in research into advanced aerospace technologies, and make links to larger companies that could be customers.

33. By demonstrating the above benefits the interview evidence supports the substance of the rationale and additionality arguments contained in the four successive ROAMEs agreed during 1990-2002.

34. The objectives of the programme were met, however they were specified in fairly open terms, without quantified baselines or targets, making it difficult to measure specific improvements in competitiveness, market share and investment.

35. The technical expertise of the DTI programme managers enabled well-informed technical appraisal of proposals and guidance to project consortia. Their knowledge of the sector and strategic implications enabled them to adapt and continue CARAD projects as change occurred.

36. The majority of the interviewed projects delivered in accordance with their grant offer. Project monitors contributed to this success, drawing respect from all interviewed participants, for their knowledge, experience, and guidance at key stages. Their experience in the technologies and project management was valued at decision points for project and programme managers, to find solutions that enabled projects to continue rather than be terminated.

Overall perspective

37. The development of aerospace technologies is by evolution rather than a series of separate discoveries, so research continuity is essential. The CARAD Programme enabled continuity and coherence of research, and provided a strategic approach for support to the aerospace sector.

38. It enabled UK researchers in companies and universities to build their capabilities and credibility, and to bid from a stronger base to European programmes. By enabling a stronger research capability in companies and universities, and supporting collaborative research within a strategic approach, CARAD helped to maintain and build the coherence and competitiveness of the UK aerospace sector, making it more attractive for inward investment and further global collaboration. This in turn increased the economic benefits that the UK derives from the presence of the aerospace sector and its suppliers, although opportunities for wider exploitation in other sectors were sometimes delayed by the need to retain confidentiality for commercial advantage.

39. It is, however, very difficult to judge whether the benefits from the CARAD Programme were greater or smaller than those that would have been realised from alternative uses of public funds such as more generic R & D support programmes.

40. To place the programme in perspective, it should be noted that the model of government support has evolved since CARAD was initiated. Support for sector-specific research and demonstration (as CARAD offered the civil aerospace sector) has been superseded by the move to encourage business investment in, and use of, technology across all sectors of the UK economy through the Technology Programme, although it is recognised that government should support strengths in important R&D intensive industries such as aerospace.

41. Within the Technology Programme, there has also been a transition to use of contractors for programme management rather than in-house resources. In addition, for the area of research support in particular, specialist assessors rather than in-house resources are now engaged to appraise proposals for grant funding.

42. Responsibility for collaborative R&D grants, together with Knowledge Transfer Networks (KTNs) and Knowledge Transfer Partnerships (KTPs) was transferred from the DTI to the newly created Technology Strategy Board (an executive non-Departmental Public Body) in July 2007. The Technology Strategy Board launched its strategic plan in May 2008.

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CHAPTER 1
Introduction, evaluation methodology and resources

Introduction

The CARAD Programme was initiated to support long-term pre-competitive research and demonstration in aeronautics. Since 1990, programme expenditure has been over £270 million (Details at Annex A). Grants were available to industry, universities and research organisations for proposals in several areas of aeronautics technology including airframes (later became aerodynamics), avionics (later became advanced systems), propulsion systems, materials and structures. Support of up to 50% funding of eligible costs was offered for three types of projects: research, demonstration, and feasibility studies. Product development was excluded. Project proposals were appraised by DTI, and projects were monitored by specialist external monitors.

In addition to the grant funded research, there were programmes of intra- and extra-mural research at the Defence Research Agency (DRA) and its successor the Defence Evaluation Research Agency (DERA)[1].

The CARAD Programme was initiated in 1990 by DTI, advised by the Aerospace Committee, a senior industry forum established in 1999 to advise DTI Ministers on strategic issues of competitiveness and global restructuring. The stakeholders included the Society of British Aerospace Companies (SBAC). The programme evolved during the 1990s to include more small firms, joint Calls with the Ministry of Defence (MoD), joint projects with EPSRC, and funding for projects of a "challenge" type for example the series of projects for the More Electric Aircraft Challenge. The strategy was determined in consultation with the Aerospace Committee.

The rationale for the programme took into account the international context. UK's global competitors in aerospace also support technology research and development in their national aerospace industries by several means, and European funding for collaborative research in aerospace is available through the Framework Programme.

The aeronautics and aerospace sector had received funding through the Civil Aircraft and Aeroengine budget for at least 18 years before the CARAD Programme. Annual funding figures are given at Annex A Table 4. Since the CARAD Programme, technology research has been supported by the Technology Strategy Board through Collaborative Research & Development.
(**http://www.innovateuk.org/**)

Reason for the evaluation

By 2002 the programme had run for 12 years with expenditure of £278 million in support of research and demonstration in a strategic sector of UK industry. Only partial evaluations had been possible since 1990, and a fuller assessment was required of the achievements of the programme compared to the original rationale and objectives.

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[1] All references to Defence Research Agency and Defence Evaluation Research Agency in this report are shown as DERA.

Scope of this evaluation

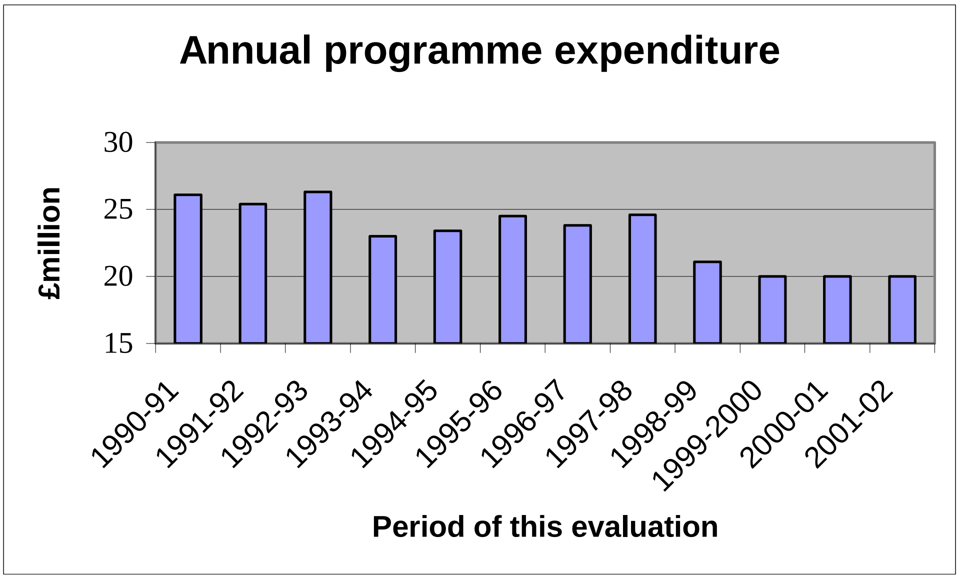
The evaluation focuses on expenditure on grants for the collaborative research and demonstration projects as this mechanism has most relevance to future programmes.
As the programme evolved four main technology areas took priority: aerodynamics, advanced systems, propulsion, and materials & structures. Technologies for cryotechnology and rotorcraft were a comparatively small part of the CARAD Programme and were not included in this evaluation. Cryotechnology included the European Transonic Windtunnel (a European capital project), and funding for helicopter technology was less than £2m over the evaluation period.

Resources for CARAD Programme

For the period covered by this evaluation, 1990-91 to 2002-03, the programme budget (Figure 1) was:

CARAD 1 - 1990 to 1993, budget £76m
CARAD 2 - 1993 to 1996, budget £71m
CARAD 3 - 1996 to 2001, budget £108.5m
CARAD 4 - 2001 to 2006, budget £100m

Figure 1 Annual expenditure



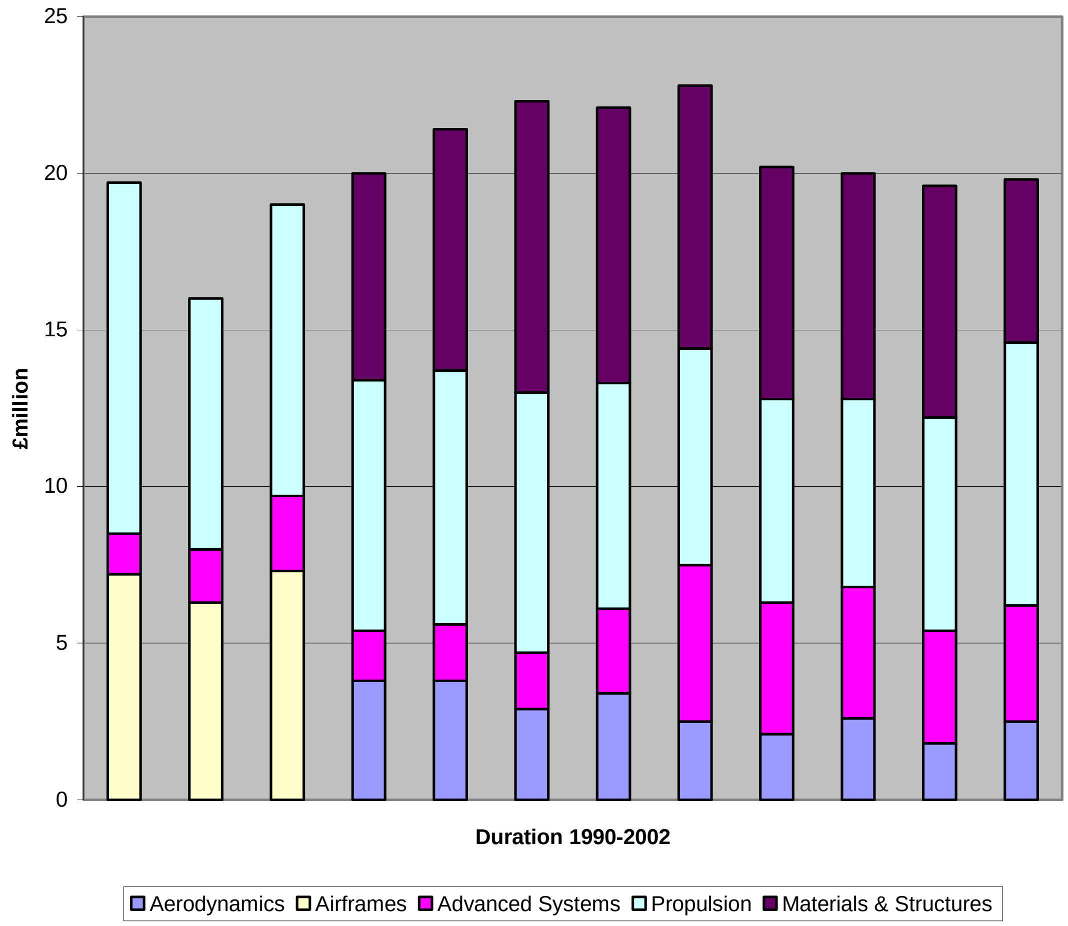
Most of the expenditure on CARAD Programme until 2002-03 was directed to research projects. Of this, the grant-aided work of at least £132 million was the priority for this evaluation.

CARAD extra-mural and intra-mural programmes, formerly managed by DERA (now QinetiQ), are considered in overview only, as those models of programme support had been discontinued by the time this evaluation was discussed. These methods of funding are not appropriate for new projects as QinetiQ is a private company. Expenditure from 1990-2002 totalled £146 million:

Intra-Mural programme	£92.8m
Extra-Mural programme	£49.5m
DERA programme management	£4m

Annex A Table 2 gives the annual CARAD spend for each sub-programme, shown in Figure 2 below. Propulsion systems have always received the largest proportion of the budget, that is around a third. The Materials & Structures area accounts for around a quarter of the expenditure. DTI's contribution towards the construction, commissioning, calibration and initial operation of the European Transonic Windtunnel (ETW) in Köln is included for completeness in Annex A Table 2, although this is outside the scope of this evaluation.

Figure 2 Expenditure for each technology sub-programme.



In total 232 organisations are shown in the CARAD Recipients database as grant recipients. Of these 159 were large[2] companies, 29 were small and medium sized[3] companies, 32 were universities and 12 were research organisations. The information is taken from the CARAD finance database for 1995-2002. (There is no database for the pre-1995 period.)

Figure 3 Analysis of organisations receiving CARAD project grants.

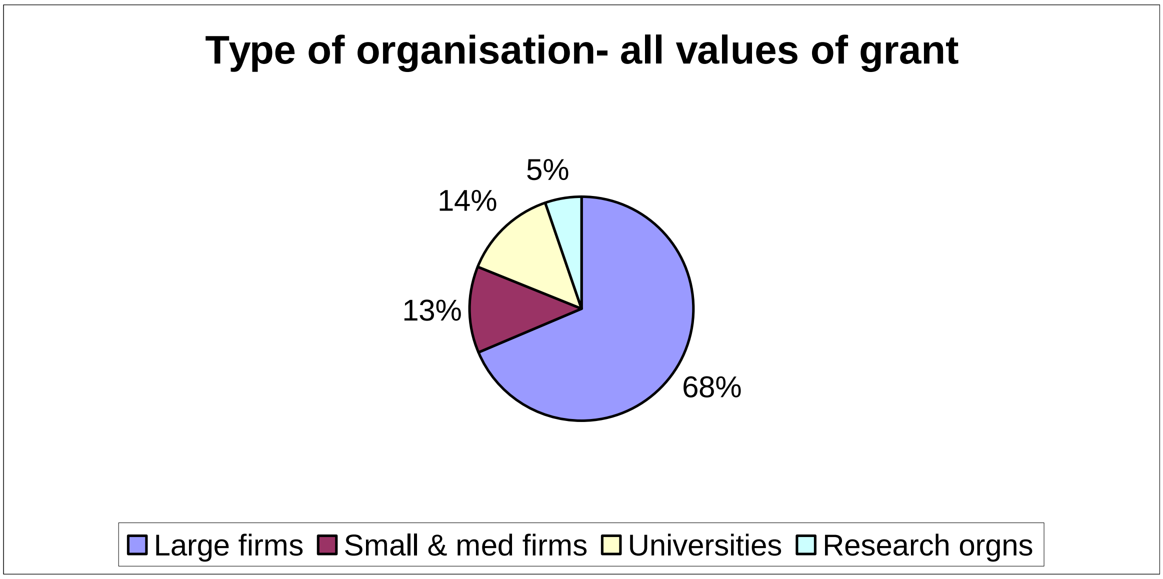
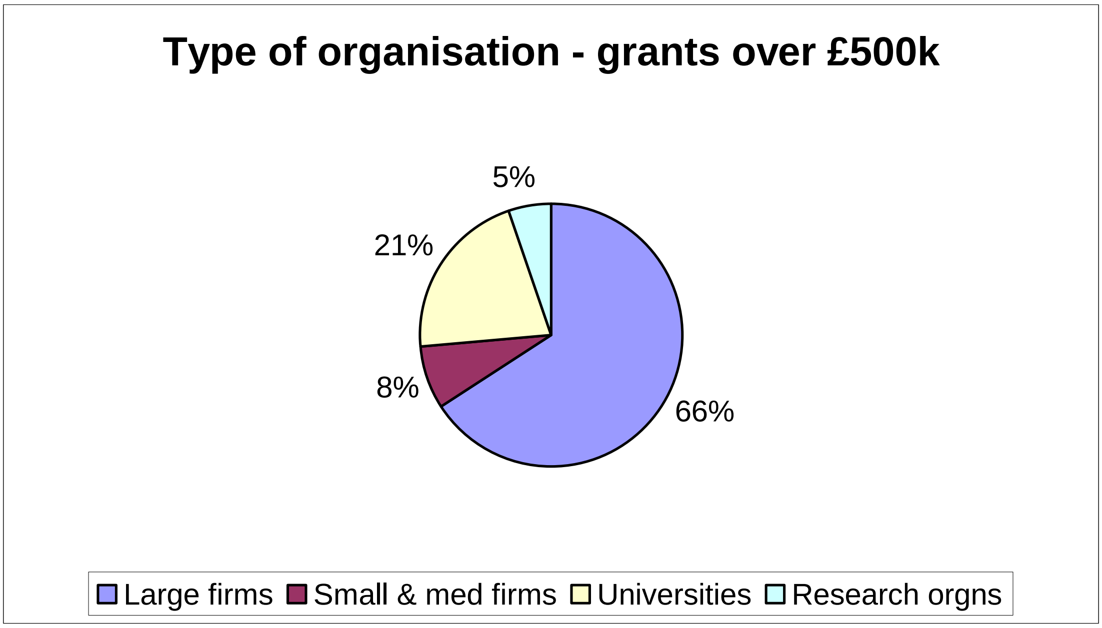


Figure 4 compares the type of organisations in receipt of grants totalling over £500,000. The participants for the evaluation survey were drawn from these recipients, named in the list at Annex B. The university participation is relatively higher than in the programme as a whole (21% compared with 14%). In contrast, SME participation is relatively lower in the larger grant values (8% compared with 13%) than in the programme as a whole.

[2] Large firms have 250 or more employees
[3] Firms with less than 250 employees

Figure 4 Organisations in receipt of grant funds totalling more than £500,000.



In respect of the Department's running costs, salary and other running cost details were calculated annually for the internal annual reports. These showed that a number of staff were assigned part-time to CARAD and that staff numbers on the CARAD Programme decreased over the period. Running cost figures are given in Annex A Table 3, and equate to around 3% of the programme expenditure.

Evaluation Methodology

The evaluation was planned as a strategic overview with particular attention on grant-funded work. The programmes of intra-mural and extra-mural work funded at DERA were considered in overview only, as these methods of commissioning research are no longer used and findings would be of limited value for future programmes.

The main technology areas reviewed were Aerodynamics, Advanced Systems, Propulsion and Materials & Structures.

The roles of EPSRC, universities, and MoD in the CARAD Programme were examined in broad terms rather than in detail.

A survey of a selection of project grant recipients provided evidence for assessment of the achievements, benefits and outcomes since 1990. Structured interviews were held with research managers in a randomly selected 20 from the 39 recipients of over £500k CARAD funding. This selection was stratified by technology area, and by industry/HEI split using proportionate allocation. There was more than one interview at larger organisations (Airbus, Rolls-Royce, QinetiQ) in order to obtain views from different projects. Participants from two of the partner organisations were interviewed in respect of four projects. Feedback was also sought on the programme management and administration. The interview schedules are reproduced at Annex C. The organisations interviewed are listed at Annex D.

In addition, views were sought about the value of CARAD support and its role in their organisational strategies from programme managers at EPSRC and MoD, and from Directors in the following organisations:

- Aerospace primes Rolls Royce, Airbus UK, and Smiths Aerospace;
- Society of British Aerospace Companies;
- QinetiQ.

Resources for the evaluation

The Department's Evaluation Methodology Group (EMG) commissioned the evaluation in 2003. The Assessment Unit in Innovation Group Economics and Evaluation team (now Science and Innovation Analysis within Department for Innovation, Universities and Skills) researched a scoping paper followed by an evaluation plan. The plan was agreed in September 2003 by EMG, assuming resources of two evaluators part-time and additional externally contracted studies. In the event the in-house resource was reduced in mid 2004. Economic advice was contributed as 17 days consultancy. The Patent Office was commissioned in 2004 to extract patent registrations in relevant technology areas.

The need for the planned external studies was superseded by studies by the Aerospace Innovation and Growth Team in 2003, for example of the technology spin-offs to other sectors, and the key characteristics of the aerospace sector. In 2004 DTI tendered for a study of Spin-offs from CARAD into aerospace and other sectors but due to the complexity of the requirement, and the likely cost of a meaningful and thorough study, no study was commissioned.

CHAPTER 2

Rationale for the CARAD Programme

Development of the rationale

> In January 1990 Ministers agreed an overarching rationale for the programme[4]:
> *Effective competition to the major US suppliers is required to avoid a monopoly that would be to the detriment of the UK as a producer, purchaser and user of civil aircraft;*
> *Many countries, beside the US, give state aids to aerospace industries enabling predatory pricing. Without state aids in UK, companies could find more favourable funding environments for technology research in competing countries. The high barriers to aerospace sector entry would inhibit new businesses from set-up in UK, thereby reducing the size of the competitive market available to UK consumers. Although the UK should not contribute to the escalation of competing subsidies, Government should be prepared to act where justified;*
> *There is a high degree of technical and financial risk over timescales of 10-15 years or more in researching and developing new civil aircraft and associated equipment. Capital markets are reluctant to invest in research where they lack understanding of high technology, the risk and the business operations.*

The rationale recognised that aerospace has significant barriers to entry as the long product cycle makes returns uncertain, and it is difficult to acquire the technological expertise. It also took into account the need for aerospace companies to maintain a programme of technological innovation across the full range of inter-dependent technologies to keep the sector as a whole competitive, to be attractive partners in collaborations nationally and internationally, and to compete with US firms. It was argued that technologies cannot be transferred easily from competitors without some depth of background knowledge of use of the technology, and therefore investment and research were the only route for firms towards innovation and staying competitive.

Wider benefits were cited as: technology transfer to other sectors; training and interchange of research staff; sub-contract business and collaboration opportunities for SMEs (leading to improved competitiveness of the UK industrial base as a whole); lower costs to UK airlines for aircraft; lower fares for UK airline passengers; and support for international standards.

There have been four successive CARAD Programmes since 1990[5], each based on a specific ROAME statement. Funding priorities throughout were set in consultation with industry, and addressed Government policy on competitiveness, fuel saving and emissions.

In the original CARAD Programme four technical sub-programmes were identified of which three (airframes, avionics and propulsion systems) are covered by this evaluation.

In CARAD 2 the scope was expanded to six sub-programmes: aerodynamics; avionics and equipment; cryogenics; helicopters; materials and structures; and propulsion systems.

For the proposed CARAD 3 Programme in 1996, the sub-programmes were aerodynamics; advanced helicopters and rotorcraft; avionics and mechanical systems; materials and

[4] From the original Ministerial approval 1989
[5] Department's internal file AU/5/2/088 Parts A, B, C

structures; and propulsion systems. Government priorities remained fuel saving and the environment (noise and emissions) in addition to cost reductions and shorter time to market. Following a request by the Programmes Committee (senior DTI officials responsible for authorising Programme expenditure), a consultation exercise was undertaken which led to the reshaping of CARAD and a revised ROAME in October 1996. This consultation, involving industry, research organisations, DERA and academia, concluded that:

- There was continuing need for a spectrum of research, demonstration and development but as demonstration activity is more expensive than research and funds were limited, the balance of CARAD towards research was unchanged;
- CARAD could be delivered as Challenge funding, despite mixed previous success, in some appropriate areas;
- CARAD funded work at DERA required improved transparency and accessibility to industry;
- University work should be supported only where the proposals and funding were through industry;
- DTI should further extend contracting out of routine elements of project technical assessments and appraisal.

The agreed CARAD 3 Programme (1996 to 2001) also addressed European issues, including maximising the return from Framework Programme 5, participation in task forces, and membership of a European collaborative research group in civil and military aeronautics (GARTEUR).

In the CARAD 4 Programme the rationale evolved towards support for competitiveness in the knowledge driven economy by generating, and pioneering, application of knowledge that is taken up later by other sectors. New aspects were brought forward:

- Support for long-term technology acquisition assisted UK to hold manufacturing investment in this global market where investment follows centres of technological expertise;
- Research support bolstered the competitiveness of larger companies, who were the heaviest investors in R&D and most able to ensure the necessary exploitation;
- The reduction of MoD research funding meant reduction in research funds for dual use technologies, and so companies in the civil research field were more reliant on DTI support;
- Many SMEs (in excess of 3000) were reliant on the supply chain in the flight systems and other areas;
- DTI support, rather than MoD (or other) support allowed IPR to remain within a company, rather than belonging to government.

To maximise benefit to the sector, the CARAD Programme supported all sizes of firms. The SMEs played a specialist role, and often were niche component suppliers if they were not able to develop technologies further with their own resources. They could be good catalysts for innovation, however small firms’ expertise might be confined to a single person and therefore had less depth of resources than large firms.

Critique of the Rationale

This rationale is well supported in nearly all its elements. A key element in the CARAD rationale was that the long timescales, uncertain outcomes and complex technological nature of aerospace research make capital markets reluctant to provide finance.

Interviews with companies and the SBAC confirmed the long term and uncertain nature of aerospace research. They noted that financial markets usually lend against the total view of a company shown on the balance sheet. Research will be only one of the demands within a company, and project finance may be offered only if the investments concerned form a clearly identifiable discrete project with a fairly certain income stream. Also, additional borrowing may result in an increase in the cost of existing borrowings or at the least in the cost at which they can be re-financed. This tends to encourage a conservative attitude to borrowing amongst large companies including those in aerospace.

Company boards in larger aerospace companies establish systems of corporate budgets and financial controls that take account of their overall financial situation, based on experience and financial prudence regarding investment for the longer-term future. There is a strong incentive for them to be enforced to avoid a cumulative loss of financial control, failure to meet short term profits forecasts etc.

In these circumstances aerospace firms will tend to set research budgets, for example as a percentage of turnover, to which they keep fairly strictly. This is confirmed by interviews carried out as part of the CARAD Programme evaluation. The larger aerospace companies will aim to build up capabilities in those technologies that they expect to incorporate in their systems. The more advanced and wide-ranging are these capabilities the more likely they are to win contracts. Gaps in their range of capabilities mean either that they have to offer customers less sophisticated systems (reducing their chance of winning the order) or go into partnership with a company that possesses the capabilities that they lack. Both options will tend to reduce or narrow their competitiveness over time unless the partner is a dedicated supplier whose cooperation can be guaranteed in the longer term.

Many governments, particularly the US, provide funding for aerospace R&D. While much of this is for military purposes the dual nature of aerospace technology means that it acts to support civil aerospace activities as well.

Public subsidies for aerospace tend to be far higher than are normal for other manufacturing sectors and are the subject of a separate international agreement between Europe and the USA. Other countries provide subsidies in attempting to get in on the act, because of the military and ‘strategic’ nature of aerospace and its role in driving advanced technology and high-technology industry. Failing to match other countries’ state aids means that UK loses out.

Aerospace has significant barriers to entry and if UK based firms fall behind their principal foreign competitors due to higher state aids abroad, the UK will find it very difficult to regain its former position.

At the higher reaches of the supply chain aerospace is a systems integration industry and complex product sector. The competitive edge of firms consists of their ability to integrate a range of technologies into a complex system or aircraft that meets customer needs. This competitiveness is based on a stock of human capital and tacit knowledge and the routines and systems, as well as the profits to finance future developments. It is not easy for new entrants to break into such a market because the complex set of capabilities involved is difficult to transfer and because new entrants lack credibility with customers.

The aerospace sector places a major role in the creation and development of new technology and technological knowledge and provides significant spin-off to other sectors. It provides significant market opportunities to a range of high-technology SMEs.

A firm needs capabilities in and access to the technologies that are used in aircraft systems. The source of a technology may be in-house, from suppliers or in some cases from universities. In the case of external sources, close business contacts and geographical proximity between the firm and the sources of technology will be a distinct advantage.

There is thus a need for adequate and appropriate research and early stage development in the technologies that the aerospace sector is likely to require. At least some of this R&D should be collaborative so that the national knowledge base and stock of expertise is cohesive, allowing synergy and economies of scale and scope and avoiding duplication. This in itself constitutes a rationale for government support (to which can be added externalities and uncertainty).

However the bulk of aerospace RTD expenditure consists of the development of the system, and integration of technologies in a way that meets the need of customers. Much aerospace RTD is not classified as R&D though it may be of equivalent technological sophistication and difficulty. R&D to Output ratios do not show that aerospace is a high-technology sector. This adds further to the pressure on research budgets as does competition from subsidised competitors and, more recently, a reduction in up-front MOD funding of R&D.

The lower levels of the aerospace supply chain tend to consist of firms or businesses that deploy a limited range of technologies to produce individual components, materials, software etc. They are often small, more likely to depend on mainly research-based technology rather than system integration expertise and probably serve customers in several or more sectors. Nevertheless, their competitiveness is crucially dependent on securing initial and early stage orders for leading edge and innovative products. This not only facilitates finance for innovation but also provides valuable feedback of information from technologically sophisticated users and strengthens their market reputation (thus increasing the chance of orders from other customers).

A further effect of the innovative supply chain is the transfer of knowledge and spin-off of technologies and processes from aerospace into linked business sectors. This is the main way in which spin-offs arise, as there is limited movement of staff and knowledge within and between sectors.

Synergy could be gained from joint research between civil and defence sectors, and part of the CARAD Programme rationale included facilitating links with defence research through joint MoD and DTI support for projects of mutual benefit. In the 4th phase of CARAD from 2001 onwards, the rationale was reinforced to note that, due to changes in Defence procurement, the MOD now provides much less up-front support for UK aerospace research. Civil aerospace research therefore took on a more significant role in advancing the technology.

Facilitating links with MoD was a minority benefit (perhaps because civil/military links would not have been relevant in all projects). Although these results show that less than half of respondents made additional links with MoD for joint research, CARAD did allow DERA to create a collaborative national programme of long-term strategic aerospace research by matching civil programmes alongside MoD military aerospace programmes, with consequent synergy and spin-off of technological knowledge to the aerospace sector. In this way, DTI expenditure had leverage on a much larger MoD total. Evidence from the evaluation indicates that CARAD has contributed to:

- Forming a coherent national programme involving DTI, MoD, Research Establishments, business and HEIs;
- Enabling high technical and financial risks in a niche market to be shared through long-term collaborative research;
- Building on the defence technology base at DRA with civil-related activities and so strengthening the technological capability for the civil industry through CARAD;
- Enabling DERA/QinetiQ participation in the European Framework programmes that support research on the civil side alone;
- Selectively funding generic research with MoD. There is a gearing effect (noted by one major participant) on the amount of research likely to be transferred within a company and transferred to industry down through the supply chain. Funding also ensures continuing military/civil synergy.

Large test facilities

Part of the rationale for CARAD support for demonstration projects was that the aerospace companies individually could not justify the investment in large-scale facilities to test technology components. There was a need to provide independent large shared test and demonstration facilities eg rigs (which could not be afforded by most companies for individual use), so that smaller companies could continue developing technology independently and the supply market could be retained.

The interviews therefore asked how much usage there had been of five sites, for example the More Electric Aircraft demonstrator from the TIMES project (Advanced Systems), Noise testing at QinetiQ (relevant to Propulsion technologies) and Inertia welding at Rolls-Royce (associated with Materials technologies). Of those interviewed, a majority in Propulsion (5 out of 7) and in Advanced Systems (5 out of 6) had used the CARAD supported facilities, but a minority in Aerodynamics (1 out of 4) and in Materials and Structures (1 out of 10) had made use of them. Some universities were aware of the demonstration and test facilities, although actual use was by large companies. Annex E2 has the survey responses.

In addition to CARAD supported facilities, companies also used other technology demonstration and test facilities eg crash testing at Cranfield University, component rigs at QinetiQ, an EC funded facility at ISPRA in Italy, a Spanish engine test site funded by Framework 5, and a thermo-mechanical fatigue testing facility in Cincinnati, USA.

Evidence of Additionality

Several interview questions addressed the extent to which CARAD funding enabled additional research. The responses at Annex E1 show strongly that respondents considered the grant funding did support additional research in all aspects of additionality set out in the programme rationale.

View of additionality at the programme level

However, as the CARAD Programme of research was decided jointly and collectively with the aerospace industry, the DTI programme management suggest that it was much less meaningful to assess additionality on a project by project basis. The collective thought process will have broadened companies' horizons and produced a better informed collective view of research requirements. The CARAD process will have changed companies' perception of research priorities and the perceived 'counterfactual' at the end of the process for any particular piece of research by any particular company may well be quite different from what the company actually would have done if CARAD had not existed. Against this background, it is argued, additionality is therefore better assessed at the programme level although it was also a factor in assessing individual projects.

Effects of CARAD funding on other plans for research

In the Propulsion area, all interviewees said that CARAD projects took priority over other in-house research projects and took specialist resources previously allocated to them. In Aerodynamics, respondents said two of four new CARAD-funded projects had taken priority over other projects. By contrast, in Advanced Systems only one of six new CARAD-funded projects had this effect, and in Materials and Structures only two of ten had done so.

The differences may be because Propulsion focuses resources on relatively few large projects, so that any new projects will necessarily subsume or displace others, whereas in the Advanced Systems and Materials areas there are a greater number of smaller projects that would not all be affected by new government supported projects.

It is difficult to assess the significance of changed priorities. The obvious implication is that CARAD projects often displaced other private research projects. However, where CARAD served to expand and enrich research that would have taken place anyway, the initial idea may have been subsumed as part of the project that went ahead. The project that went ahead would not then be wholly displacing other activity (ie there would be some input additionality).

The economic impact of changing companies' research portfolios will depend upon the characteristics of the displaced research. If such research was marginal in the sense that it was only expected to cover its costs (allowing for the cost of capital adjusted for the degree of risk involved) then the economic cost of displacement is zero. If however the project was expected to do more than cover its costs then displacement has a positive cost. However this implies a constraint on the size of aerospace companies' research budgets, which would support both the rationale for CARAD and the potential for additional benefits of government support.

The wider benefits

The programme funding generated benefits beyond the individual projects.

By providing a focus for the aerospace sector to discuss long term research with DTI and within the sector itself, CARAD facilitated a more strategic approach and a collective sense of direction. In particular it helped to remove a bias against high risk (high return) and/or longer-term research and made it less likely that such projects might be cut for extraneous reasons.

CARAD encouraged collaboration between prime contractors, their customers and suppliers (often small), universities, PROs and RTOs. Although Rolls-Royce already had links with universities, this was less true of other companies prior to CARAD. New links were created and the larger companies also brought their existing academic links to CARAD projects. This pooling of skills, expertise and knowledge made greater technological possibilities available to any individual firm. Collaboration improved the cohesiveness of the UK knowledge base, achieved economies of scale and scope and by spreading technological knowledge across a wider range of organisations increased the chance of beneficial spin-off. An example of this was the PACTS 21 series of projects, that built a community of expertise in advanced aircraft systems, components and standards.

Expenditure on aerospace research rose by at least the amount of DTI funding and for the reasons set out above was pound for pound more effective.

More recently, interviews with suppliers Airbus UK, Rolls-Royce, Smiths and with the aerospace trade association SBAC confirmed that CARAD may have caused more of the world's aerospace research (for example on composite materials) to be located in the UK than otherwise would have been the case.

CARAD research provided companies with world-class elements of technology that they exploited well in world-class products, processes and systems. It also helped them to meet, or have less chance of falling foul of, regulatory standards, for example PACTS 21 produced aircraft systems components/processes/standards, and supported safety standards.

CARAD funded research that captured spin-off from military to civil aerospace technology.

By strengthening the technology base of UK companies, CARAD increased the ability of UK firms, research institutes and universities to successfully bid for funds under the EU Framework Programmes and to undertake a leading role in their projects. For example the ANTLE project was co-ordinated by Rolls-Royce, building on work in the CARAD demonstrator project ALPS/ACCORD. For Airbus UK, a sequence of CARAD projects led to funding for TANGO in Framework 5 and ALCAS in Framework 6, and subsequently to award of contracts for military aircraft. The European research experience expanded their range of options for undertaking promising research, improved their access to foreign technology and improved contacts with potential overseas partners.

DERA in particular was able to develop its expertise and contribute to UK strength in Europe through co-ordination of Framework projects, a role that utilised their technological knowledge and their project management skills. Grants from DTI and from the EU covered 100% of DERA costs for this work. However the change to QinetiQ and consequent commercial status, meant that QinetiQ could obtain only 50% grant funding for Framework projects, thereby restricting their project opportunities to those with a commercial client. This in turn reduced the overall benefit to the UK.

Enhancement of the technological expertise of the lower tier suppliers who also produce leading edge products, materials and software for other sectors, and thereby transfer expertise in advanced technologies and techniques.

Effort was made to encourage the direct dissemination to other sectors of technological knowledge generated by CARAD supported research. Case studies could not be published due to commercial and security confidentiality constraints. Dissemination has taken place by other routes such as presentations at conferences.

The interview evidence supports the substance of the rationale and additionality arguments contained in the four ROAMEs. The details of views on additionality are at Annex E1, identified for each of the four technology sub-areas.

CHAPTER 3
Objectives of the CARAD Programme

To what extent did CARAD fulfil its objectives?

The main objectives at the time CARAD was launched were:

- To improve UK industry competitiveness and market share by developing world-class technology from which to launch successful ventures in world civil aerospace markets;
- To make UK industry an attractive partner in civil collaborative projects in Europe and internationally;
- To encourage longer term industrial investment in innovation without early prospect of commercial return;
- To help maximise spin-off to civil aviation from military research and demonstration support;
- To increase collaboration with HEIs and promote maximum “pull through” of academic research;
- To help meet global standards e.g. for reduced emissions (aircraft & aeroengines);
- To study the scope and recommend ways of disseminating CARAD technology to non-aerospace sectors in UK, and other R&D programmes (1990-2000);
- To promote the participation of SMEs in collaborative ventures (1990-2000).

Background on the aerospace sector

In order to assess the extent of the CARAD contribution to these objectives it is helpful to take into account the following information:

The OECD STAN database[6] notes that in 1990 (first year of the CARAD Programme) the aircraft and spacecraft sector had 157,000 employees, and value added of £6.74billion.
Over the period 1990-2002, the period covered by this evaluation, figures from the Society of British Aircraft Manufacturers (SBAC) indicate that total sales of the UK aerospace Industry remained broadly flat in real terms.[7] Turnover reached £17.71billion in 2004; SMEs were responsible for about £0.54billion. However this was the net result of several divergent trends. Defence sales, the greater part of the total in 1990, fluctuated over the period but remained roughly flat; their lack of buoyancy reflects the end of the cold war. Civil sales, to which CARAD principally relates, grew significantly between 1990 and 2001, but subsequently fell back as a result of the events of 11 September 2001. Later figures for orders indicated a recovery. Employment fell steadily over the period producing a trend rise in productivity of the order of 5% per annum.

According to the SBAC 114,345 people were employed in aerospace in 2004 with an estimated 140 thousand jobs in other sectors supported by demand from the aerospace

[6] Data for both 1990 and 2002 adjusted to 2004 values
[7] The several sources of data on aerospace such as the SBAC and the OECD STAN Database vary in coverage. Moreover some of the data series fluctuate considerably making calculated growth rates very sensitive to the choice of beginning and end dates. The above description is intended to be broadly consistent with all the data sources. Annex F –based on STAN – contains graphs showing how UK performance compares with that of the other main Aerospace producers.

businesses. About 33% of aerospace employees have a university degree or equivalent and labour productivity is high correspondingly high. Expenditure on R&D amounted to some 11% of turnover in 2004 and aerospace had a net positive trade balance of £3.34 billion. The sector is already highly globalised. Over one-third of UK turnover is accounted for by foreign owned companies and UK owned companies have nearly one-third of their turnover overseas.

<u>Extent to which the Programme objectives were met</u>

Technology examples from CARAD-funded projects are given in the DTI aerospace annual reports for 2001/02, and 2002/03:[8]

- in advanced systems, two projects were instrumental in decisions for the electrical systems on the A380;
- research on new power components was used in development of More Electric Technologies for actuation and electrical power control. Benefits included increased reliability and reduced fuel burn and emissions;
- in aerodynamics, there were performance benefits and new modelling methods;
- Airbus and QinetiQ contributed to a major project for design of wings for very large aircraft (Airbus A380 size).

Examples of world-class technology were noted in the evaluation interviews:

- research contributions to the Rolls-Royce hollow turbine blade and the Trent 900 and 1000 engines;
- life assessment techniques for engine components;
- engine noise research included new silencing concepts that are of increasing importance to competitiveness and are carried into validation and products commercialisation by aerospace firms;
- research on carbon-fibre composite airframe structures and components resulted in manufacturing with improved materials at lower cost, and assured UK companies as leaders in composite components. (the AMCAPS projects);
- benefits were achieved in methods of bonding and welding composite materials;
- new generation alloys were tested for discs within aero engines;
- new flight systems were developed from the series of PACTS 21 projects.

Examples of UK companies as partners in EU Framework and international projects:

- Rolls-Royce co-ordinated a 5-year EU-funded project ANTLE for advanced near-term low emissions (in the EU initiative EEFAE). Research from CARAD projects was used within ANTLE, a project that demonstrated new engine technologies to reduce emissions of carbon dioxide and nitrogen oxides, improve reliability and lower the cost of ownership;
- In Framework 5, Airbus UK led the HIRETT project to improve the design process for aircraft wings;
- QinetiQ was able to build on success in turbine design and testing to win EU funding in Framework;

[8] DTI URN 03/95

- UK firms were also successful in Critical Technology Projects and in Technology Platforms (in Novel Wing Configuration, Power Optimised Aircraft and Aircraft Cabin Environment).

Longer term investment was encouraged by discussion between DTI and the industry of the strategic direction of research within CARAD. Examples are:

- The PACTS 21 technology and standards project developed architectures and components for flight systems that formed a basis for systems for the Airbus A380, A400M and A340 aircraft;
- The More Electric Aircraft Challenge sought to encourage research into technologies which might help the replacement of hydraulic systems on civil aircraft with electronic systems.

Examples of spin-off from military to civil:

- The DTI team worked with the MoD Applied Research programme to explore dual-use civil/military technologies for example in propulsion where the technology is generic. MoD provided the example of laser peening which was developed for military use but now used on engine fan blades in civil applications;
- Building on past MoD research, DTI supported development of lightweight titanium metal-matrix composite technology to enable new architectures in more-electric aircraft. These showed potential to replace steel components, thus saving weight and costs.

There were 47 projects with university partners among the 161 projects funded between 1994 and 2002. Of these 47 projects, over one third were in Materials and Structures, and a further third in Advanced Systems, with most of the remainder in Propulsion. CARAD funding reinforced existing collaborations and encouraged new business/university links. The collaborations recorded in interviews included:

- University of Birmingham worked with a small firm on rotary engines. Their seal-less engine project research provided test evidence of viability, and led to a further CARAD project on Low Emissions and to an EPSRC award to design a new engine gearbox with a lighter engine built from lighter material;
- University of Southampton worked on models for the design process and reliability of landing gear, and the project developed a tool used in the landing gear process.

Examples of supporting global standards for reduced emissions:

- Reduced emissions would follow from fuel-saving measures in propulsion technologies for example the Tractor Prop Fan project addressed wing-mounted contra-rotating propellers;
- In the Propulsion area, the Low Emissions project succeeded in reducing emissions from engines through cooling in a more environmentally friendly way than use of oil lubricant, and increased engine efficiency by reduction of heat in the rotor;

- The projects grouped under the More Electric Aircraft theme in Advanced Systems have supplied benefits of reduced fuel burn and emissions;[9]
- Aerodynamic efficiency has been assisted by several projects for example SATOW which established smaller sized control systems allowing greater freedom in wing configuration.

Dissemination of aerospace research outside the aerospace sector to other UK sectors and to other research programmes was limited because of confidentiality constraints of the participants. The booklet of project descriptions could offer only summary information.

Small and medium sized firms were one sixth of the 232 organisations taking part in the CARAD Programme. The interviews showed that they were supported to enter new markets and technology areas:

- CARAD enabled Advanced Composites Group to enter the aerospace market through taking part in a Materials & Structures project.
- For the small company LUSAS, participation in the CARAD Programme opened the way to composite materials, and strengthened links with universities and their client.

This review of projects demonstrates that the portfolio of research projects funded by CARAD produced outcomes that met the stated objectives of the programme, although the dissemination objective was limited. However, the programme objectives were qualitative rather than quantified. It is therefore very difficult to judge:

- how much contribution CARAD made to progress against each of these qualitative but directional objectives;
- the extent to which CARAD funding was essential in delivering these outcomes.

Nor does our interview programme provide a direct test of whether the objectives were appropriate in the first place (or the balance of importance between them). Interview respondents recognised these objectives as desirable outcomes for the UK aerospace industry and for CARAD; but the deep stakeholder involvement in the design of the programme makes such a pattern of response almost inevitable.

[9] DTI Aerospace and Defence Technology Report 2002/2003

CHAPTER 4
Main Outcomes from the CARAD Programme

This chapter addresses the main themes raised in interviews with DTI programme managers and grant recipients in the four main technology sub-programmes of Propulsion technologies, Advanced systems, Aerodynamics and Materials & structures. The interviews were with a sample of the organisations that received most funding (Annexes B and D). The questions (Annex C) were to determine the effect on business performance, gains from CARAD projects, the effects on collaboration, and dissemination of technology developments within and beyond the aerospace sector.

To set the context for considering the outcomes, it may be interesting to know first the reasons given for applying to CARAD for support. The main reasons given in the survey for taking part in the CARAD Programme were:

- to gain access to new technology;
- to improve skills;
- and therefore to increase profits.

As a lower priority, participants wanted to make new contacts in the sector. Other reasons less generally cited were to explore or solve particular technical issues, to follow-up results of a previous CARAD project, or to help win internal company research budget.

The DTI CARAD Programme managers' view was that the grants were the main reason for applying to CARAD. A secondary reason was the opportunity not otherwise available to work with partners whose products, skills or customers were complementary and could expand their future markets. Another strong factor was that the programme was tailored to the needs of the aerospace sector.

Gains in world-class technology and new products

The interviews showed that a majority agreed they gained world-class technology through CARAD participation and were able to develop new products or services, although these had resulted in increased turnover or profit in fewer than half the respondents, possibly because the short time since the end of the projects (1 or 2 years) meant profits were not yet realised. In two cases the respondent was a university that would not expect to make a commercial exploitation. Examples of types of new technology are noted in the Wider Benefits section of Chapter 2, and in the examples of meeting Objectives in Chapter 3. Interview responses are summarised at Annex E2.

Skills benefits

The training of highly qualified people creates opportunities for knowledge transfer to colleagues and network contacts. In the Propulsion, Advanced Systems and Aerodynamics technology areas, all those interviewed said that participation raised the skill levels in their organisation, whereas in Materials & Structures 8 out of 10 interviewed had gained through increased skill levels.

Evidence from the interviews was that benefits occurred mainly at the Design stage in the product cycle, rather than at the stages of Prototyping, or Production. The research results were codified as local guidance, manuals, standards, job instructions, drawings etc in addition to becoming tacit knowledge through the experience of staff, and much of this knowledge is guarded within companies for their commercial advantage. Knowledge does transfer through movement of staff to other employers, though the interviews showed that there was relatively little movement of staff between the aerospace engineering companies. Therefore the outward impact on the aerospace sector may be confined to those with partnership or collaborative links to the researchers, and companies to whom the researchers subsequently move.

Collaboration and contacts

Companies collaborate with universities for their intellectual strength, their laboratory and testing facilities, and to stay in touch with the leading edge technologies as they emerge. For example QinetiQ had engaged with virtually all engineering departments in UK to maximise the expertise available.

CARAD played a role in building similar links through the collaborative research grants, and the intra and extra mural funding arrangements, and the links continue on a project-by-project basis. Interview evidence was that 20 of the 27 project participants had made new contacts through CARAD, and 23 were continuing to work with their CARAD partners after the project, although only 12 of them were in a follow-on CARAD project with the same partners. Thirteen of the 27 had undertaken collaboration in Europe with some of their CARAD partners. Details of the responses, by technology area, are at Annex E.

Spin-offs and wider pull-through of technologies from aerospace

The main means of technological spin-off from aerospace is through its requirement for new/more demanding uses of advanced technologies. This enables firms in its supply chain to develop new capabilities that can then be used to supply other sectors. Knowledge transfer between partners in collaborative research projects augments this effect. Licensing of technology from dedicated aerospace companies seems a less likely route for spin-off (judging from interviews carried out as part of the evaluation of CARAD) though some organisations do this and it may be more common down the supply chain. The same is true of movements of highly qualified people as interviews revealed little movement (2% turnover annually) of experienced staff from aerospace to other sectors. Other routes for spillovers are through spin-out companies, or through consultancy services provided by leading technology companies, where the benefit of these may flow into other sectors through technology insertion and acquisition.

The main effect of spillovers is at the lower end of the supply chain, where technology advances and process improvements filter down and are available to suppliers for use in the whole range of their markets which often extend beyond aerospace to transport, power generation, engineering, specialist materials, security etc. However in respect of global prime suppliers, the benefits that are pushed through to their supply chains are realised globally, not necessarily in the UK. Similarly UK firms may benefit from demand from leading aerospace producers based abroad. However realising these benefits depends on having a strong technological base in the UK because:

- UK firms will only obtain foreign orders for products incorporating leading edge technology if they are at the technological forefront;

- Absorbing knowledge of advanced technology from abroad requires a sufficient degree of capabilities and knowledge in the UK.

Information about the extent of technological spin-off from aerospace is included in the studies by Ricardo and Cranfield University in 1995[10], and by NASA in 2003 and 2005[11]. More cogent and recent evidence can be found in a study (The 'ABOTTS' Report) carried out by Qi3 for BNSC in 2005[12] on spin-off from Space. This suggests that spin-off may be rather greater than past studies indicate, for example the study demonstrated how development of new satellite system could encourage the development of a number of new technologies in the UK.

Dissemination

Dissemination from projects took place, both within and beyond the aerospace sector, although in many instances it was limited by commercial and security considerations. According to the CARAD interviews, the proportion of interviewees that were prepared to disseminate their project results ranged from two of four in Aerodynamics through to all six in Advanced Systems. Those that had actually made results available showed a different profile ie one of six in Advanced Systems through to three of four in Aerodynamics.

The technology results from seven Propulsion, three Advanced Systems, one Aerodynamics and nine Materials & Structures projects (in all) were considered applicable to other organisations in the aerospace sector and in other industry sectors. However there was a considerable gap between technology being considered applicable (in these 20 of the 27 interviews), and the actual transference that had taken place (in only seven of the projects).

In respect of both dissemination of technology results and transfer of applicable technology, the interviews showed that some technology results that were considered possible to transfer had not actually been transferred. It is difficult to draw a firm conclusion about the reasons for this, as the interviewees available were not necessarily the individuals who knew the background to each project and reasons for non-transfer. For more details see Annex E2 – Dissemination and transfer.

Patent data

DTI considered a patent search to identify spin-offs and the Patent Office provided data for patents registered since 1990 by the main CARAD participants in aerospace technologies. However an initial reading of this data showed it is difficult to relate specific patents to CARAD programme projects. The difficulties in tracing spin-offs included:

- The combination of CARAD technology with technologies from other research sources into products and services made it difficult to attribute specifically to CARAD;

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[10] Wider Economic Benefits of Skills Diffusion from the UK Aerospace Industry by the Ricardo Group. Wider Economic Benefits from Technology Transfer from the UK Aerospace Industry by Cranfield University. Both commissioned by the Aerospace Division of DTI, 1995.

[11] Spinoff 2003 by the Office of Aerospace Technology in the National Aeronautics and Space Administration in United States. ISBN 0-16-067895-1, and Spinoff 2005 at www.sti.nasa.gov/tto/Spinoff2005

[12] Analysis of Business Opportunities for Transfer of Technologies from Space 2005 at **www.so.stfc.ac.uk/publications/pdf/Abotts.pdf**

- The multiple routes taken to product development by the methods and technologies results from research projects;
- The length of time since project completion in some cases;
- Spin-offs may not be officially recognised by patents or licences.

Summary of outcomes of the CARAD Programme

The interview evidence showed the main benefits were gains in skills, knowledge and world-class technology, followed by development of new products and services, with the consequent increase in turnover and profit and an improvement in market position. Annex F shows the trends in value-added and employment over the life of the CARAD Programme, and comparisons with major aerospace competitor countries.
Interview evidence stated there had been some improvements in performance and productivity from projects that had completed during the previous 9 years (1995- 2004). The payback period of one major participant was estimated to be between 12 and 20 years.

As CARAD provided support for collaborative research, it encouraged companies to work together, and some companies surveyed saw CARAD as a means of funding the efforts of partners with whom they wished to collaborate but who might otherwise be reluctant or unable to commit resources to the research concerned. The programme reinforced existing partnerships and formed some new links that have led to further research and commercial collaborations.

The collaboration therefore encouraged knowledge transfer and improved the breadth, quality and coherence of the UK research base. In an industry where firms are accustomed to keep their technological capabilities 'close to their chest ' CARAD encouraged a more open and sharing approach to research.

The majority of participants said that CARAD had funded research that was additional in several respects. The research would not have taken place without government funding, or would have been delayed, or of a smaller scale. For organisations with research bases in other countries, the availability of CARAD funding had been a factor in participants' decisions to carry out their research in the UK, although alternative government funding could have been sought in the US, France, Germany, China, or India. The only aspect of additionality that was not achieved by the majority of interviewed participants was making new collaborative links with MoD, which was not appropriate to all participants.

Aerospace prime suppliers indicated that CARAD was only a part of their research portfolios, intended to supplement company research by funding projects that were high risk, longer term, and required expertise that was not available in the company nor its usual close collaborators. The CARAD projects also indirectly boosted their international research status, as the collaboration experience gained in the UK provided a base for bidding as a project leader to the European Framework Programme. UK successes in Europe opened the way for successive collaborations and consequent further gains in technology, experience, and directing research.

Technologies were developed that helped to promote the "public good" (e.g. a cleaner environment, safety and security):

- Developments for rotary engines offered a more environmentally friendly way of engine cooling, to reduce heat in the engine and so improve the efficiency of the rotor and reduce fuel-consumption.
- A lighter weight rotary engine was produced in aluminium, offering efficiency gains.
- The TATTLE project improved gas turbine design, leading to improved performance.
- The demonstrator project AMED 2 resulted in improvements in cost, weight and fuel-efficiency for small engines. Developments in lighter materials are to be exploited in the Trent 1000 series of engines for the Boeing 787 aircraft.
- For safety aspects, the CARAD programme team worked with the Explosion Hazards programme with DoT and MoD to support projects meeting objectives of both.
- Safe design margins were explored for titanium fan blade discs to examine performance at low temperatures.
- Safety critical systems for aircraft were researched with University of York
- Health and usage monitoring (HUMS) projects were undertaken to address maximising life of parts without compromising safety.

With regard to the supply chain, CARAD had a role in maintaining the currency of kmar1am1llsnowledge and competitiveness by bringing the primes into contact with some suppliers outside their normal circle, and by raising the demands on their supply chain, which in turn increased usage of new technology and processes down the chain and in suppliers from associated sectors.

CARAD demonstrated “joined-up” government support for research, linking civil with defence, and industry with universities. For example, DERA could run civil and military programmes together, which gave extra leverage over either programme alone. CARAD also brought in other government funding from EPSRC, and enabled universities to take part through Extra Mural grants. DERA could therefore orchestrate technology research through the aerospace sector from the basic research stage through to its use in industry. Without the CARAD Programme (and the European Framework programme) there would have been very little drive for civil research at DERA, and potential for defence/civil synergy would have been lost.

Overall the benefit to the civil aerospace sector was through joint development of technologies, thereby gaining economies of scale and scope in aerospace research. CARAD projects with support from both MoD and DTI addressed a wider range of technology in order to cover both military and civil potential uses, and the projects were of a larger scale as more funding was provided. More comment from MoD is at Annex G.

CARAD research projects had a role to play in furthering three of EPSRC's objectives:

- Supporting world class research in the engineering and physical sciences addressing the challenges facing the UK economy and society

- Developing talented scientists and engineers

- Supporting the knowledge economy

The EPSRC aerospace portfolio was valued at approximately £10M annually. EPSRC has established strategic partnerships with Rolls-Royce and BAE systems, in which both the EPSRC and the industry partner contribute money and expertise, and EPSRC has a seat on the industry led groups, Aerospace Technology Steering Group and the National Aerospace Technology Group.

CARAD encouraged large companies to work with universities that could gear their research funding by Research Council grants. Most proposals to EPSRC in the aerospace sector were through "responsive mode", in which they were compared to other engineering-wide proposals and funded if they met panel criteria and assessment as the "best" research. Support from both EPSRC and DTI enabled synergy and some strategic coherence in the aerospace area.

CHAPTER 5
Programme management and administration

The programme was managed within DTI (now Department for Business, Enterprise and Regulatory Reform) by the Aerospace Marine and Defence team in Business Relations Directorate, and its predecessors. The Technology team provided a Deputy Director for overall programme control supported by Assistant Directors for the sub-programmes, with administrative and finance support. The team maintained close contact with aerospace technology developments and had the technical expertise to discuss potential research with the sector, to appraise CARAD proposals and discuss changes of direction and problems. Some team members undertook project monitoring tasks although an external monitor was engaged for most projects.

The running costs of in-house staff (Annex A Table 3) were £6.28 million from 1990 to 1999, averaging £698,000 annually, (about 3% of the programme expenditure). Staff cost information was not available for 1999 onwards, although the staff numbers remained constant at 13 full-time equivalents from 1999 through 2002. The percentage of time spent by Assistant Directors varied from 50% to 80% of a full-time post, depending on the volume and complexity of projects. Less time was required from Assistant Directors if there was a supporting Project manager.

Views of the programme managers

The following observations were made about the CARAD Programme:

- There was the capacity to decide on support for a strategic and coherent set of technology projects that the aerospace sector understood, and there was scope to support research over the long term to reflect the long time horizon in aerospace research and development.
- Bidders could take time to build a sound proposal within the strategic scope because they were fairly certain of funding. Proposals with a *more considered plan could then form a group of complementary projects, and the companies were more certain of working with technologies to meet future market demands.*
- The CARAD Programme was attractive to business because it was flexible, easy to use and tailored to the needs of the aerospace sector. Bidders had a reasonable chance of success without too much overhead in making an application.
- External experts and regulators like Civil Aviation Authority added more expertise to the projects and kept DTI managers up to speed with developments on the sector.
- There was value in having a small (Deputy Director and 3 Assistant Directors) team of in-house programme managers with a technology background that could make strategic overall judgements on the selection of projects for CARAD based on their view of the whole aeronautics technology sector. They could manage the programme with fewer needs for external advice so saving time and costs. As they

were well briefed in the technology areas and close to the projects for which they were responsible, they could be flexible in addressing problems and managing aspects such as company take-overs. This minimised the loss of projects from the programme.

- Experience had shown that there was value in using a mix of methods to invite proposals. Calls were good for bringing in co-ordinated funds from other government bodies and giving certainty of timing and scope. However an open continuous method gave the possibility of discussion of ideas with the bidders to focus them in a strategic direction, and maximise the quality and timeliness of the proposals.

- The requirement for a formal written appraisal of a proposal submitted to the open continuous programme was a good discipline that helped DTI managers to understand the issues, the risks, any gaps, and ensured a thorough consideration of the proposal.

- Joint calls with other government departments eg the DARPs[13] were a positive factor, enabling broader scope for the projects and wider ultimate markets for the technology results, for example into the defence sector. When the EPSRC was involved in a call the universities could be fully funded which ensured more universities took part and that they played a full role in the research. This had consequent benefits for the project outcomes using their depth of skill and experience in the technologies and DTI funding could be focused on business participants. Inclusion of Regional Development Agencies in a Call allowed a focus on clusters of expertise. Generally, joint calls made larger amounts of funding available, making the Calls more attractive and producing a wider range of proposals from which to select. Monitors could be shared provided they understood the needs of all the government clients.

<u>Operational aspects that could be improved.</u>

The programme managers also offered the following comments on scope for improvement of the programme operations:

- The open continuous submission method took the pressure off and allowed companies to delay coming forward with new bids. Companies also tried to push the boundaries of the programme, as there was little competition, and were sometimes surprised that they had to justify their proposals in as much detail as was demanded by DTI.

- In joint calls with other government departments the biggest problem was that policies for handling IPR and commercial rights were not common to all government bodies, which could prevent consortia from being able to work together. This was especially a problem between MoD and business participants. Other difficulties were aligning budget availability in the same timescale, and reconciling different objectives and appraisal criteria in the different government

[13] DARPs were Defence Aerospace Research partnerships sponsored jointly by MoD, EPSRC and DTI.

funding providers. The different objectives were dealt with by compartmentalising the projects to match work packages to appropriate objectives and appraisal criteria, which then raised the question of whether these different packages could be considered a coherent project. There was also difficulty with the large size of MoD, its many different requirements, and many directorates, who used different applications of their rules.

- The appraisal criteria could have been better defined both for the DTI assessors and the bidders. Some external appraisers understood the technologies well but not aspects of the need to show economic benefit to the UK, so there had to be supplementary expertise.

- It was thought that there was scope for the programme to be visibly more fair and open, and to use more external monitoring officers. However there was also the issue of finding individuals for the monitoring role who were independent of participants and had sufficient technology expertise to be effective.

- More flexibility was required in agreeing addition or removal of deliverables from the project requirements during the course of a project. Strict adherence to an offer letter and all the proposed work packages may result in wasted effort if some avenues are considered not worth pursuing partway through a project.

Monitoring

For each project the reports and associated review meetings were usually held quarterly to record project progress against agreed milestones, timetables and costs. Project teams, and DTI staff or their appointed technical monitors attend, with MoD staff as appropriate. Using Technical Services Agreements, technical monitors were drawn from the Civil Aviation Authority, the National Physical Laboratory and MoD's Procurement Executive, DSTL and QinetiQ.

A progress report on the CARAD Programme (expanding on the published report) was circulated to DTI Innovation IPC each year, although this was not produced after 1999/2000.

Monitors attended regular (generally quarterly) progress meetings with the project partners and advised programme managers whether milestones and deliverables had been achieved. DTI retained the powers to vary any grant conditions and authorise payments.

The monitors were rated excellent or good for their technical and management advice by 25 of the 27 interviewees. Programme managers were generally content with the procedures for monitoring projects and the individuals who carried out the monitoring role.

From the financial data available for 1995 to 2002, it was not possible to be certain of the total cost of monitoring within the CARAD Programme, however a total cost of £343,000 was identified for contracts to external monitors. Programme expenditure for the same period was £154m, so it could be estimated that external monitoring represented around 0.2% of programme expenditure.

Although not part of this evaluation it is worth noting for completeness that a DTI/DERA Framework Agreement from 1 April 1993 set out the basis for management, financial arrangements and reporting on all DERA Intramural and Extramural work under CARAD.

Administration – application procedures, claims, payments

On initiation, 12 of the 27 interviewed said the procedures were easy. The remainder were neutral or did not have direct experience from which to comment, as they were not lead partners or were not in the project team at the time.

Interviewed participants had a strongly positive opinion of the administration arrangements for CARAD:

- 24 of the 27 were satisfied or completely satisfied with their contacts with DTI throughout the project lifetime regarding aspects such as the response of DTI staff to enquiries, applications, claims, requests for extension of projects and/or changes of partners.
- Several of those interviewed compared the CARAD Programme procedures favourably with the complexity and duration of the procedures for the European Framework research programme.

Twelve of the 27 participants interviewed said the claims process was good. The remainder were neutral or had not been involved with claims and payments. The programme managers considered the claims procedures helped to enable their control of the programme by giving the flexibility to decide when to audit the projects, and the authority to agree payment of grant after taking written reports from the monitors.

Marketing of CARAD

Generally the programme had not required heavy marketing as it was well known in the aerospace sector. DTI staff gave presentations, wrote articles for the press on project successes and held annual meetings with the larger companies to discuss their plans for proposals. Universities held dissemination events. The DTI website carried information on the opportunities and how to apply for funding. There had been a need to encourage proposals from time to time in the Advanced Systems area and this was carried out through the relevant National Advisory Committee[14].

[14] National Advisory Committees were set up as initiatives of the Research & Technology Task Force within the Defence, Aerospace and Systems Panel of the Foresight initiative, 1999-2002.

CHAPTER 6
Conclusions

The objectives of the programme were met, however they were specified in fairly open terms, without quantified baselines or targets, making it difficult to measure specific improvements in competitiveness, market share and investment. Interview evidence (Annex E1) confirmed that DTI support was responsible for additional collaborative research that contributed to improvements in all the aspects addressed by the programme's objectives.

Extra research was enabled that is estimated to be at least the amount of Government funding. World-class elements of technology were developed, some of which were well exploited by business in development of world-class products, processes and systems (bearing in mind 100% was not appropriate for research) Although it is difficult to quantify exploitation from specific CARAD projects (Annex E2) it may be possible to adapt the methodology used to identify Space spin-offs.

As set out in the rationale, the value of the CARAD Programme was in support for competitiveness in the aerospace and related sectors by enabling leading edge research and demonstration, and subsequent exploitation. Government funding ensured that research took place in the high risk long term strategic areas, and encouraged companies towards collaboration. The networking and knowledge transfer between companies and universities as project partners extended to the rest of the aerospace supply chains, and to other industry sectors with similar components, processes or services. Collaborations often remained beyond the original project, to pursue further research, disseminate results, and set up student placements.

There were benefits in terms of a strengthened supply chain in the aerospace sector, and increased skills. Synergy with military research sponsored by the Ministry of Defence enabled applications of advanced technology for civil aerospace (examples in Chapter 3) However interview evidence showed limited benefit through transfer of technology knowledge to other companies and sectors (Annex E2).

Although the evaluation intended to identify and attribute spillover benefits from the programme, there was difficulty because:

- CARAD technology is combined with technologies from other research sources into products and services;
- There are multiple routes to product development using the methods and technologies results from research projects;
- Up to 10 years may have passed since project completion and traceability is hindered by changes in company structures and staff;
- Spin-off technologies, products and services may not be officially recognised by patents and licences.

There was a positive effect from the collaboration experience in strengthening the technology base of UK companies. Businesses, universities and research organisations with successful experience of project leadership and participation in the CARAD Programme were better able to win and lead European Framework research projects, with consequent gains in technology, funding, partners and potential access to new markets.

In accordance with the programme rationale to strengthen the aerospace sector, CARAD enabled DTI to take a strategic view of the coherence of research in the sector that no single player could achieve, and to focus discussions with the aerospace sector on long term development of strategic technologies. These discussions also gave companies a forum to discuss among themselves. The sector was then able to attract more investment from UK and overseas, and the scale of CARAD (at least £20 million annually) would have been a major factor in this. In being both responsive and steering the strategic direction of technology research, DTI had a positive effect on UK's reputation and position in Europe and globally.

In support of the rationale for the 4th phase of CARAD, the programme provided a means by which SMEs could play a greater part in research into advanced aerospace technologies. SMEs will typically be cash constrained and may find it difficult to raise external funding for what may be somewhat speculative long-term research that is not directly tied to any current order. The programme provided the funding for research and links to larger companies who could be customers for the advanced technology developments. One sixth of the businesses taking part in CARAD were small or medium-sized, and they gained in terms of technology, partners, skills and new contacts.

There were benefits to the public good in safety, security and environmental applications and standards that would probably not have taken place when they did without government steering and support.

Dissemination from projects took place, both within and beyond the aerospace sector although in many instances it was limited by commercial and security considerations.

The technical expertise of the programme managers enabled well-informed technical appraisal of proposals and guidance to project consortia. The DTI team was widely respected by participants for their technical knowledge and positive approach to enabling research to continue in changing circumstances. Their knowledge of the sector enabled them to understand strategic implications and adapt CARAD projects as change occurred. This was reflected in a higher administrative overhead for the CARAD Programme.

The majority of the interviewed projects delivered in accordance with their grant offer. The monitors drew respect from all interviewed participants, for their knowledge, experience, and guidance at key stages. Their experience in the technologies and project management was valued at decision points for project and programme managers, to find solutions that enabled projects and programme to continue rather than be terminated.

The development of aerospace technologies is by evolution rather than a series of separate discoveries, so research continuity is essential. The CARAD Programme enabled continuity and coherence of research, and provided a strategic approach for support to the aerospace sector. It enabled UK researchers in companies and universities to build their capabilities and credibility, and to bid from a stronger base to European programmes. By enabling a stronger research capability in companies and universities, and supporting collaborative research within a strategic approach, CARAD helped to maintain and build the coherence and competitiveness of the UK aerospace sector, making it more attractive for inward investment and further global collaboration. This in turn increased the economic benefits that the UK derives from the presence of the aerospace sector and its suppliers.

However on the evidence of the interviews carried out, it appears that new knowledge and skills is retained in the CARAD participants and their supply chain. The need to keep commercial advantage prevented transfer of new or improved technology results to other users who might benefit. Potential exploitation opportunities have been delayed, and these should be taken into account against the benefits to the aerospace sector.

It is very difficult to judge whether the benefits from the CARAD Programme were greater or smaller than those that would have been realised from alternative uses of public funds such as more generic R & D support programmes.

The CARAD Programme was designed as sectoral support in the late 1980s and evolved through the 1990s. However the global technology market, and the greater openness between sectors means that government support is now directed to bring sectors, technologies and disciplines together to gain from synergy and encourage further knowledge transfer. The Technology Programme sponsored by the Technology Strategy Board is a current model of government support for research collaboration and knowledge transfer.

ANNEXES

Annex A Tables of expenditure

Annex B Major recipients of CARAD grants post 1995

Annex C1 and C2 Interview schedules

Annex D Organisations interviewed

Annex E1 Additionality and E2 Outcomes - evidence from interview responses

Annex F Aerospace sector data for UK - 1990-2002

Annex G Links with MoD, DERA and QinetiQ

Annex H Studies contributing to this evaluation

Annex I Spin-off technologies noted by ROAME statement for CARAD 4

Annex A Expenditure within the CARAD Programme

Table 1 - Annual CARAD spend - £ million

1990-91	1991-2	1992-3	1993-4	1994-5	1995-6	1996-7	1997-8	1998-9	1999-2000	2000-01	2001-02	Total
26.1	25.4	26.3	23.0	23.4	24.5	23.8	24.6	21.1	20.0	20.0	20.0	278.2

Table 2 - Annual spend by sub-programme - £ million[15]

	1990-91	1991-2	1992-3	1993-4	1994-5	1995-6	1996-7	1997-8	1998-9[16]	1999-2000	2000-01	2001-02	Total
Aerodynamics				3.8	3.8	2.9	3.4	2.5	*2.1*	*2.6*	*1.8*	2.5	25.4
Airframes[17]	7.2	6.3	7.3										20.8
Adv Systems	1.3	1.7	2.4	1.6	1.8	1.8	2.7	5.0	*4.2*	*4.2*	*3.6*	3.7	34.0
Propulsion	11.2	8.0	9.3	8.0	8.1	8.3	7.2	6.9	*6.5*	*6.0*	*6.8*	8.4	94.7
Mat & Struct				6.6	7.7	9.3	8.8	8.4	*7.4*	*7.2*	*7.4*	5.2	68.0
Helicopters[18]				0.4	0.4	0.3	0.3	0.3	-	-	-	-	1.7
Cryotechnology[19]	6.1	9.3	7.4										22.8
ET Windtunnel				2.8	2.1	2.1	1.5	1.7	0.9	0.2	0.4	0.3	12.0

Table 3 – Running Costs £ k

	1990-91	1991-2	1992-3	1993-4	1994-5	1995-6	1996-7	1997-8	1998-9	1999-00[20]	2000-01	2001-2
Salaries & Other	651	722	667	740.7	737.5	714	688	657	706	N/A	N/A	N/A
Staff in Post	18	17.5	16	16	16	15.5	14.5	13	13	13	13	13

[15] CARAD Annual Reports 1990-91 to 2001-2
16 Figures in italics, from 1998-9 to 2000-01 are calculated from % figures given in the annual reports
[17] Airframes includes Helicopters, Aerodynamics and Materials and Structures
[18] Helicopters and cryotechnology are excluded from this evaluation
[19] Cryotechnology includes European Transonic Windtunnel
[20] No running cost figures are available from 1999/2000. The number of staff in post appears not to have changed given the numbers for 2001/2.

Annex A Expenditure linked to but not assessed in this CARAD Programme evaluation

Table 4 DTI funding for civil aerospace before the CARAD Programme - the Civil Aircraft and Aeroengine budget £ Million

Fin Yr	72/3	73/4	74/5	75/6	76/7	77/8	78/9	79/0	80/1	81/2	82/3	83/4	84/5	85/6	86/7	87/8	88/9	89/0	Total
	14.4	18.0	16.2	16.6	17.9	19.6	15.8	18.7	23.7	25.6	28.8	28.9	32.5	30.2	30.3	25.4	26.5	28.7	417.8
Of which																			
ETW*[21]												0.1	0.1	0.1	0.9	1.4	2.6	4.8	10.0

Table 5 Funding for DERA Intra and Extra Mural programmes outside the scope of this evaluation
Annual spend by DRA/DERA/QinetiQ £ Million

	1990-91	1991-2	1992-3	1993-4	1994-5	1995-6	1996-7	1997-98	1998-9	1999-00	2000-01	2001-02	Total £m
IM	8.8	6.6	7.7	8.4	9.4	8.7	9.3	7.6	6.8	6.2	7.3	6.8	92.8
XR	5.6	4.7	4.8	4.3	5.4	5.7	4.9	4.0	3.6	3.0	2.7	0.8	49.5
Prog. Man	0.4	0.2	[22]	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.3	0.3	4.0
													146.3

[21] European Transonic Windtunnel – outside the scope of this evaluation
[22] Not recorded separately, subsumed in IM and XR

Annex B   Post 1995 major recipients of CARAD grants

Organisation	SME	Sub Programmes	No of Projects
ABB Alstom Power UK Ltd		Avionics, Materials & Structures	6
Advanced Composites Group Ltd	Yes	Materials & Structures	5
AEA Technology		Avionics, Materials & Structures	4
Aerodynamics & Inds Tech Ltd		Propulsion	1
Airbus UK		Avionics, Materials & Structures	5
ARA		Aerodynamics, Cryogenics	4
BAe (Airbus UK)		Aerodynamics, Avionics	32
BAe Sowerby (SRC)		Aerodynamics, Avionics, Materials & Structures	14
BAe Systems Electronics Ltd		Avionics	14
Birmingham University		Avionics, Materials & Structures, Propulsion	6
Cambridge University		Propulsion	5
Cranfield University		Avionics, Heli, Materials & Structures, Propulsion	8
DERA/QinetiQ		Aerodynamics, Avionics, Heli, Materials & Structures, Propulsion	51
Dowty – (Smiths Industries)		Avionics, Aerodynamics, Materials & Structures	10
Dynex Semiconductor Ltd		Avionics	2
FEA	Yes	Materials & Structures	4
FR-HiTemp Ltd		Avionics, Materials & Structures	6
GEC – all parts (BAe Systems)		Avionics, Heli	12
GKN Westland – all parts		Avionics	18
HIP (Infutec)		Avionics, Materials & Structures	2
Hurel-Dubois UK (SNECMA)		Materials & Structures	4
Hyde Group		Materials & Structures	3
Imperial College		Avionics, Materials & Structures, Propulsion	4
Inbis Ltd (Ricardo Hitec)	Yes	Materials & Structures	2
Leica UK		Materials & Structures	3
Lucas – all parts (Goodrich)		Avionics, Materials & Structures	13
Messier-Dowty (SNECMA)		Avionics, Materials & Structures	7
Oxford University		Avionics, Materials & Structures, Propulsion	4
Rolls Royce (Bristol)		Avionics, Heli, Propulsion	7
Rolls Royce (Derby)		Avionics, Materials & Structures, Propulsion	32
Sheffield University		Avionics, Propulsion	3
Short Brothers –(Bombardier)		Avionics, Materials & Structures	8
SIADS Ltd – all parts		Avionics	15
Southampton University		Avionics, Heli, Materials & Structures, Propulsion	5
Stewart Hughes (Smiths Ind)		Avionics	3
TRW – (Goodrich)		Avionics, Materials & Structures	6
Ultra Electronics		Avionics	10
Westland (AgustaWestland)		Avionics, Materials & Structures	3
York University		Avionics, Propulsion	3

Heli equals Helicopters. Avionics later known as Advanced Systems. Organisation names are those at the time of the grant, and later names are in brackets.

Annex C1

CARAD Interview schedule for selected recipients of grant amount greater than £500,000 in total

Organisation name, name of interviewee, position in organisation, contact details.
Name of CARAD Project, and Technology Area within CARAD eg Propulsion.

1. **Basic information about the organisation**: ownership, Number of employees in the UK and outside of the UK (full-time equivalents), ownership UK or foreign.
Main business sector, the type of role or contact with the civil aerospace industry eg supplier/integrator/prime/other.
What % of turnover and what % of profit does civil aerospace contribute.

2. Confirmation of the other project partners, the lead partner, the start and end dates for the project.

3. **Reasons for participation in this project**,
How would you rate the following statements,
where 1= Strongly agree, 2= Agree, 3=neither agree nor disagree,
4=Disagree and 5 = Strongly disagree

	Rating
To develop technologies where it had limited or no experience	
To develop entirely new technologies	
To gain a place at the leading edge of technology internationally	
To gain the status of receiving government support for research	
To build contacts and networks from the collaboration	
To improve skills and competencies	
For increased profit and /or turnover	

Were there any other reasons for your organisation taking part?

The initiation of the project
4. How would you rate the application procedures?
Where 1 = Very easy to use, 2= easy to use, 3= Neither easy nor difficult,
4= Difficult to use, and 5 = Very difficult to use
Do you have any comments on the application procedures?

5. Did you have contact or discussions with DTI about the proposal during the application process? Do you have any comments on your contact with DTI at these early stages?

6. What were the main aims of the project?

Moving forward to the time after the project,
7. Of the project aims, approximately what percentage was achieved?
8. If less than 100%, what were the reasons for the shortfall?
9. What were the main results of the project as a whole?
10. Since the end of the project what has happened to the project results, both in this organisation and in the consortium overall?

11. Has the organisation exploited the project outputs/results, or are there plans to do so?
If Yes, what happened?

12 Has the research led to a follow-on project? If so, was it under CARAD? what is the name of the project? Are or were the same partners involved? If No or Some, who else is in the consortium?

13 Do you still collaborate with any of the partners from this project? If so, who? Are these partners part of your supply chain?

14 As a result of this project, was there any European collaboration? If so could you give brief details of type of collaboration, technology, partners.

Dissemination and transfer outside the project collaboration

15. Are you aware of any opportunities there have been to disseminate your project results outside the consortium? If so, what were they?

16. Are you aware of any requirement or opportunities provided by the CARAD programme to disseminate CARAD results? Would you have been prepared to disseminate any findings outside the project or sector?

17. In your opinion are these project results applicable:
a. outside the consortium within aerospace?
b. If Yes, to what extent, and are potential users aware of these results?
c. in other sectors outside aerospace?
d. If Yes, to what extent, in which sector(s), and are potential users aware of these results?
e. Do you know of any technology or processes transferred from this project to other sectors? Please provide details

18. **Looking at the effect on your organisation**, can you say:
how much your organisation agrees with the following statements where 1= Strongly agree, 2=Agree, 3=Neither agree nor disagree, 4=Disagree, 5 = Strongly disagree.

if these benefits occurred, at what point in the product cycle?
* Stages might be: Design, Prototype, Design for manufacture, Manufacture, Sale of original equipment, Servicing, Sale of replacement equipment.

	Rating	**Product cycle (see *above)**
The organisation has gained world-class technology		
The organisation has developed new products as a result		
The organisation has developed new services as a result		
The organisation has licensed new designs, processes etc		
The organisation has increased its profit and /or turnover		
The organisation has improved its market position		
The organisation has gained new contacts		
The skills within the organisation have improved		

The project enabled the organisation to collaborate with new organisations: Large companies Small companies Universities Research establishments		
The organisation, through the project, has contributed to international standards development		
The organisation has been able to understand and appreciate research done by others.		

19. If skills and knowledge within the organisation have improved, would you say these improvements are written down or are they unwritten (tacit) knowledge?

20. Did the project take priority over any other projects/activities that were under consideration at the time? If so the effect can be described as:
Displacing another project in order of priority ***Yes/No***
Reducing specialist staff for other projects ***Yes/No***
Other markets/products or projects were dropped ***Yes/No***

Referring back to Q 11 on **exploitation of results**,
21. If the research has now been commercialised is it now bringing any financial benefits to the organisation? ***Yes/No***

If so, are they quantifiable in profit or other terms? ***Yes /No***

If so, are you able to indicate in what range the profit was in the last FY?

<£500K	<£501- £1m	<£1m - £10m	£10m-20m	>£20m

22. For this project can you say how much your organisation agrees with the following statements where 1 = Strongly agree, 2=Agree, 3=Neither agree nor disagree, 4= Disagree and 5 = Totally disagree

	Rating
The grant has enabled research within the organisation that would not have taken place otherwise	
The grant has enabled the organisation to carry out the research earlier than otherwise	
The grant has allowed the organisation to collaborate with new partners	
The grant has enabled new links with MoD research	
The grant enabled a broader scope of research to take place	
The grant enabled a larger scale of research to take place	
The grant enabled research with a longer-term horizon to be undertaken	
The organisation would have undertaken this research with a lower level of support, eg 30%	
The organisation would have undertaken this research without DTI support	

If either of the last two answers is 1 or 2 then please specify why the research would have gone ahead.

23. Overall do you consider your organisation's participation in the project was worthwhile and value for money? Any comments?

24. Has your organisation sought research funding from other public or private sources If yes, which sources and with what success?

The DTI CARAD procedures

25. Who was the project monitor appointed by DTI for this project, and what were the arrangements for project monitoring (include frequency of contact, format of reports)?
How would you rate your satisfaction with the monitor?
Where 1 = Excellent (eg always there to help and motivate when necessary), 2= Good, 3= Average, 4= Poor, and 5 = Very poor (eg ineffective, did not really see the purpose of the role).

26. Confirm the amount of grant and percentage support for this project.

27. Were you involved in making grant claims to DTI? If yes, how do you rate the CARAD processes for grant claims and payments where 1 = Very good (straight forward and claims were paid quickly), 2= Good, 3=neither good nor poor, 4= Poor, and 5 = Very poor (bureaucratic and having to wait at least a month for the claim to be processed).
Do you have any specific comments on the claiming process or any problems?

28. **Looking back at the process overall:**
How satisfied were you with the contacts you had with the DTI managers of the project at various points in the process. answer again on a scale of 1 to 5 where:
1 = Completely satisfied, 2=Satisfied, 3= Neither satisfied nor dissatisfied,
4= Dissatisfied and 5 = Very dissatisfied.

	Rating
Contact with DTI throughout the application process	
Overall contact with DTI throughout the project	

Are there any comments you would like to make on DTI project or programme management?

29. Has your organisation used, or do you see a future need for any of the following demonstration facilities (wholly or partially funded by CARAD)?

Name of Facility	**Need for – *Y/N***
More Electric Aircraft -TIMES project	
Optical Network/Databus from FONDA project	
LORCAS at QinetiQ	
Noise test facility at QinetiQ	
Inertia Welding at Rolls-Royce	

Does your organisation use any other external demonstration facilities? (provide names)

In conclusion,
30. Are there any issues not covered today that you think would be helpful to the CARAD evaluation, or any thoughts or concerns for future DTI products?

31. Would your organisation be willing to allow us to use this project as a case study if selected?

Next steps – participants were told DTI would collate all interview material and individual responses would not be identifiable in a report providing an overall view of CARAD from 1990-2003.
They were thanked for their time and preparation , and asked to send any further comments to the evaluators at DTI.

Annex C2

Issues and questions to Directors of major participants and stakeholders

The aerospace sector –what are the barriers to entering the civil aerospace sector in UK

Civil Aerospace research The company/organisation's expenditure on R&D.
Has external capital been sought to fund research

Risks in research – what are seen as the risks (eg technical, funding, long timescale)

Movement of skilled researchers between organisations - what has your organisation experienced - the skills/experience leaving the organisation, and destination of the staff
What gains if any from recruitment.

(For business) How does your company value university research
What type of research has the company funded with universities and what are the benefits
Are there continuing longer-term links

Overall, what role does, or did, government-supported research play in the strategic plans of your company for example Research Council funding, MOD and CARAD

Reasons behind the decision to bid to CARAD rather than any other source
Deciding factor or factors

What has the CARAD grant(s) enabled

What Additionality was there for the research that DTI funded
What would have been the organisation's approach if DTI had offered a lower level of support (say 30%) or no support
How significant would it be if DTI research funding were reduced or withdrawn

CARAD benefits
What have these been (eg what influence has it had on the company's direction, growth, productivity, competitiveness, influence in Europe.)
Are the benefits quantifiable in profit terms or as percentage of the company's profits based on CARAD

Outcomes
To what extent are the benefits internal to the company or are results mainly covered by licensing or patents

Any spin-offs known from your CARAD projects to other sectors

What was the payback period on the technologies/products/processes researched in the CARAD projects
Was the participation in CARAD was worthwhile and value for money

Working with others
Would your organisation have worked with your CARAD partners as a matter of course, or was the collaboration initiated by the requirements for CARAD   Has CARAD brought other collaborations or network contacts.

Current trends in your supply chain – eg towards networks, or towards integration of functions in single organisations, or towards larger/smaller companies.   Influence of CARAD collaborations on the supply chains in the sector

Has CARAD funding affected the company's policy on researching with Small firms ie are you working with smaller companies to a greater extent, or lesser extent, or about the same

What were the gains from Defence spin-offs or DRA/DERA/QinetiQ work
Has the change in status of DERA to QinetiQ affected your view of it as a partner in CARAD

What other collaborations does the organisation have outside CARAD

Any thoughts on the process/procedures of working with DTI on CARAD

Effect of CARAD participation on your organisation's ability and reputation in international research collaboration

Importance of CARAD research results in contributing to international or European standards

Annex D

Organisations interviewed

Companies
QinetiQ, Farnborough
Airbus Government Relations and Technology, Bristol
Smiths Aerospace, Wolverhampton
Smiths Aerospace, Cheltenham
Goodrich Control Systems, Birmingham
Goodrich Actuation Systems, Wolverhampton
Alstom Power Technology Centre, Whetstone
Rolls-Royce HQ
Rolls-Royce, Research & Technology, Bristol
Rolls-Royce, Operations Technology, Derby
Bodycote Hot Isostatic Pressing Ltd, Chesterfield
LUSAS, Kingston upon Thames
Advanced Composites Group, Heanor

Society of British Aerospace Companies

Universities
Imperial College London, Dept of Mechanical Engineering
University of Southampton, IT Innovation Centre
University of Birmingham, School of Engineering

Research association
Aircraft Research Association Ltd, Bedford

DTI managers- Aerospace and Defence team
Dr R Kingcombe
Dr S Bishop
Mr I Wilson
Dr G Richards

Annex E1

Additionality - from interviews with project managers and participants.

Responses are grouped by each of the four technology areas – Propulsion, Advanced Systems, Aerodynamics and Materials & Structures

Propulsion (seven interviews):
Five said CARAD enabled research to take place
All said it enabled research to take place earlier
Four said it enabled collaboration with new partners
In two cases CARAD enabled links with MoD
Five said CARAD enabled a broader scope and larger scale of research
Six said CARAD enabled longer-term projects.
Opinions were evenly balanced on whether they would have carried out the research with a lower level of support ie research with lower than 50% support or demonstration projects with lower than 30-35% support. Views were much clearer on absence of any support at all, where four definitely would not have undertaken it without any DTI support although two said they would have done.

Advanced Systems (six interviews):
CARAD had enabled research to take place and to happen earlier than otherwise, for five of them. CARAD had enabled a broader scope, and larger scale for four of the managers.
Collaboration with new partners was a result for three of the project managers.
In one case CARAD enabled links with MoD.
In five cases CARAD enabled research to be longer-term than otherwise.
Five said they would not have undertaken the project with a lower level of DTI support, and all said they would not have done it without any DTI support.

Aerodynamics (four interviews):
All four agreed that CARAD grants had enabled research to take place and to take place earlier than otherwise, with a broader scope and on a longer-term basis.
Three said it enabled larger scale projects.
Two said it brought new collaborations.
One said the grant had enabled links with MoD.
Three would not have done the research with a lower level or no support from DTI.

Materials and Structures (ten interviews):
Nine agreed the CARAD grant had enabled research to take place, and to take place earlier than otherwise and on a larger scale.
Longer-term research was enabled in eight projects.
Broader scope was enabled in seven of projects interviewed.
However there is no clear view on whether grants had enabled new contacts.
Two said it had enabled links with MoD.
Six managers thought their projects would not have gone ahead if DTI had offered a lower level of support than they received (say 35% instead of 50%).
Seven said they would not have gone ahead at all without any DTI support.

Annex E2

Outcomes from CARAD grant projects – from interviews with project managers and participants.

Type of benefits gained by the participants

Summary of 27 interviews in order of benefits most frequently reported:

new contacts	20
world-class technology	18
improved market position	16
increased knowledge and skills	16
development of new products	13
increased profit and /or turnover	12
ability to offer new services	9
licensing new technology designs	4
contribute to international standards	4

It was noticeable that the so-called "softer" or unquantifiable benefits of making new contacts and improved staff skills are reported with the same frequency as the harder commercial benefits of world-class technology, market position and profit/turnover.

Benefits reported grouped by each of the four technology areas – Propulsion, Advanced Systems, Aerodynamics and Materials & Structures:

Propulsion (seven interviews):

increased knowledge and skills	7
development of new products	6
improved market position	6
new contacts	5
world-class technology	4
increased profit and /or turnover	4
ability to offer new services	2
licensing new technology designs	1
contribute to international standards	1

Advanced Systems _ (six interviews):

increased skills and knowledge	6
new contacts	4
world-class technology	2
new products	2
increased profit/turnover	2
contribute to international standards	1
ability to offer new services	0
licence new designs	0
improved market position	0

Aerodynamics (four interviews):

world-class technology	4
increased skills and knowledge	4
ability to offer new services	4
improved market position	3
new contacts	3
contribute to international standards	2
licence new designs	1
increased profit	1
development of new products	0

Materials and Structures (ten interviews):

increased skills and knowledge	9
world-class technology	8
new contacts	8
improved market position	7
development of new products	5
increased profit	5
ability to offer new services	3
licence new designs	2
contribute to international standards	0

Achievement of objectives for project and participants

In the 27 projects interviewed, on average:

85.5% of the project objectives were achieved
and 87% of the participants' aims were achieved.

Each technology area showed different rates of success:

Propulsion:

93% of the project objectives were achieved
97% of the participants' aims were achieved

However in some demonstrator projects, only 75% of objectives were achieved, possibly because a range of technical options were chosen for demonstration and during the project it would have become clear that there was no business case for pursuing some of the options. This would be usual for demonstrator projects.

Advanced Systems:

82% of the project objectives were achieved
90% of the participants' aims were achieved.

Aerodynamics:

97.5% of the project objectives were achieved
97.5% of the participants' aims were achieved.

Materials and Structures:

81% of the project objectives were achieved

79% of the participants' aims were achieved.

Financial benefits

Propulsion – Three of those interviewed reported financial benefits, although there had been some significant products resulting from CARAD supported research. Those benefits reported were in the range £1-10m and one was over £20m, however most interviewees could not quantify benefits. These projects had taken place between two and nine years previously.

Advanced Systems – Three said there were financial benefits, although only one could quantify (in the £1m -£10m range)

Aerodynamics – Three had financial benefits and two could quantify them (at less than £500k and between £500k and £1m)

Materials and Structures – Five had identified financial benefits, although these were at the extremes of the scale (over £20m and below £1m).

Value for money from the CARAD Programme.

Propulsion – All considered the CARAD Programme was value for money.

Advanced Systems - All thought CARAD was value for money

Aerodynamics – Three interviewees considered CARAD was value for money. The remaining one was a project where no commercial return was in sight although 90% of project aims had been achieved.

Materials and Structures – All those interviewed considered it was value for money.
One major participant stated that it had repaid between 20 and 40 times the value of grants.

All but one of the 27 interviewed had used other funding sources such as EPSRC, MoD and European research funding and could compare the relative benefits.

Collaboration

Propulsion:
Five of the seven interviewed said they had made new contacts through CARAD.
Five were still working with their CARAD project partners, most of whom were in their supply chain.
Four had undertaken a follow-on project under CARAD with some of the same partners.
Three had undertaken a European research collaboration as a result of the CARAD project.

Aerodynamics:
Three had made new contacts in CARAD.
All four were still working with their CARAD partners although these partners were not in their supply chain as primes were working with research associations and universities.
One of those interviewed had undertaken further collaborative research with the same partners
Two had collaborated in European projects following a CARAD project.

Advanced Systems:
Four had made new contacts in CARAD.
All six of those interviewed were still working with their project partners, and for four of them their partners were in the supply chain.
Four of those interviewed were working on a follow-on CARAD project with the same partners.
Two were working in a European collaboration as a result of the original CARAD project.

Materials and Structures:
Eight of the ten interviewed had made new contacts through CARAD.
A different eight were still working with their CARAD partners and for two interviewees, their partners were in their supply chain.
Three of those interviewed had started a follow-on project under CARAD
Six had started a European collaboration as a result of the original CARAD project.

Dissemination and transfer

Propulsion — Four were aware that they should disseminate the results and were prepared to do so, and in majority of projects it had taken place. In the seven projects interviewed, the technology results were applicable to the rest of the aerospace sector and to other sectors. Potential users were aware of the results in five, and technology had been transferred in two of these cases.

Advanced Systems – All six interviewees were aware of the requirement to disseminate results of the project and were prepared to do so. Dissemination had taken place from one project. In all six interviews, potential users were said to be aware of the results that were applicable widely in the aerospace sector and in five cases, results were also applicable in other sectors. Technology was actually transferred from one project.

Aerodynamics – Three had disseminated their project results. Results for three of the projects were applicable in aerospace, which gave a high rate of dissemination in aerospace, but only one set of results was applicable in other sectors (this may be expected with aerodynamics technology). No technology was actually transferred as it was still commercially sensitive at the time of interview.

Materials and Structures – Nine of the respondents were prepared to disseminate results and five had done so. All the results of projects surveyed were applicable to the rest of the aerospace sector, and nine said the technologies were applicable in other sectors. Six interviewees said potential users were aware of the new results and five said that the technology had been transferred. Where it had not been transferred the projects had completed within the last 2 years.

Large demonstration facilities

Twelve of the 27 interviewed had used demonstration facilities provided by CARAD funding:

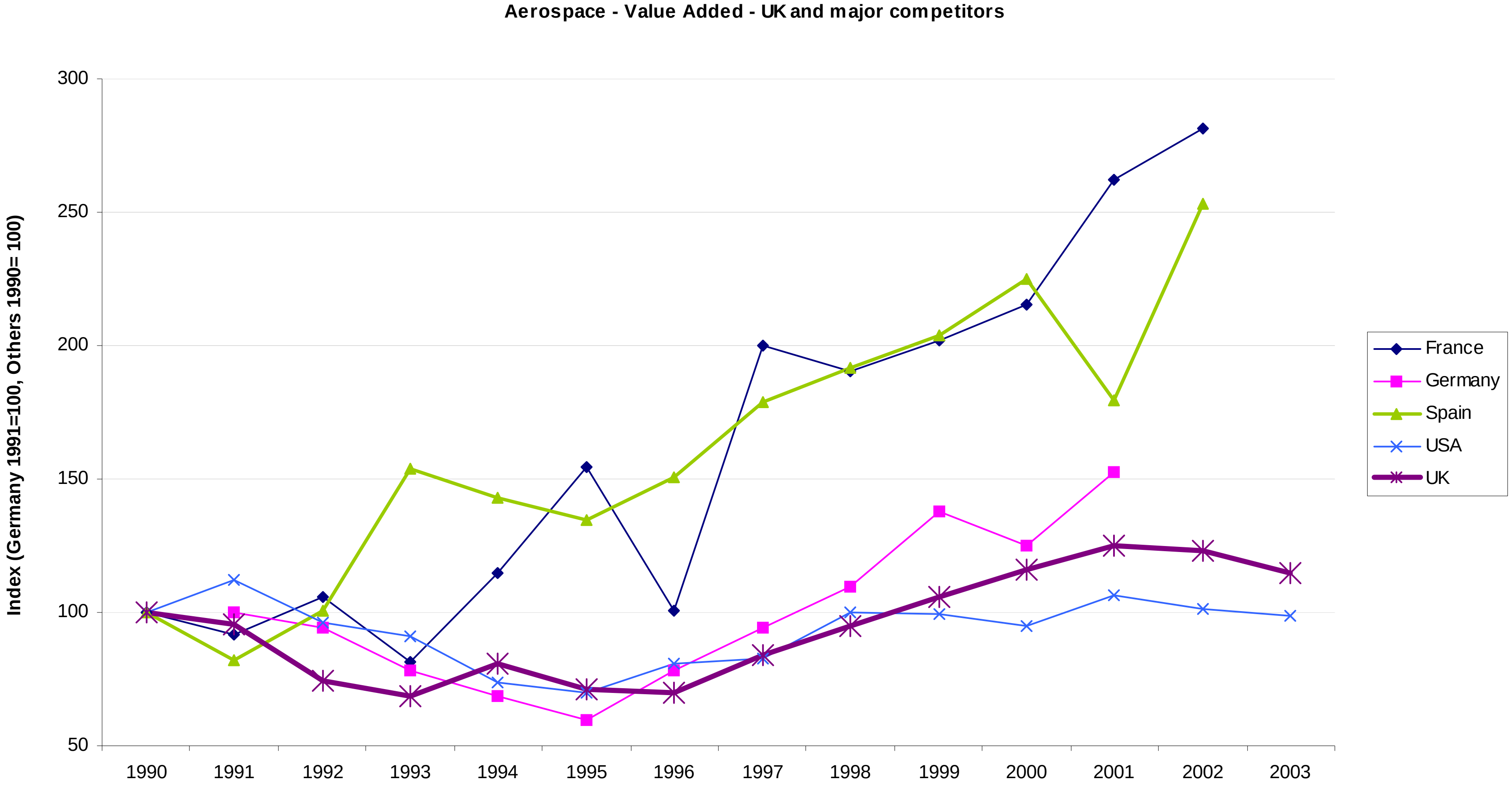
Propulsion – five of the seven interviewees had used CARAD demonstration facilities. These were not only the Noise test facility as expected, but also those for More Electric Aircraft and Inertia welding.

Advanced Systems – five of the six interviewees had used the More Electric Aircraft demonstrator from the TIMES project associated with Advanced Systems.

Aerodynamics - one interviewee had used the Noise test facility for Propulsion.

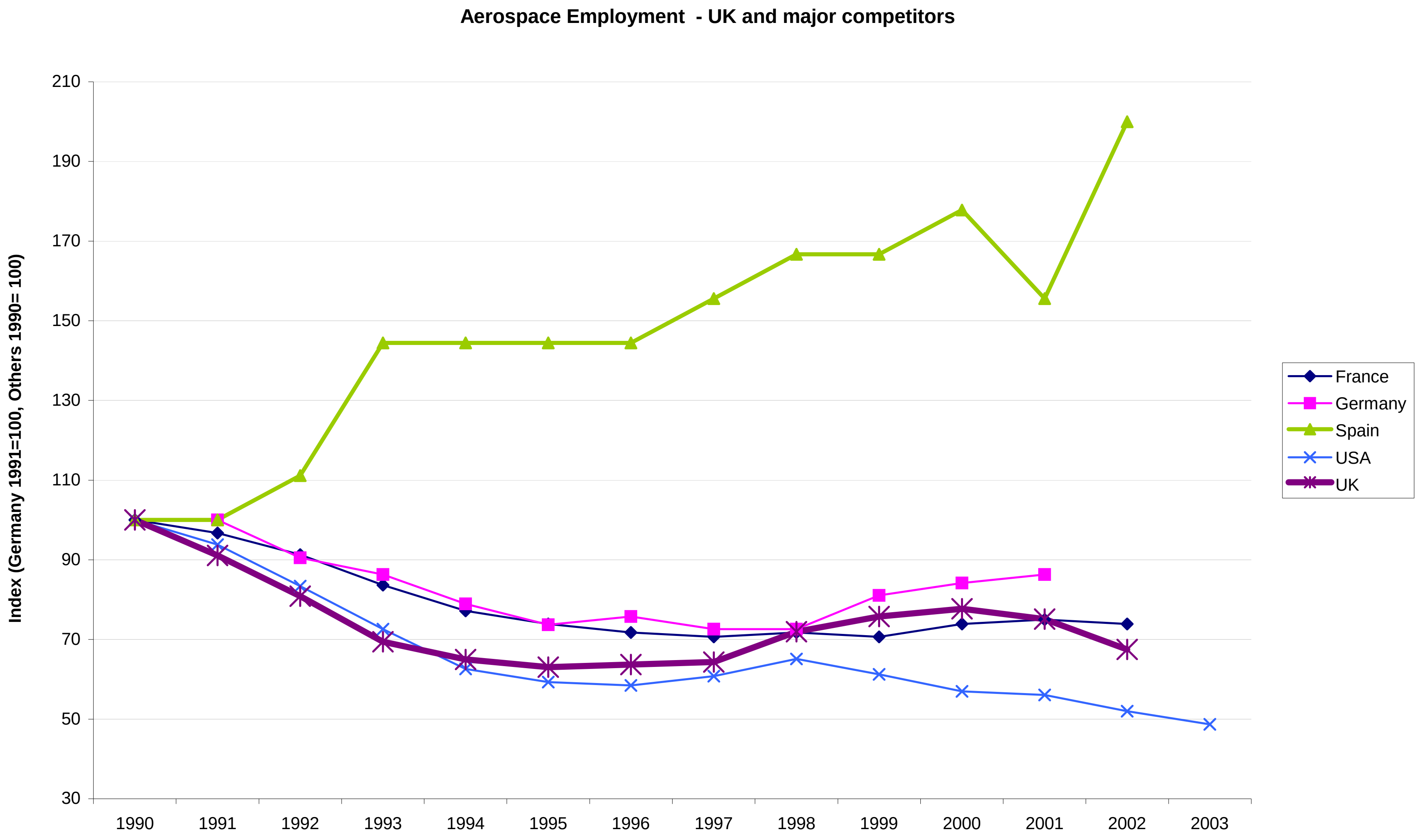
Materials and Structures – one interviewee had used the Inertia Welding facility, for materials testing. Some have investigated the possibilities but not used them. Larger companies have their own materials testing facilities.

Annex F



[23].

[23] Source OECD STAN database



Aerospace Employment - UK and major competitors
Index (Germany 1991=100, Others 1990= 100)
210
190
170
150
130
110
90
70
50
30
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
France
Germany
Spain
USA
UK

Annex G

The links with MoD, DERA, and QinetiQ

Links with Ministry of Defence research

Views from MoD were that their access to the CARAD Programme and the involvement of the Defence Science and Technology Laboratory (DSTL) in monitoring projects has been extremely valuable in three ways:

DSTL staff were aware of the DTI funded work in the CARAD Programme and could ensure that work was not duplicated, thereby deriving the maximum benefit from complementary arrangements between MoD and DTI funded programmes in similar areas.

DTI and the CARAD contractors benefited from access through the DSTL monitors to similar work funded by MoD.

It has helped DSTL staff be aware of the wider picture on aircraft materials and structures research and helped them to retain their currency of knowledge.

The CARAD projects formed an extremely valuable interaction and synergy between MoD and DTI funded work, with DSTL as the conduit. In an effort to continue this interaction, DSTL staff has been heavily involved in the assessment process for the DTI Technology Programme. MoD staff confirmed that the Materials and Structures area has always been particularly productive and DSTL has excellent links with the DTI technology managers for the Materials and Structures areas who have agreed to keep DSTL involved and to give them sight of projects that might be of interest to MoD. DSTL were involved in monitoring some of these projects.

Propulsion technology, where the technology is generic to military and civil, has been another area where very strong links continue. Rolls-Royce's recent strategy has been to develop compressor research under a military heading, while turbine research is generally under a civil banner. However, there is again real synergy from the defence / civil interaction and DSTL has maintained an oversight of both sides.

Examples of joint MoD/DTI funded work include:
Joint UK/US defence collaboration on High Cycle Fatigue, which has exploited DTI funded research on foreign object damage
Joint MOD / DTI sponsored work on repair has involved work on Titanium funded by DTI, with work on Nickel funded by the MoD but both 'customers' use both materials.

Examples of CARAD developing civil applications from military research include laser peening, which was developed for military but is now used on civil fans and thermal barrier coatings.
In most cases the exploitation has worked seamlessly as the work has been at the pre-competitive stage, with information sharing and joint development of skills being the main technology transfer mechanisms.

The Defence Aerospace Research Partnerships Call of 2002 was held jointly by DTI and the MoD. Management of this call was through the CARAD Programme at DTI. The EPSRC supplied suggested referees and commented on the strategic fit of the proposals.
Overseeing of the projects was led by MoD.

Synergy with defence research through the DERA intra-mural and extra-mural programmes

The Defence Research Agency 1991 (DRA), later the Defence Evaluation Research Agency 1995 (DERA) carried out government research with 100% government ie MoD and DTI funding known as the intra-mural programme. DTI also funded research carried out by teams of companies/HEIs/Research Associations under DERA management, known as the extra-mural programme.

Most of the participation by the Farnborough site in the CARAD programme took place in the time of DERA (1995 – 2001). DERA was a key adviser to DTI on aerospace technology. Work was commissioned under the Framework Agreement.
The agency had the expertise to manage the extra-mural programme and carry out the intra-mural programme and also provided project managers and monitors for CARAD projects. DERA was organised in technology divisions for each of the CARAD technology areas – aerodynamics, avionics, materials, structures and propulsion. DERA had a manager to review intra and extra mural input to the CARAD Programme, and co-ordinate the DERA contribution, and participate in a committee of DERA technology specialists and DTI specialists and industry representatives. More than half of the CARAD Programme expenditure was directed to the intra and extra mural programmes - see Annex A Table 5. DERA contributed strongly to the strategic direction of CARAD.. Although CARAD grants provided only 1% of DERA turnover in cash terms, the gearing of the grant funding was between 20 and 40 times that amount.

From the viewpoint of QinetiQ (formerly DERA) staff the arrangements worked satisfactorily in the joint military/civil technology programmes where civil participation was funded by CARAD. DTI contributed a percentage of support that was considered appropriate for the civil industrial aspects of the projects, for example in the Aluminium Lithium programme. There were common elements of the projects/programmes that both DTI and MOD could support and other packages that were military only. DERA had the flexibility of staff expertise and management capability to deal with the variable geometry of these joint programmes and share skills in challenges common to civil and military applications. The CARAD projects and the DERA staff gained benefit from the experience and interchange of expertise within the programmes.

Effect of CARAD on DERA, later QinetiQ

CARAD played a significant role in the strategic plans of DERA. Although for DERA the CARAD income of £13m annually was only 1% of turnover, it gave a significant leverage and coherence effect on research in DERA and the aerospace sector. CARAD enabled a full national co-ordinated aerospace research programme, with the universities and the military research establishments, and the QinetiQ view was that its contribution to UK research base was far more than the face value of the programme.
DERA's strength in the Advanced Systems area of aerospace was in the provision of test facilities (eg LORCAS civil avionics systems 100% funded by DTI) The research staff were primarily technology specialists and developed project management skills as the organisation became increasingly commercialised.

On Propulsion, DERA were active in the early 1990s in proposing research for the extra-mural programme. DERA had a good view of industrial and technical requirements in aerospace.

Without CARAD, the DRA/DERA/QinetiQ organisation would not have had the funding to collaborate with civil partners nor for their participation in collaborative research programmes.

Effect of DERA privatisation on the CARAD Programme

With the creation of QinetiQ, the possibility of contributing to a strategic view of CARAD was lost. The intra and extra mural programmes with their planned format, ceased. Currently work is bid for competitively through the Technology Programme.

Since 2001, CARAD proposals from QinetiQ have become more focused on industrial needs and are led by the large companies eg Airbus or Rolls-Royce, with the consequence that QinetiQ must focus on industry requirements. Their income is derived from contract research on civil products or commercial defence products (some MoD funds), and there is also private venture funding for projects.
QinetiQ's new role resulted in a reduced ability to lead and/or collaborate in CARAD or other collaborative programmes like European Framework, because all their work is now customer driven. This leaves little or no scope for discretionary or long term generic research in matched funding programmes, apart from areas such as Materials & Structures where QinetiQ manage to persuade their industry partners to provide the 50% financial contribution on behalf of QinetiQ.

Another effect of privatisation was that QinetiQ became a commercial competitor of several previous partners, who are now wary of further collaboration with them. Their suitability as independent monitors for government research has ended, with a consequent loss of income to QinetiQ and increasing difficulty for government in finding experienced independent monitors for technology research projects.

The situation now is that only universities and research institutions can undertake 100% funded research for government. The end of intra and extra mural programmes resulted in loss to UK government of an in-house specialist resource with understanding of government and business applications and the interaction between them. The synergy gained from research in technologies of benefit to both civil and defence requirements has also been lost, as have the contacts in global and European networks of government research institutions, and the knowledge of government research issues in other countries.

In 2005 the balance of work within QinetiQ as a whole was 80% for MoD support and 20% for DTI support. In the technology-rich part of QinetiQ, the balance was weighted more towards DTI/civil aspects (66% military and 33% DTI / civil).

The opportunities in this interface have reduced over time. Since 1992 MoD has changed the basis for commissioning their work from vote-funded research establishments to funding of individual projects.

Annex H

Studies/analyses contributing data

Previous studies drawn on

Aerospace Innovation and Growth Team report 2003

[1]Wider Economic Benefits of Skills Diffusion from the UK Aerospace Industry by the Ricardo Group.
and
Wider Economic Benefits from Technology Transfer from the UK Aerospace Industry by Cranfield University.
Both commissioned by the Aerospace Division of DTI, 1995

"ABOTTS" Report Analysis of Business Opportunities for Transfer of Technologies from Space by Qi3 for BNSC, 2005

Annex I

Spin-off technologies – examples from the ROAME statement prepared in support of the CARAD 4 Programme in 2001

Spin-off	Source in Aerospace Technology	Application of Technology
Health		
Artificial joints	Titanium alloys	Titanium artificial joints have a longer life and result in fewer rejections
Heart pacemaker	Piezoelectric technology used for measuring vibrations in gas turbines	Control heart pacemakers to match body activity rate.
Artificial limbs	Braided carbon fibre composite materials developed for propellers	Carbon fibre artificial limbs result in a reduction in weight from 20 Kg to 3 Kg
Patient support structures and accessories	Glass/carbon fibre composite/honeycomb materials	Composite materials are used for patient support structures and accessories used with medical diagnostic equipment
Spectacles	Computerised lens design	Varifocal spectacles
Oxygen equipment	Developed for fighter aircraft	Medical, mountaineering and diving oxygen equipment
Crime and Security		
Night vision	Military aerial reconnaissance	Thermal imaging cameras for police and other emergency services
Body armour	Fighter aircraft and helicopter armoured seats	Bullet and knife-proof vests. Used by police.
Specialised glass	Aircraft windscreens	Toughened and security glass in banks, VIP transport and train windscreens
Transport		
Braking systems	Disc brakes and automatic braking systems	Application to cars and trains
Structures	Integrated structural design	Application to cars and trains
Computer modelling	Finite element analysis	Very widely used for all types of structure
Computer modelling	Computational fluid dynamics	Application to cars and trains
Simulation	Aircraft simulation	Training and leisure use
Seat belts	Parachute harness	Car seat belts
Heated windows	Electrically heated windscreens	Application to cars and trains
Magnesium alloys	Aerospace materials	Lightweight castings for vehicles and machinery
Bearings	Aerospace self-lubricating bearings	Bearings used in French TGV train, various tram systems, fighting vehicles and Formula 1 cars

Spin-off	Source Aerospace Technology	Application of Technology
Other Commercial Applications		
Heat exchangers	Superplastic forming and diffusion bonding of titanium	Benefits giving radical reduction in space and weight and improved reliability inn hostile environments
Non-aeronautical gas turbines	Derived from aero-engine gas turbines	Ship propulsion, electrical power generation and pumping
Carbon fibre reinforced plastics	• Resin transfer moulding • Braiding technology • Carbon fibre injection moulding	• Used for motor vehicle spoiler production • Monocoque composite car chassis development • Applied to automotive moulded parts such as distributors
Creep feed grinding	A specialised form of metal grinding	Giving significant reductions in manufacturing costs and higher quality
Electron beam welding	High quality welding of thick sections of difficult materials	Techniques now widely used in automotive applications, eg turbocharger units, transmission components, instrumentation and medical prostheses
Touch probe	A 3-dimensional automatic measuring sensor for positioning of detailed equipment such as pipe assemblies	Most co-ordinate measuring machines now use this technology
Instrument displays	• Flight control computers • High immunity data transmission from aircraft utility systems • Helmet mounted sights from combat aircraft	• Sub-sea oil well head controllers • Train control • Fire-fighting, surgery and Formula 1 racing
Adhesives	Adhesive bonded wood and metal aircraft structures	Using on road and rail vehicles and bridges. Speed, strength, longer life, quicker assembly, lower costs
Hot isostatic pressing	Method of reducing porosity in gas turbine blade materials	Motor vehicles, other machinery, construction, industrial plant, mining equipment, agricultural machinery, electrical equipment
Finite element analysis	Computerised analysis of aerospace structures	Structured optimisation of virtually all structures
Instrumentation	Wind tunnel instrumentation	Laser based velocity meter
Inertial navigation	Precision gyroscopes	Marine inertial navigation
Electronics	Transistorised circuits	Clocks, watches, domestic appliances
Radar	Airborne radar	Marine navigation

Spin-off	**Source Aerospace Technology**	**Application of Technology**
Manufacture	Spark machining	Die manufacture
Manufacture	Explosive electro-hydraulic forming	Steel dental plates, artificial limbs, large tube manufacture
Fuel	High octane fuels	Motorcars
Plastics	Acrylics	Building and agriculture
Adhesives	Synthetic resin adhesives	Furniture and marine industry
Manufacture	Vacuum melted steel	Ball bearings
Safety	Safety critical software	Application to railway signalling and nuclear power
Renewable energy	Propellers	Wind generators

Others identified by DTI Aerospace and Defence team are:

Spin-off	**Source Aerospace Technology**	**Application of Technology**
Radar for reversing	Infra red sensor	Cars
Synthetic modelling	Simulation	Cars, ships, houses, garden
Computer games, Theme park rides	Simulation	Entertainment
Navigation & display	GPS	Marine, cars

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