Defence & Aerospace

The Sector

Defence and Aerospace are major elements in the global economy. In the UK, they contribute significantly to wealth creation and quality of life, both directly and in terms of technology spin-off to other sectors. Aerospace alone contributes a £2-3B surplus to the UK's trade balance. The UK is a leader in design and manufacture of advanced systems, deriving from programmes of R&D supported by industry and Government. In both Defence and Aerospace, the UK's market opportunities are enhanced by the operating competitiveness of UK companies which has improved radically over the past 15 years.

The role of Government is more important in Defence and Aerospace than in any other industrial sector. In Defence and Aerospace, governments are market forces and, in terms of UK technology, the Defence Research Agency is a key national resource.

The Future

Defence and Aerospace are important markets for the future. The global market for Civil Aerospace is likely to grow significantly over the next 10-20 years. The UK is well placed to exploit this growth, through its involvement in the Airbus project, because of strong market positions in aeroengines and the equipment sector, and in market niches such as aerostructures and civil helicopters. Defence markets, although declining since the end of the Cold War, remain very substantial and offer many opportunities to exploit new technologies. New technologies are changing the nature of warfare, and new demands on defence forces require new technological solutions.

The sectoral issue for the UK is whether it wishes to continue as a leader. The UK is in competition with other economies, notably the US, France and Germany, to host a significant share of the world Defence and Aerospace industry. To continue as a leader the UK must set strategic goals similar to those adopted by our competitors who are making vigorous efforts to sustain their product and technology bases. We cannot continue `consuming our technological inheritance' - and must begin now to regenerate our product range by adequately funded, well-focused investments in new technology.

The Panel's Vision, towards which its recommendations are geared, is:

Industry, Government and Academia working in partnership so that UK Defence and Aerospace continues as a major contributor to wealth and national security.

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Forward with Foresight

The following technology areas should be given particular priority in industry and the universities in view of their high potential impact:

- Systems Integration
- Process Technologies
- Materials and Structures
- Simulation, Modelling and Synthetic Environments
- Aerodynamics (including Emissions and Noise)
- Sensor Systems, Data Fusion and Data Processing
- High-integrity, Real-time Software

If the UK is to sustain its competitive position, Industry and Government must reverse the trend of declining R&D investment and facilitate the exploitation of technology. The Panel recommends that mechanisms for Government funding should be revised to increase the focus on wealth creation and to provide a better balance between the phases of basic research, applied research and technology demonstration. Specifically, the following is proposed:

- Two new University-linked Applied Research schemes should be established, focused on Dual-Use Technologies (£24M pa) and Civil Aerospace (£40M pa) with a significant industrial contribution to ensure market relevance and commitment to exploit the results.

- The level of DTI funding for Industrial Applied Research in Civil Aerospace, through the Civil Aircraft Research and Demonstration (CARAD) scheme, should be increased to £25M pa with a matching contribution from Industry.

- Technology Demonstrator Programmes (TDP) should be increased significantly. DTI funding for Civil Aerospace TDPs should be increased to £30M pa immediately, rising to £65M pa over three years, with Industry providing a similar level of funding. The level of activity in MOD-funded Defence TDPs also needs to be increased.

A number of other significant policy issues must be addressed if UK Defence and Aerospace is to exploit fully the technology which this country has, or can develop:

- The Challenge to Companies. Companies must develop and implement plans to increase industry R&D investment significantly against long term technology goals.

- National Strategies for Defence and Aerospace Technologies. Industry, Government and Academia should establish strategy frameworks for Defence and Aerospace technologies.

- MOD Procurement Policy. Government and industry should review MOD procurement policies to place more emphasis on UK industry competitiveness and wealth creation.

- Market Distortions. Government, with Industry support, should establish effective means to monitor and correct market distortions.

- International Defence Collaboration. Government must accelerate where appropriate the establishment of common defence requirements and acquisition in Europe.
- Financing. Industry and Government, in partnership, should work to reverse the current declining UK spend on research and demonstration.
- Air Traffic Control. The UK should seek to work within Europe to define standards for an advanced air traffic control system and participate in supporting demonstrator activity.
- Space. Consideration should be given to adjusting the balance between national and European funding and reforming European and UK space institutions.
- Skills. Undergraduate training in multi- and inter-disciplinary subjects supporting the Panel's key technical priorities should be developed.

The Defence and Aerospace Panel will, as part of on-going Foresight activities, work with relevant Government Departments and the Defence and Aerospace community to set the strategic objectives for Defence and Aerospace technology over a 15-year perspective and to address the means of achieving these objectives. The stakes are high in terms of security, wealth creation, trade and employment. The Panel believes that, by implementing the Foresight recommendations, the UK can respond to the competition and take a major step towards increasing, not just maintaining, its share of a substantial global market.

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Disclaimer

The work of the panel has benefited greatly from its Government members and support staff. However, the constraints of their positions made them unable to comment on issues of Government policy.

Special Notes

The panel decided early in its work that whilst some classified material might have to be considered by the panel, its main report should be unclassified. Sensitive areas such as chemical and biological defence and nuclear issues have therefore been excluded.

During the course of its work, the Defence sub-group prepared a paper covering possible scenarios the global defence market and force requirements. This paper is available, on a restricted circulation, by personal application to OST.

Progress Through Partnership: Preface

The Technology Foresight Programme is a major initiative whichwas announced in the 1993 White Paper 'Realising Our Potential'.The Programme brings together industry, academia and Governmentto consider how the UK can best take advantage of opportunitiesto promote wealth creation and enhance our quality of life. TheProgramme has been driven forward with great energy and enthusiasmby the 15 independent Technology Foresight panels. The Programmehas reached out to over 10,000 people.

I believe that the current findings from the Technology Foresight Programme will prove invaluable. They will help businesses, academic institutions and policy makers to **Progress Through Partnership**. I know that, encouraged by the Office of Science and Technology, several other organisations are embarking on the Foresight approach. Only by bringing together science and business more effectively will we secure the economic performance necessary to maintain our competitiveness.

The Foresight panels have generated visions of the future which will lead to more informed decision-making in both the publicand private sectors. I would like to thank them for their wholehearteddevotion to this important mission. We now look forward to a busyand exciting period as the results of Foresight are drawn togetherand the Foresight process moves forward.

Progress Through Partnership: 12 Defence and Aerospace

FOREWORD

The first UK Technology Foresight programme has comeat a time of great challenge and opportunity in Defence andAerospace. The end of the Cold War brought a welcomereduction in tension between East and West, and heraldedsubstantial reductions in the defence budgets of manycountries. Yet, the world is experiencing threats to peacefrom a less predictable range of conflicts and tensionsaround the world. At the same time, the nature of warfare ischanging. Conflicts will increasingly be won at thecutting edge of technology and defence technologycontinues to advance rapidly.

Civil air transport has seen dramatic growth since the end of World War 11, and traffic is likely tocontinue to grow at between 5 and 6 percent per annum over the next 20 years. The air transportindustry achievement in reducing fares to between one half and one third of what they were 40years ago, in real terms, has facilitated huge changes in people's lifestyles and in theglobalisation of business. Yet, during the last five years, airlines worldwide have experiencedsevere financial pressures which have translated into a deep recession and unrelenting pressureson aircraft prices and costs.

Pressures in both the Defence and Aerospace sectors have already causedsignificant industrial restructuring. The process of restructuring has further to go, particularly inmainland Europe, but the UK Defence and Aerospace sector is now in a position whereoperationally it is extremely competitive. The challenge for UK Industry and Government is toredress the relatively low investment in technology in recent years, so as to exploit thesubstantial opportunities which technology can provide:

- in Defence, both in support of nationalsecurity and in pursuit of export opportunities;
- in Civil Aerospace, to gain an increasing shareof a rapidly growing market.

In this report, we describe the strategic issues and priorities which emerged from an extensive programme of analysis and consultation. This report is the product of the effort, insight and enthusiasm of a very large number of people within UK Defence and Aerospace. I would like to thank all of those who made submissions, responded to the Delphi survey and attended workshops. I would also like, particularly, to give my personal thanks to the members of the Panel and to the OST staff who supported us.

This report is, of course, only a first step. The value of its ideas and recommendations will depend entirely on the action, co-operation and commitment of Academia, Industry and Government. In many of our consultations, the viewwas expressed that 'Foresight must be seen to make a difference'. I believe that Foresight can andwill make that difference.

ROY McNULTY, Chairman, Defence and Aerospace Panel

1. EXECUTIVE SUMMARY

1.1 Defence and Aerospace are major elements in the global economy. In the UK,these sectors contribute significantly to wealth creation and quality of life, bothdirectly and in terms of technology spin-off to other sectors. We are world leadersin Defence and Aerospace, with a long record of success - in technology, productinnovation, productivity, and a substantial positive contribution to the UK'sbalance of trade. The UK is a leader in design and manufacture of advancedsystems - for example, the first advanced 'fly-by-light' control systems weredeveloped in the UK. The UK's share of OECD exports is higher for Defence andAerospace than it is for any other sector. Much of today's success derives frompast investment in technology by Industry and Government.

1.2 Defence and Aerospace are important markets for the future. The global market forCivil Aerospace is likely to grow significantly for the next 10-20 years. The UKis well placed to exploit this growth, primarily through British Aerospace's sharein Airbus and the strong market positions developed by Rolls-Royce and the UKequipment sector, but also through other market niches such as aerostructures andcivil helicopters.

1.3 The Defence industrial and technology base is fundamental to national security.In world Defence markets, the UK is currently second only to the US in terms ofdefence exports. Defence markets, although declining since the end of the ColdWar, remain very substantial and offer many opportunities to exploit newtechnologies. New technologies are changing the nature of warfare, and newdemands on defence forces are requiring new technological solutions.

1.4 The role of Government is more important in Defence and Aerospace than in anyother industrial sector - partly because of Government's responsibility for nationaldefence and as the defence industry's principal customer, but also because of theactive role which the UK and other governments play in the Civil Aerospacesector. In Defence and Aerospace, governments are market forces and, in terms ofUK technology, the Defence Research Agency is a key national resource.

1.5 In both Defence and Aerospace, the UK's market opportunities are enhanced bythe operating competitiveness of UK companies which has improved radicallyover the past 15 years, a trend which can be expected to continue. Relative toFrance and Germany, the UK industry has restructured much morecomprehensively to meet the market conditions of the 1990s, and is today verycompetitive in terms of costs, quality and cycle times.

1.6 The issue for the UK in the Defence and Aerospace sector is whether it wishes tocontinue to have a leading industry. Increasingly, Defence and Aerospace involvesglobal markets and global industries in which competition is intense. Companieshave to locate work wherever the technology, skills and R&D investments can bebest provided and also where markets dictate. The UK as a nation is incompetition with other nations, notably the US, France and Germany, to host asignificant share of the total world Defence and Aerospace industry. At present,other nations are making vigorous national efforts to sustain their Defence andAerospace technology and product bases. In contrast, the benchmarking workcarried out by the Panel indicates an emerging decrease in the UK's technologycompetitiveness, particularly in the Defence sector, even though our underlyingscience capability remains strong.

1.7 The UK still has the opportunity to continue as a leader in European Defence and Aerospace, keeping abreast of France whose ambition to lead Europe is alreadyabundantly clear. However, the UK must set strategic goals similar to those inFrance, and must begin now to reverse the massive reductions in UK R&Dinvestment which UK Industry and Government have allowed to take place. Theproblem is clear - the Delphi survey indicated that potential future wealth creatingdevelopment opportunities in Defence and Aerospace are most constrained bytechnical feasibility and by lack of funding. The consultation process undertakenby the Panel revealed widespread concern that, in UK Defence and Aerospace, weare 'rapidly consuming our technological inheritance'.

1.8 The Panel's Vision, towards which its recommendations are geared, is:

Industry, Government and Academia working in partnership so that UK Defence and Aerospace continues as a major contributor to wealth and national security.

This vision implies that the UK, in industry, government and academia, iscommitted to retain its position in world Defence and Aerospace markets: aposition which today represents 6% of UK manufacturing output, which generatesa substantial trade surplus (Aerospace alone has been generating a surplus ofaround £2-3B per annum for the last decade), and which currently employs directlysome 300,000 people. The Panel recognises that the implications of Foresightare not only for technology but also ultimately for production, trade and jobs.

1.9 The vision parallels the themes of the science, engineering and technology (SET) White Paper 'Realising our potential' and the Panel's recommendations,summarised below, are aligned with those policy themes.

1.10 The Panel addressed its remit of identifying the most promising sector market and technology opportunities, and the barriers to their realisation, by first drawing on the Panel members' own expertise and a range of other experts to establishprovisional ideas, then subjecting these initial views to widespread consultationthrough a Delphi survey, regional workshops and seeking submissions fromProfessional Institutions and Trade Associations. The principal criteria used bythe Panel for prioritisation, derived from the Steering Group criteria, were marketsize and growth potential, UK science and technology capacity, and UK industrialstrengths and weaknesses.

1.11 The Panel considers that the focus in Defence and Aerospace should be not only on technology but also, to perhaps an even greater extent, on the exploitation oftechnology to develop world-beating products. Against that background, the Panelmakes the following principal recommendations, which are detailed in Section t3of this report.

1.12 Key Technical Priorities

1.12.1 The following technology areas should be given particular priority inview of their high potential impact. In identifying these priorities, thePanel has recognised that the UK cannot lead across the whole spectrumof Defence and Aerospace, but needs to focus its strengths on the subsectors and niches which are important for national security or whichhave significant potential for wealth creation.

1.12.2 Systems Integration

Systems integration capabilities should be given a much higher profileas a key technological requirement of advanced systems and a vitalcomponent in maintaining the all-important prime contractor role.

1.12.3 Process Technologies

Emphasis should be placed on business-process-based developments,including systems integration, design, lean manufacturing andconcurrent engineering to provide dramatic reductions in costs and timeto market; an industry-led structure should be established to ensure goodco-ordination of the various initiatives in these areas and to ensure thatresults are put into productive use as widely and quickly as possible.

1.12.4 Materials and Structures

The UK must retain and develop its indigenous research andmanufacturing base for materials and related technologies which arecritical to our world class standing, particularly where access to keymaterials from abroad is denied.

1.12.5 Simulation, Modelling and SyntheticEnvironments

Emphasis should be placed on research into all aspects of this developingarea, and on the necessary supporting technologies.

1.12.6 Aerodynamics (including emissions andnoise)

Continued emphasis should be placed on experimental research, and onthe development of new computational techniques in this area, includingemissions and noise, to enhance the UK's ability to design world-leadingfixed and rotary wing aircraft and engines.

1.12.7 Sensor Systems, Data Fusion and DataProcessing

More support is required for research in industry and HEIs in these keyareas to maintain the edge in militarily vital areas such as monitoring,surveillance, command and control.

1.12.8 High-integrity, Real-timeSoftware

More support is needed for research in industry and HEI's fordevelopment and demonstration of the necessary tools, methods andprocesses.

1.13 Technology Exploitation

1.13.1 If the UK is to sustain its competitive position, Industry andGovernment must reverse the trend of declining R&D investment andfacilitate exploitation of technology. The onus to lead these changesrests primarily with Industry. Whilst the Panel makes recommendationson Government funding and mechanisms, these can be effective only insupport of initiatives from UK companies.

Company initiatives, inturn, will happen only if Boards and senior executives give totechnology the same emphasis as is given to other elements ofcompetitiveness, such as costs, and if companies can generate the profitmargins required to reinvest in R&D. Hence a key factor in selectingpriority areas has been the need to reduce development and manufacturingcosts.

1.13.2 Mechanisms for Government funding should be revised to increase thefocus on wealth creation and to provide a better balance between thephases of Basic Research, Applied Research and TechnologyDemonstration. The Panel recommends below some revisedmechanisms addressing joint Industry/University applied research,applied research conducted in industry and technology demonstration.These recommendations seek to increase the usable research and,through more technology demonstration, to reduce the costs andtimescales of development and manufacture.

- **Two new University-linked Applied Research**schemes should be established, focused on **Dual-UseTechnologies** (£24M per annum) and **Civil Aerospace**(£40M per annum), with a significant industrial contributionto ensure market relevance and commitment to exploit theresults.
- The level of DTI funding for **Industrial Applied Research inCivil Aerospace,** through the Civil Aircraft Research andDemonstration (CARAD) scheme, should be increased to £25Mper annum, with a matching contribution from Industry.
- **Technology Demonstrator Programmes** (TDP) should beincreased significantly. DTI funding for Civil Aerospace TDPsshould be increased to £30M per annum immediately, risingprogressively to £65M per annum over the next three years.Industry must provide a similar level of funding. The level ofactivity in MOD-funded Defence TDPs also needs to beincreased, with consideration being given to expanding theirscope to include process as well as product technologies.

1.13.3 These recommendations reflect a significant increase in R&D investmentby Industry and Government, achieved both by re-focusing existingfunding and providing new investment. When implemented, this wouldrestore the UK Government investment in civil aerospace R&D to paritywith that of France and Germany, though still well behind the US, andwould provide the stimulus for a substantial increase in Industry'sinvestment in new products.

1.14 Other Key Priorities

1.14.1 A number of other significant policy issues must be addressed if UKDefence and Aerospace is to exploit fully the technology which thiscountry has, or can develop. The Panel recommends that early action istaken in the following principal areas.

1.14.2 The Challenge to Companies. Companies must develop andimplement plans to increase Industry R&D investment significantly.Companies should review their technology plans, and their processes fordeveloping such plans, in relation to this report. Industry should fostertechnology benchmarking, share best practice in technology planningand exploitation, and promote increased levels of networking andcollaboration.

1.14.3 National Strategies for Defence and AerospaceTechnologies. Industry and Government (OST, MOD and DTI)should work together, with Academia, to establish national strategic/policy frameworks for Defence and Aerospace technologies. Theseframeworks must incorporate agreed high-level objectives towards whichall concerned with this area should work and must be supported byprocesses which monitor progress.

1.14.4 MOD Procurement Policy. Government and Industry should reviewMOD Procurement policies and related Defence Science issues so that,whilst continuing to emphasise value-for-money for the Defence budget,there is also an emphasis on UK industry competitiveness and wealthcreation; other policy issues arising from Foresight should also beaddressed in this review.

1.14.5 Market Distortions. Government, with Industry support, shouldestablish effective means of monitoring continuously MarketDistortions and take action either to eliminate them or to avoid UKIndustry being disadvantaged; a formal joint review should be completedannually.

1.14.6 International Defence Collaboration. Government, in consultationwith Industry, must accelerate where appropriate the establishment ofcommon defence requirements and acquisition in Europe. However,Industry and Government must also work together to ensure thatcollaborative programmes are structured in ways which are efficient andwhich provide reciprocal market access. Government and Industry mustalso work closely together at a strategic level to ensure that UKcompanies have equitable opportunities in new European collaborativedefence programmes whilst, at the same time, recognising thatopportunities will continue to exist to collaborate and trade on a two-waybasis with the United States.

1.14.7 Financing. Industry and Government, in partnership, should respond tothe threat of loss of market opportunity in the Defence and Aerospacesectors arising from strategic investment by competitor nations, byreversing the current declining UK spend on research and demonstration.The new funding schemes recommended by the Panel should be adopted;these will assist Industry, DTI, MoD and the Research Councils to co-operate and align with market requirements. Higher priority must begiven by MoD to Technology Demonstration, by reprioritising withinexisting programme budgets for this phase so as to reduce risks,maintain the skills base, and support the exploitation of availabletechnology. For Civil Aerospace programmes, Launch Aid terms shouldnot disadvantage the UK industry with respect to its competitors and"partners". Consideration should be given also to establishing a LaunchAid scheme for Defence export products.

1.14.8 Air Traffic Control. The UK should seek to work within Europeto define the specification and standards for an advanced air trafficcontrol system based on open systems architectures, including thedemonstration of its capability, which would have application on aworldwide basis.

1.14.9 Space. Consideration should be given to adjusting the balance betweennational and European funding for space activities. The UK should worktowards making ESA more efficient and to develop new mechanismswhich focus more on competitiveness and market requirements, andconsideration should be given to creating a UK Space Agency with adedicated Space budget.

1.14.10 Skills. Undergraduate training in multi- and inter-disciplinary subjectssupporting the Panel's key technical priorities should be developed;more attention should be given to developing short courses in specialisttechnologies to enable staff in industry to update their currentknowledge.

1.15 Future Foresight Activity

1.15.1 The Defence and Aerospace Panel, as part of on-going Foresight activities, and in line with the SET White Paper, should work with the Office of Science and Technology and other Government Departments concerned in the setting of strategic objectives for Defence and Aerospace technology over a 15-year perspective, and to consider:

- gaps or imbalances in the education, training and research efforts;
- benchmarking the UK industry and science base against those ofour major competitors;
- the balance between civil and defence research, and between basicresearch, applied research and technology demonstrators;
- the balance between domestic and international research and thescope for international collaboration, in Europe or elsewhere;
- how research links between industry, academia and defence canbe improved;
- opportunities for achieving synergies across programmes;
- scope for greater concerted action both within the public sectorand between the public and private sectors.

A process such as this would make a major contribution bylinking Foresight with NSTAP and MOD initiatives, and wouldassist in making best use of the available skills and resources.

1.15.2 The Panel's consultation process showed widespread support for an effective follow-up of the Foresight work. The Panel stresses that OST and the other Government Departments involved must have the resources to perform these tasks effectively, and that this activityshould be linked closely with the relevant bodies in MOD, with the DTI Aviation Committee, and with relevant Trade Associations.

1.16 The Panel believes that effective action taken on its recommendations will yield excellent returns for the UK What is at stake is well illustrated by scenarios basedon those developed recently by SBAC for the UK Military and Civil Aerospacesector (Table 1.1) .

Table 1.1 - Aerospace Market Scenarios

Scenario	UK Market share (% of OECD)	UK Sales (£B, 1991 prices)	UK Employment (000s)	Balance of Trade (£B, 1991 prices)
1991 Baseline	9.4	11.0	160	+2.5
The Situation in the Year 2011				
Accelerating Decline	4.9	7.2	59	-3.5
Steady Decline	6.3	9.3	75	-1.4
Maintain Share	9.4	13.9	112	+3.2
Grow Share	11.0	16.2	131	+6.0

Based on SBAC Competitiveness Challenge (1994)

The Panel believes that, by implementing the Foresight recommendations, theUK can take a major step towards maintaining its share of this growing market.If we could grow our market share, UK turnover from Aerospace alone couldincrease by nearly 50% in real terms, contributing an additional £5.2B per annumto UK GDP.

1.17 In the time available, it has not been possible to address every aspect of Defence and Aerospace technology exhaustively and more work is needed in some areas.However, the Panel believes that what has been done to date must be built on,providing a common focus for all involved in this sector and a means ofstimulating the cultural and other changes needed for success. An importantelement in these changes is fostering of much more openness in Industry, andbetween Government and Industry on research and development thinking. It isessential for Foresight that effective action is taken in response to the Panel'srecommendations - the consultation process in Defence and Aerospace indicateda widespread feeling that 'Foresight must be seen to make a difference'. Theactions taken will determine not only the future course of UK Defence andAerospace but the credibility of the Foresight process itself

2. INTRODUCTION

The Current Position of the UK

2.1 Defence and Aerospace is a sector in which the UK is currently a world leader and has a long history of excellent science and of product innovation. The UK is oneof very few countries with the capability to design, manufacture, integrate andmarket complete sea, land and air-based systems: fixed and rotary wing aircraft,aeroengines, air traffic control systems, warships and submarines, air-to-air andair-to-surface missiles, low level air defence, field guns and military land vehicles.There is also a strong and diverse equipment sector providing sub-systems andcomponents worldwide. Many subsystems, such as the wings for Airbus andaeroengines, have great technological sophistication and complexity, and highadded value.

2.2 Defence and Aerospace is also a sector in which science and technology areparticularly important to competitiveness. Indeed Defence and Aerospace has oneof the highest R&D intensities of all major UK industrial sectors - in 1992 the UKdefence and aerospace industry R&D amounted to £1.63B, representing 25 percent of the total R&D undertaken by UK business in all sectors[2]. Aerospace R&Din the UK is at a level of 9.5 per cent of gross sales and Defence R&D is 14 percent of gross sales, compared with 2.2 per cent for UK manufacturing industry asa whole. Pharmaceuticals is the only other UK industry with a comparable R&Dintensity (12 per cent of gross sales)3. The Defence and Aerospace sector's strongdependence on science and technology makes it a good vehicle for UK wealthcreation, given that scientific research is a particular UK strength.

2.3 Over 300,000 people are directly employed in the Defence and Aerospace sector (roughly 7 per cent of the UK manufacturing workforce) and at least 300,000 jobsare generated indirectly. The sector accounts for 6 per cent of the UKmanufacturing output and has grown significantly faster than UK manufacturingas a whole over the past 10 years[3]

2.4 The UK's share of OECD exports is higher for Defence and Aerospace (at 11.7%) than it is for any other Foresight sector, (DTI statistics 1991). Defence andAerospace companies are among the UK stop exporters: in the UK league tableof exporters (1993), British Aerospace occupied first position, Rolls-Royce occupiedthird position and GEC occupied fourth position. Defence exports in 1993totalled some £7B, giving the UK over 16 per cent of the market, second only to the USas a defence exporter. Aerospace has the highest export ratio (60 per cent) of allthe main UK industrial sectors and has consistently achieved a positive balance oftrade of between £2B and £3B annually 3. Only one other sector has a better tradebalance in recent years, namely chemicals and pharmaceuticals and, significantly, this is another sector in which science and technology play a key role incompetitiveness.

2.5 Defence and Aerospace is demonstrably one of the most successful UK sectors, but the issues at stake are whether the UK will continue to be a leader in this industry, whether Defence and Aerospace will remain an attractive sector for UK investment, or whether companies currently in the UK will progressively transfer their work to other countries. To answer this, the Panel has had to consider the following: how the markets will develop; how strongly the sector will contribute to wealth creation and quality of life; whether the UK has the national resolve and cohesion to make the necessary investments and to translate science into sales; whether technology will continue to give decisive competitive edge in Defence and Aerospace;

and whether the UK can maintain sufficient technological edge in the future.

Defence and Aerospace Markets

2.6 The end of the Cold War has brought heightened threats of regional conflicts,proliferation of weapons of mass destruction and increased demand for peacekeeping and humanitarian actions. Whereas western force structures have reduced, and the development and production of new weapons systems has been sharply reduced, the defence market is growing in the newly developing nations, especially in the Asia-Pacific region. Recent conflicts have, moreover, demonstrated that technology can provide the winning edge and nations, such as those in the Middle East and possibly in the Far East, are likely to have a continuing requirement for high performance defence systems.

2.7 The Civil Aerospace sector has grown at an average rate of 6.2 per cent per annum over the past 20 years, driven by a rapid growth in air travel. On most forecasts,this growth is set to continue, particularly because of the projected increase in airtravel in the developing nations. Here, technology will contribute to both productperformance improvements and product competitiveness.

2.8 The future markets for Defence and for Civil Aerospace are discussed in detail in Sections 3 and 4 respectively. Detailed analysis of the future defence market iscovered in a restricted circulation supplementary paper.

The Contribution of Defence and Aerospace to Wealth Creation and Quality of Life

2.9 Defence and Aerospace contribute directly to national and personal freedom, and to wealth creation and quality of life. Despite the ending of the Cold War, a strongdefence capability remains essential to national security. The predictability of theCold War period has been replaced by uncertainty and, over the timeframe of theForesight process, the UK may be threatened, directly, or indirectly through denialof access to vital resources. The UK's defence capability gives the nation influencein world events and maintenance of order through its ability to contribute to UNand international operations, so securing a better quality of life for the UK and theworld. Our own national security and international influence depend on, and aresustained by, a strong national technology base. That national technology base alsocontributes substantially to wealth creation through exports of defence equipment.

2.10 The Civil Aerospace sector, by making air travel increasingly cheap and easy to use, is a major contributor to the efficiency of business and the quality of life.Directly and individually, it is enriching life for much of the UK populationand contributing to worldwide economic growth, understanding and inter-culturalexchange. The UK has historically maintained a roughly constant 10 per centshare of the Civil Aerospace market over many years. If the UK can achieve amodest expansion in its share of this growing market, the increased turnoverwould make a significant contribution to UK growth over the next 20 years.

2.11 Defence and Civil Aerospace are global industries. They are high value, relatively low volume markets, requiring leading-edge technologies. The requirement forstate-of-the-art technology provides a major stimulus for product and technologydevelopment from other sectors ('spin in'), and Defence and Aerospace oftenprovides technology, products or processes which can be exploited by othersectors ('spin out'). Examples of the latter are shown in Figure 2.1.

Figure 2.1 - Examples of Spin-off into other sectors

Gas Turbine Power Generation

Technologies developed for civil and military aero-engines have been utilised inthe development of efficient gas turbine sets for land-based power generationand oil pumping, and marine propulsion applications.

Liquid Crystal Displays

MOD's need for reliable displays led to a UK programme on ultra-stable liquidcrystals, and the resulting materials are now world standard in all LCDs, civiland military.

Military Communications

Techniques such as low bit rate vocoders, frequency hopping and spreadspectrum modulation were all devised to allow military communications underconditions of jamming. All are now in use in civil radio systems allowing moreefficient use of spectrum by virtue of their tolerance to interference.

Thermal Imaging Systems

Developed for the military for passive detection and characterisation of enemyplatforms and installations, this technology has been commercially developedfor applications such as personnel location and earth observation.

Carbon Fibre Composites

Carbon fibre was initially developed for Aerospace components, but soon foundnumerous applications in sports equipment where light weight and stiffness areimportant. Carbon fibre composites are just beginning to appear in civilengineering applications such as cables for suspension bridges. Large scale useof carbon fibre in civil engineering could lead to some previously unattainablefeats, such as bridges across the Straits of Gibraltar.

Wind Turbines

Technologies developed for helicopter rotor systems have been applied in thedevelopment of wind turbines for power generation. These technologiesinclude aerodynamics, dynamics and noise aspects.

Analytical Techniques and Methods

An aerospace requirement for high accuracy calculation of fluid flows andstructural stresses has stimulated use of techniques such as Finite ElementAnalysis in other industries. Other users have gained from reduced productdesign and development time and cost. Such techniques have had a majorimpact in non-aerospace industries, notably off-shore oil and gas explorationand automotive.

Adhesives

Considerable advances in adhesives have been developed for the Defence andAerospace sector in order to simplify production techniques and yet meetdemanding environmental requirements. This adhesive technology has been usedparticularly in the automobile industry, and applied more widely in engineeringand general use.

Creep Feed Grinding and Electron Beam Welding

Specialised processes developed for the manufacture of aero-engines.Aerospace proved the commercial acceptance of these techniques for use inother industries. These processes have been used particularly in theautomotive, instruments and corrugated board industries.

Measurement Touch Probes

Used in the aero-engine industry to rapidly and accurately measure the position ofdetailed components in three-dimensions. A company was formed to 'spin-off'this technology to other sectors of industry and exploit its commercial potential.This has had a significant impact in manufacturing, where most co-ordinatemeasuring machines now use this technology.

Specialised Coatings for Glass

Production of windows for aerospace applications is a highly demanding processsince windows are part of the aircraft primary structure. Coatings applicationswere transferred from aerospace to other applications by company internaltechnology management systems. Recipient industries include rail, security andenergy saving glazing.

Increasingly, the Defence sector will be looking for technologies with true 'Dual Use'potential, where the cost of technology development can be shared with partnersrequiring similar capabilities.

The Need for National Resolve and Investment in Defence andAerospace

2.12 In Defence and Aerospace, more than in any other sector, government has acrucial impact on national competitiveness. Government is the predominantmarket force, being the main customer for the UK's defence industry, its principalsource of R&D funding and having the statutory responsibility for the health ofthe UK civil aerospace industry through the 1982 Civil Aviation Act. The successof the industry derives largely from the previous levels of investment by industryand government in research, development and procurement during the 1970's and1980's. There is a widely held view that failure to maintain investment at theright level today is likely to degrade seriously the UK's future competitiveness inglobal markets. The role of Government is equally important in the UK's maincompetitor nations: US, France and Germany. The crucial difference is that thesenations are currently sustaining their national investments in Defence andAerospace more vigorously than is the UK

2.13 A special feature of Defence and Aerospace is that new product developments are characterised by long timescales and high costs, requiring long-term investment. Technology incorporated into new products takes typically 15 years to reach the market place and thereafter the products may have a life of 25 to 50 years: the EFAconcept dates from 1983, but Eurofighter 2000 will not enter service before 2000and is likely to remain in service until 2030-2040; this is an example of a productwhose technologies have their origin in research carried out in the 1960s and1970s.

2.14 These very long timescales make the sector relatively unattractive for private venture investment, and thus government assistance is crucial. For a company toinvest speculatively to develop a new defence equipment is unacceptably risky.Civil aerospace manufacturers can defray some of their risk by requiring airlinesto take options on future aircraft and, in the case of sub-system suppliers such asRolls-Royce, by ensuring their products fit a wide range of aircraft, although theseapproaches normally lead to increased sales concessions at the beginning of theprogramme. The risks can therefore be high and at times profitability can be lowor negative. However, Defence and Aerospace companies have a responsibility totry and change the prevailing culture by persuading their shareholders that a largerproportion of profit must be re-invested in R&D for long-term growth. Thismust be coupled with government action, to change the attitude of the financialmarkets towards companies who succeed in establishing a long term R&Dinvestment culture, and to make patient money more readily available eitherthrough the markets or by direct investment. In the case of defence equipment,government should bear an equitable and realistic share of the risk.

2.15 It is the view of the Defence and Aerospace Panel that only through having a more coherent UK strategy for Defence and Aerospace can the UK compete in the longterm with the US and France, both of which are targeting Defence and Aerospaceas a key national sector. The US, although an important sub-system market forUK companies, has the industrial and market strength and the clear intention tomaintain US world leadership in the Defence and Aerospace markets. France hasa clear national strategy to lead Europe in the whole area, and has the coherencebetween government and industry to pursue this plan effectively. Japan isdeveloping an aerospace capability that could enable it to become a major worldforce probably within the next decade, and there is a growing challenge from thetechnologically and economically emerging nations such as Taiwan and Korea.The UK has to respond to these challenges.

The Role of Technology in maintaining the Competitive Edge

2.16 Military capability never stands still; it is driven strongly by new threats and new technologies. Technological superiority strengthens deterrence and so can avoidconflict. If employed, the technological edge offers the potential to reducecasualties and shorten wars, but maintaining the technological edge is proving tooexpensive for many countries and unless procurement and operating costs arereduced, the potential export market may decline. Hence future technologicalinnovation needs not only to increase system performance, but also contribute toreduced acquisition cost, improved production techniques, reduced time tomarket and lower support costs.

2.17 Threats are constantly changing; new threats and opportunities will emerge with the rise of new technologies developed by other industrial sectors: biotechnologyand information systems are two such examples. Biotechnology will add greatly tothe risk from biological and chemical weapons, with the increasing scientificunderstanding of biological processes creating many new threats, and offeringopportunities to develop countermeasures. The very heavy dependency ofdeveloped nations on their information systems infrastructure also makes themvulnerable to information systems warfare (ISW). The techniques associated withcertain of these new technological threats, for example biotechnology weapons anddirected energy weapons (DEW), have not been discussed in this report or itsannexes because of security classification. However, the systems and technologiesthat are covered in this report constitute the vast majority of those from whichthe UK is likely to derive its exports and wealth creating opportunities.

2.18 Technology trends in Civil Aerospace have also been, explored in this report. The main challenges facing the sector are the requirement to secure substantial costreduction through new technology and business processes, and environmentalconcerns, such as aircraft noise, aeroengine emissions and land use. The RoyalCommission on Environmental Pollution produced its report on 'Transport andthe Environment[4] during the course of the Panel's work expressing particularconcern about aircraft emissions.

2.19 There is always a possibility that significant market opportunities may arise from totally revolutionary concepts. However, there is also substantial scope forimprovements to conventional aircraft and systems. Although these opportunities,discussed in Section 4, may seem incremental developments, they will make greatdemands on materials, structures, avionic systems, manufacturing processes andtheir underlying science. More radical opportunities such as second-generationsupersonic transport and various novel aircraft concepts are also addressed.

Maintaining the Technological Edge

2.20 The panel conducted a broad review of the UK Science Base (reported at Annex G) which found that, in general, UK academic capabilities provide a soundfoundation for the future needs of the UK Defence and Aerospace industry. Thiswas confirmed by the Delphi survey, where in scientific and technologicalcapability, the majority of Delphi respondents indicated that the UK is currentlyleading in 46 per cent of all of the topic areas addressed in the Defence andAerospace Delphi questionnaire, compared to 14 per cent for all of the Foresightpanels.

2.21 The Delphi survey in Defence and Aerospace also showed that technicalfeasibility and lack of funding were perceived to be the key constraints by amajority of expert respondents in 72 per cent and 88 per cent of the Delphi topicsrespectively. The response on technical feasibility suggests that continuedinvestment in science and technology is crucial if marketable products are to beproduced. It also suggests that although the UK may currently have a strongposition in relevant science and technology, this is a lead which is in danger ofbeing eroded. The response on lack of funding highlights the concern that the UKtoday is consuming its technological inheritance. Current UK success derivesfrom past farsighted R&D programmes, particularly in governmentestablishments and in industry, which have yielded world class technology. TheUK must continue to make sufficient investment in key technologies and intechnology demonstrators for continued success. This will require a nationalstrategy and concerted investment in new technology.

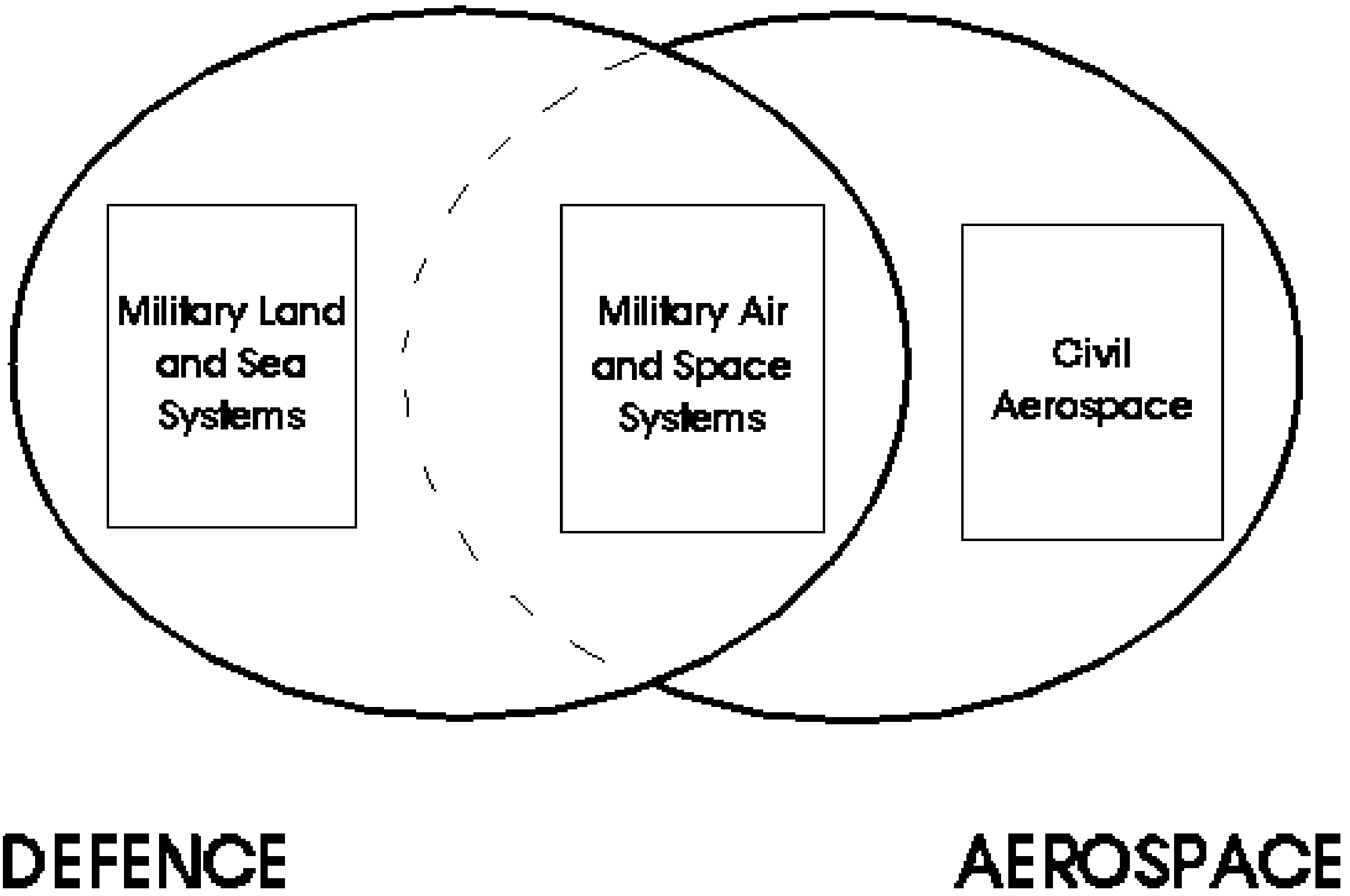
2.22 The UK is also seen from the Delphi survey as being not sufficiently effective in turning its strength in science and technology into marketable products.Therefore, in addressing wealth creation the Defence and Aerospace panel hasconsidered not only future technologies and products but also how the UK canimprove the whole wealth creation process from science and invention tosuccessful sales and well satisfied customers.

The Work of the Panel

2.23 The background against which the Defence and Aerospace panel commenced its work is a world in which uncertainty dominates the defence and security scene, and in which growing international competition in defence and civil markets isforcing industry to innovate continually to meet market needs and improvemarket share. Whilst the challenges are significant, the opportunities are certainlythere for the UK, providing it can adapt imaginatively and cohesively. The task ofthe Defence and Aerospace panel has been to help industry, academia andgovernment focus more clearly on the technology and policy priorities.

2.24 The two main areas which make up the sector **-** Defence and Aerospace - share a major common technology base. They can be depicted as two intersecting regionsas shown in Figure 2.2 (not to scale). The sector was divided into **Defence** and**Civil Aerospace,** and the panel mainly operated in two sub-groups coveringthese sub-sectors. Defence comprises sea, land, air and space systems used formilitary purposes, whilst civil aerospace comprises aircraft and ground- and spacebased systems which enable the commercial transportation of people and freight.Some issues concerning **Space** fall within both these sub-sectors and these aredealt with in the respective Defence and Civil Aerospace sections of the report. There is a separate section, however, summarising specific technology and policyissues facing the Space sector.

Figure 2.2 - Structure of the Sector



2.25 Details of the membership and working methods employed by the panel can be found at Annex A. The panel consulted extensively through an initial scopingsurvey, a two-stage Delphi survey, regional workshops and by seeking writtensubmissions from relevant trade associations and professional institutions. Theresults of these consultations are detailed in Annexes B to E respectively, and havebeen drawn on extensively by the panel in reaching its final conclusions.

3. DEFENCE TOPICS

3.1 Wealth creation in Defence requires export of defence equipment and support services, or exploitation of defence technology within the civil economy.Improved quality of life rests largely with expansion of the economy and withmaintenance of a favourable security environment with the smallest level ofintrusion on society, including reductions in the cost of provision. The DefenceSector sub-group therefore focused largely on means to improve exportperformance and maximise gains by closer linkage with other sectors.

3.2 Process Employed. The Panel prepared a forecast of global security issues as a basis for analysing and forecasting the global defence equipment market. It thenidentified the technologies required to produce this equipment and, based on anassessment of the current competitiveness of the UK Defence Industry, derivedthe most important technology areas for investment and the policy changesneeded to realise benefit from this investment. The Defence sub-groupprioritisation process is described below and includes an initial list of productopportunities. This list of products excluded those which are not exportable forreasons of either policy or security (eg nuclear). Although sufficient analysis hasbeen carried out for the purposes of this study, more detailed work isrecommended as part of the ongoing work of the Panel (see Section 9).

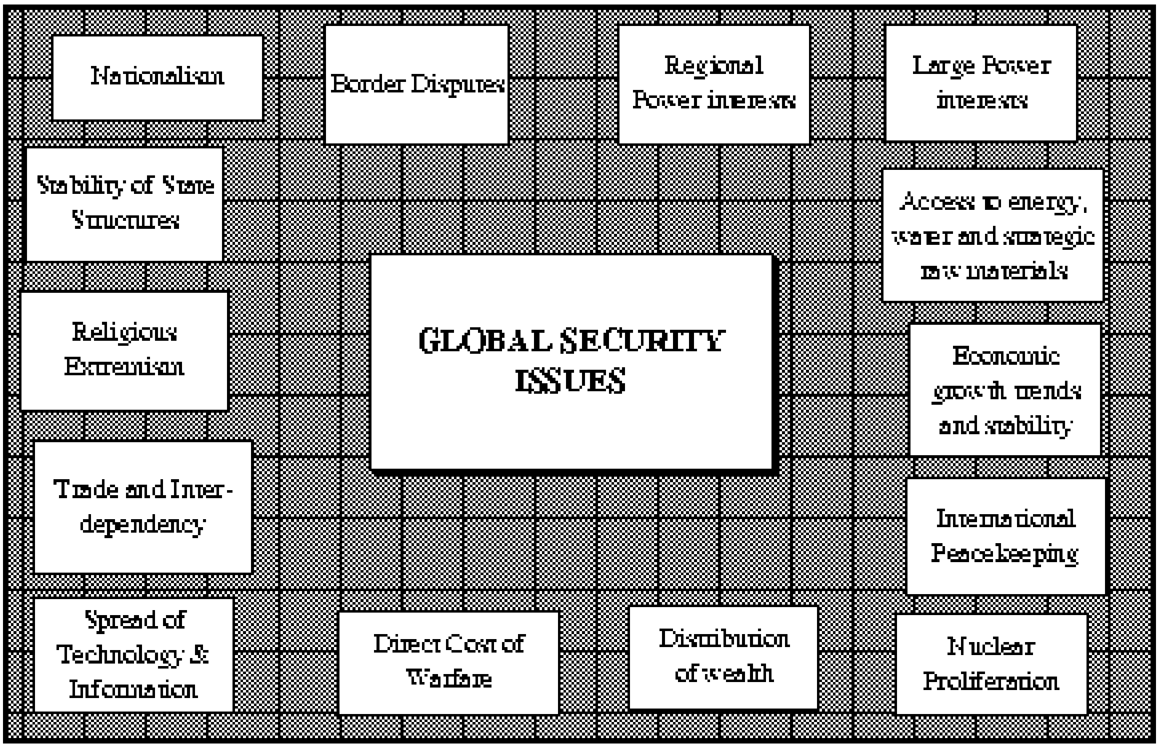
Security Analysis

3.3 Risks. The collapse of the Warsaw Pact has greatly reduced the threat of global conflict which dominated Western defence and security policy for over 40 years.Western governments have responded by reducing defence budgets and forcestructures, but regional and localised conflicts continue in many areas of theworld. The historical causes of armed conflict remain. Post Cold War optimismhas been replaced by a realisation that the incidence of these conflicts willprobably grow, requiring concerted international peacekeeping - and possiblypeacemaking - action by developed and developing nations, and a demand fordefence equipment from countries in regions of instability.

3.4 Capabilities. The capabilities of potential combatants will continue to grow,driven by the desire for military success with minimum economic and socialimpact, and by the wide availability of sophisticated military equipment. In theshort term this will represent equipment from the post Cold War reductions byNATO and the Warsaw Pact, and from industry over capacity; including tacticalballistic missiles (such as SCUD), now owned by several countries, and mainbattle tanks (over 20 countries now own more than 1,000 tanks). Increasinglyconflicts will be won or lost at the cutting edge of technology, but thesetechnologies are subject to a high rate of obsolescence.

3.5 Likelihood Tension and instability will continue to be the norm in severalregions. For each, it is possible to postulate of a range of scenarios from the benignto the extreme[5]. The likelihood of conflict is influenced by a range of complex,often interrelated, factors (see Figure 3.1). In view of the complex and chaoticnature of the global system, which offers ample opportunity for the unforeseen, and for the arrival of consequences seemingly unrelated to precursor events, noattempt was made to attribute likelihood to the different scenarios. However, eventhe most benign case does not preclude conflict, nor continued expenditure onmilitary technologies.

Figure 3.1 - Global Security Issues



3.6 UK Security and Defence Policy. The UK's defence and security policies,set out in the Statement of the Defence Estimates[6], are based on a securityarchitecture in which NATO, EU, WEU, CSCE and the UN all complementeach other. A crucial foundation to much of the work of these organisations willbe the retention of the ability to call on credible and effective military forces in order to underpin their activity. The UK will need to maintain capabilities:

- To ensure the protection and security of the UK and our dependentterritories, even when there is no major external threat;
- To insure against a major external threat to the UK and our allies;
- To contribute to promoting the UK's wider security interests through themaintenance of international peace and stability.

The MOD planning assumption is that the likelihood of a direct and majormilitary threat to the UK is now remote. This has already led to asubstantial reduction in UK and European demand for defence equipment.

3.7 Principal Military Capabilities Required. After careful consideration,the Panel concluded that the principal capabilities likely to be required by the worldmarket are encompassed within the UK requirements. The critical requirementfor the UK Armed Forces is to maintain a wide spectrum of capabilities in orderto respond effectively to the above demands. Defence capability is delivered by acombination of military systems, their logistic support, trained manpower andsupporting infrastructure. The principal components of such a capability areoutlined below, and are likely to be found in other significant military forcesaround the world.

3.7.1 Intelligence, Information, Surveillance and Target Acquisition. In peace, transition to war and on operations there is a need for timely,accurate information concerning the dispositions, movement andintentions of friendly, hostile and potentially hostile forces, by day andnight and in all weathers. There is also a need to deny information to theopposition.

3.7.2 Command, Control and Communications. Timely and wellexecuted command and control of all forces in a theatre of operations iscrucial to success. This depends significantly on reliable, robustcommunications at all levels between all Services, agencies and allies andon the ability to collect, collate and fuse the data required bycommanders for prompt decision making. Again, there is the need todeny these key functions to the opposition.

3.7.3 Firepower and Manoeuvre. Success depends on the effectiveemployment of firepower and manoeuvre. These capabilities call for avariety of highly mobile, agile, protected weapon platforms and a rangeof lethal and non-lethal weapons. Precision in munitions and in targetingwill be crucial.

3.7.4 Force Projection. It must be possible to assemble and project theforce into the theatre of operations. Appropriate land, sea and air transport willbe required. Key weapon systems must be compatible with strategictransport means.

3.7.5 Protection of the Force. The force requires protection en route to thetheatre and in theatre, from land, sea and air threats, including weaponsof mass destruction.

3.7.6 Sustainability. It must be possible to sustain the force, both in a stateof peacetime readiness and in the theatre of operations. Reliability,robustness and endurance are key characteristics for defence systems.

3.7.7 Training. Environmental pressures and the cost of live firing and sea/field/ flying training encourage the increasing use of realistic simulatorsand simulations for individual and collective training at all levels.Command and staff trainers will be crucial for maintaining anddeveloping key skills and for mission rehearsal.

Defence Market Analysis

3.8 Current World Defence Export Market. Uncertain figures, varyingexchange rates and the existence of 'black programmes' makes it almost impossible toestimate the total world expenditure on defence. The Defence sub-group chose tofocus instead on the estimate of the value of the world defence export market.Figure 3.2 illustrates the global export market over the ten years from 1984 to1993. Prices are in current and constant (1984) terms. In constant prices, after aninitial dip in 1985, the market remained fairly static through to 1988. FollowingEast - West rapprochement, world wide recession and the end of the Iran-Iraqwar, procurement in 1989 reduced substantially. The 1990 invasion of Kuwaitpromoted a sharp but temporary increase in Middle Eastern defence spending. In1991 the termination of the Gulf War, the collapse of the Soviet Union,continuing economic problems in many importing countries and the previousplacement of orders, together conspired to reduce procurement expenditure to itslowest level during the period. The recovery in 1993 (still some 12% lower thannew orders placed in 1984) was largely due to the conclusion of a number ofoutstanding orders following protracted negotiations. It is apparent that a few veryhigh value sales can have an increasingly large and distorting influence on theoverall size and shape of the market in any one year: for example 6 major ordersin 1993, worth in excess of US0 billion, together accounted for over 40% ofnew business.

3.9 Future World Defence Export Market. Threat perceptions, economicfactors, and, to a lesser extent, developments on export licensing laws and arms control,will continue to shape the market. Over the next five years, the world defencemarket may fall by around 20%. The market within Europe and North Americacould decline by between 10 and 30%, regardless of regional scenarios. OutsideEurope, a combination of economic growth and the need for defence in anunstable world will fuel the demand for defence equipment and will provide afoundation for an increase in export sales, but the market will become ever morecompetitive. There is likely to be an increase in the market in the technologicallyemerging nations. Annual GDP growth of around 5% among Asia Pacific states,and the potential for tension and conflict, suggest this region could replace theMiddle East as the major market for military exports. Improved nationaleconomies and the ability to absorb high technology will cause the small valueLatin American market to increase. The African market will remain small,although there may be niche opportunities for the UK in South Africa.Customers in developing nations will seek to meet requirements themselves andactively pursue inward technology transfer and systems integration with itsassociated software, to enhance their own technology base as part of externallysourced purchases. Also, there will be a growing tendency for developing nationsto fund new purchases by offset deals, rather than hard currency.

3.10 Current UK Export Performance. The UK has enjoyed considerablesuccess as an exporter of defence products with exports of nearly £7B in 1993, second onlyto the US. Saudi Arabia is the single most important customer, with Hawk andTornado accounting for a major proportion of product sales. Other products thathave achieved significant market success are air defence systems, radiocommunication equipment, artillery guns, military helicopters and electronicbased sub-systems for inclusion in air and naval platforms. The charts at Figure3.3 show past and current UK export performance over the last ten years incurrent and constant 1984 prices, with a breakdown of the current orders byregion and by sector.

3.11 Future UK Market Share. The range of military capabilities required inthe accessible" world market is unlikely to change significantly over the period of theforecast. Hence the range of equipments supplied by the UK defence industry toworld markets is unlikely to reduce, provided that the products are competitive inperformance, price and support, and the market is not distorted. However, sincethere is still worldwide production over-capacity, which will become moremarked as the remaining Cold War induced programmes are completed, the needfor further industrial rationalisation will remain. The critical priority for the UK isto define a strategy whereby it can maintain and enhance its competitive positionin world markets, building where appropriate upon MOD requirements.

3.12 Future Export Market Requirements. Through its analysis of theglobal security scenarios, the factors affecting future warfare, wider consultation and itsanalysis of world defence markets, the Panel concluded that defence exportmarket demand is likely to focus principally on the requirements shown in Table3.1. There will be no demand for anything the customer feels able to makehimself. In all cases, there will be an active pursuit of dual use technology transferand systems integration. For all platforms, high degrees of autonomy andsurvivability will be sought.

Table 3.1 - Future Demand in the Global Defence Export Market

1. Information Systems (Warfare (ISW) providing measure and counter measure for ISTAR, Command, Control and Communications (C3), and electronic Warfare (EW)
2. Power projection using land/sea/air systems and their support components.

3.
Ballistic missile defence.
4.
Air superiority (including ground based air defence).
5.
Conventional long range/interdiction (including air/land/sea launched missiles).
6.
Internal security equipment.
7.
Non lethal weapons.
8.
High mobility ground attack systems.
9.
Precision strike

3.13 The Casualty Factor. There is an emerging expectation that conflicts can andshould be won promptly, with a minimum of casualties and collateral damage. Ifthis expectation is to be met, this places a premium on precision weaponry, wellmatched sensors and data fusion, and platforms linked to responsive and robustcommand, control and information systems. The costs of development, acquisition and life cycle ownership of such systems are significant; and it isincreasingly difficult for nations to amortise development and acquisition coststhrough overseas sales.

UK Industry Competitiveness

3.14 The competitiveness of the UK Defence industry was assessed through a survey undertaken jointly by the Defence Industries Council (DIC) and the DEtA, andby analysing export performance (see Para 3.10 above).

3.15 Competitiveness Survey. The survey was not designed to meet the needsof Technology Foresight, rather to assess the current competitiveness of Britishindustry in the defence marketplace, focusing on products available for export.Nevertheless, as it is a current survey, it is included as a helpful 'snapshot' ofindustrial opinion. The responses from several hundred senior managers fromacross the industry were aggregated to produce an assessment of the product rangeand technical competitiveness of UK companies measured against worldcompetition. The survey was based on a common taxonomy of defence productsand technologies. The results of the survey were scrutinised by five expert panelscovering Air, Land, Sea, Weapons and CIS/electronics.

3.16 Conclusions. In summary, industry wishes to maintain a wide spectrumof capability, rather than concentrate on particular areas. Platforms and wholesystems are key because they provide a focus for development of many other subsystems, and are essential for sustaining systems integration skills and productsupport which increasingly provide the added-value. The survey concluded that:

3.16.1 Current Position. UK Defence industry is level with its majorcompetitors in about two-thirds of the areas, significantly ahead in about10% and lagging significantly in about a quarter. Where the UK islagging, the reason is more often associated with a lack of currentproducts and projects that can sustain competitiveness (as a consequenceof the phasing of major UK procurements), rather than any current lackof know-how or technology.

3.16.2 Strengths. Examples of the areas in which the UK is considered to beworld leading include:

sonobuoys, naval mine countermeasuretechnologies and vessels, torpedoes, acoustic absorbing materials,explosives detection and EOD, tandem warheads, short range air-to-airmissiles, offensive-counter air munitions, suspension systems, combatcapable trainers, medium lift helicopters, advanced wing and rotordesign, VSTOL engines, helmet mounted displays, ESM systems, radar(over-the-horizon, bi- and multi-static, imagery, antennas, polarimetric)and terrain referenced navigation.

3.16.3 Weaknesses. The major weaknesses in competitiveness were:

- The UK lags in some major platform markets, notably militarytransports and attack helicopters, primarily due to the lack of anexisting developed product.
- The UK is lagging in areas, such as off-the-shelf electroniccomponents, in which off-shore suppliers dominate themarketplace. This need not give cause for major concern, exceptwhere such components provide performance critical edge (egsensors), and provided we can assure supply of all thoseexternally sourced components necessary to support key defenceproducts.
- There are some important areas where the UK position is laggingand worsening because there is no major investment currently;there is real concern that with many of today's best-sellingproducts (eg Tornado, Hawk, Rapier, Lynx, Javelin/Starburst)deriving from technologies developed 10-20 years ago, failure toinvest now will seriously damage our future market position.
- The UK is generally behind its major competitors in its use ofconcurrent engineering, advanced design and procurementintegration.

3.16.4 Sector Competitiveness. Table 3.2 indicates how respondents believethe UK is positioned in Air, Land, Sea, Weapons and CIS/Electronics.The Weapons area shows the highest percentage for 'UK behind', mainlydue to our lack of developed stand-off weapons and long range missiles.

Table 3.2 - UK position by market sector

	UK in front	UK about level	UK behind
Air	9%	63%	28%
Land	7%	72%	21%
Sea	9%	69%	22%
Weapons	15%	39%	46%
CIS/Electronics	6%	69%	25%
Other Technology Areas	7%	69%	24%

3.16.5 Improving Competitiveness. The trends in the UK position were asfollows: 78% thought the position was not changing, with 7%improving and 15% worsening. However, the respondents alsoconsidered that in 65% of all areas it is 'extremely important' or 'highlyimportant' to increase the UK's competitiveness. Table 3.3 maps thesepriority action responses onto the benchmarking data. This matrixshows that industry feels it is important to maintain investment over awide spectrum of product and technology areas, irrespective of UKindustry's current position relative to the competition. Industry does puta slightly higher priority on increasing competitiveness in areas wherewe are either level or behind.

Table 3.3 - Comparison of Need for Action to increase competitiveness against UK Position

	No need to increase	Quite important	Highly important	Extremely important
UK in front	3%	40%	46%	11%
UK about level	8%	26%	53%	13%
UK behind	13%	21%	45%	21%

Key Technology Areas

3.17 The Panel identified the technology areas required to develop the range of export equipment identified above and which would contribute to wealth creationthrough dual-use or cost reduction. These are outlined in paras 3.20 to 337 below, with illustrative examples of more specific technologies shown for each section.These examples are not meant to be exhaustive, nor to indicate priorities for actionwithin each broad technology area, but rather to indicate the topics that will haveto be considered in drawing up detailed technology plans. It should be noted thatsome examples, such as data fusion and synthetic environments, appear undermore than one heading.

3.18 Process. The panel scrutinised each key defence requirement emerging from its market analysis and the DIC survey described above, identifying the defenceproducts needed to support that capability from the set of broad defence systemsderived from the full taxonomy. This list of products excluded those which arenot exportable for reasons of either policy or security (e.g. nuclear). Theprioritisation process is described in Annex H and includes Defence SystemsDesignations (Appendix 1) and a list of Product Opportunities (Appendix 2). Theproduct list is not exhaustive and is a high priority area for further work withDefence industry and MoD in partnership. The final stage in the process identifying the broad technology capabilities that are required - was based on ananalysis of the characteristics of key defence products and their technologyrequirements. Though an initial analysis has been carried out for the purposes ofthis study, again further work is recommended as part of the ongoing work of thepanel (see Section 9). An example of the analysis carried out is shown at Appendix 3 to Annex H.

3.19 MOD Processes. The Defence sub-group recognised that the MOD has existing processes to guide their technology investment for future UK systems needs. TheMOD Panel members have confirmed that the Panel's technology conclusionsare broadly in accord with MOD's own work Similarly, the technologies shownbelow are in line with the views of the industrialists in the Panel.

3.20 Systems Integration. This area, sometimes referred to as Systems Engineering, is a key skill for UK industry and is applicable to all levels of the customer/supplier chain. Essentially, systems integration refers to a holistic approach tounderstanding a requirement and the means of satisfying it, both physical,functional and organisational. Thus, to a defence planner, it may represent theinteraction of a federation of systems and elements in, say, a combined force. Toan industrial Prime Contractor, with the responsibility for the performance of amajor platform or system, systems integration refers to the ability to understandand model the overall requirements for a major system and the interaction andperformance of its many interrelated parts in an unambiguous way,accommodating the various sub-system technologies; then to design the completesystem together with its manufacturing processes and production facilities. Thisprocess must take into account all relevant factors such as the performance of thecomponent sub-systems, initial and life cycle costs and in-service supportrequirements. Naturally, some of the technologies described later contribute tothis overall function.

Examples: Operational Requirements & Analysis, requirements capture,option assessment, systems models, software engineering, preliminarydesign, Life Cycle Cost (LCC) modelling, operability (sea keeping,robustness, adaptability, flexibility), rapid prototyping, HumanComputer Interface (HCI), CAE/ CAD/CAM, assembly/ integration/test,system architecture, interoperability and standards, syntheticenvironments.

3.21 Life Cycle Cost Reduction. Reductions in defence budgets will requirelife cycle cost considerations to be given equal priority to system performance.Computer-based tools and techniques will be required to integrate the design,development and manufacturing of complex systems within an appropriatelystructured business environment. Concurrent engineering and multi-disciplinarydesign and optimisation tools will allow the early consideration of issues such asmanufacturability, maintainability and life cycle costs with due regard for systemperformance.

Examples: Manufacturing process technology, structural materials,joining methods, intelligent knowledge-based system (IKBS) engineering,case based learning/engineering, modularity and interoperabilitymethodology, information systems.

3.22 Modelling, Simulation and SyntheticEnvironments.

3.22.1 Modelling and Simulation. The reduction in Defence budgets hasincreased the sensitivity of major equipment decisions, both for MODand for Industry. Improved modelling and simulation of physical andmanufacturing processes will improve our ability to predict thebehaviour, costs and risks of future systems, and dramatically reduce thedevelopment timescale. While it is essential that modelling andsimulation is supported by validation trials, improvements will reducethe need for costly and time-consuming physical developmental testing.

3.22.2 Synthetic Environments. Synthetic environments(SEs) - synthesisedrepresentations of worlds which permit interaction between players (realand simulated) - allow defence equipment simulators, battle models andreal equipment to link into a global simulation. This distributed,interactive simulation (DIS) will provide better methods of identifyingrequirements, provide associated design, cost and logistic modelling atreduced cost and in significantly shorter timescales, improve forcestraining, and allow meaningful sensitivity analyses to be performed.Synthetic environment technology is equally applicable to a wide rangeof applications in other sectors.

Examples: Structural materials modelling, Computational FluidDynamics (CFD), Radar Cross Section (RCS), materials &structural dynamics, physical & chemical process, vulnerability/lethality, electromagnetic modelling, techniques for highperformance/parallel computing, protocols, visualisationschemes, virtual reality, multimedia data sources, virtual,constructive and real simulations, wide-area real-time securecommunications, CALS/CIRPLS, concurrent engineering.

3.23 Material Design and Manufacture. Material developments are a prerequisitefor many technological advances. Lighter, stronger structural materials arerequired for improved vehicle performance. Special materials such as ceramics areneeded for extreme high temperature operation. Optical and electronic materialsare essential for advances in computing and communications. Insensitiveexplosives and propellants are required for safe weapons handling and to resistcounter-measures.

Examples: Structural materials, special application (eg. ceramics,metal matrix composites), joining technologies, machining of advancedmaterials, and surface engineering, appropriate non-destructiveevaluation and repair techniques. Semiconductor materials, insensitiveenergetic materials.

3.24 Sensors, Signal & Data Processing and Fusion. The detection ofemissions of various kinds and the processing of the data so obtained and its fusion withinformation from other sources is crucial to the production of an accuraterepresentation of force locations and movements (own and enemy). Sensors ofmany kinds are needed together with their associated signal processing systems.Sensors are also needed for optimising own system performance, egengine control, health condition monitoring, control and guidance.

Examples: RF, IR, acoustic, sonar, magnetic, biochemical, imageprocessing/tracking, pattern recognition, image understanding, machineperception, data fusion, safety of mechanical and structural systems.

3.25 High-integrity, Real-time Software Engineering. Tools andmethods are needed to develop and certify safety critical software while reducing therequirement for built-in system redundancy and costly and time-consumingtesting. As well as cost and timescale reductions during development, aconsiderable reduction in the risk of using real-time safety critical software willresult.

Examples: Formal methods, dependable neural/fuzzy architectures,safety critical methods.

3.26 Smart Structures and Skins. A smart structure or skin has sensors,electronics and actuators physically embedded in the structural material. This will lead toimprovements in product performance and reductions in cost. For example, asystem which monitors the effects of cumulative in-service damage to a structurewill lead to a reduction in inspection and maintenance costs. Other possibilitiesinclude the reduction of sensor signatures for stealth, eg use of conformalantennas.

Examples: Structural health monitoring, stealth, flight control sensors,conformal antennas, aerodynamic and hydrodynamic shapeoptimisation, electronic, IR, laser, optronic materials and processes,electromagnetic compatibility (EMC).

3.27 Human Factors. Improved understanding of human factors will result in more competitive products better suited to customers' needs through improved systemusability and performance, increased reliability and safety, and lower system lifecycle costs. Codification and development of the human science base and itsapplication through improved design practice and support tools are required if thisis to be realised. Advances are required in modelling and measuring the balancebetween human and equipment in achieving capability; the interaction betweenthem, the nature and adequacy of the protection provided and the levels ofperformance obtained in service or in combat.

Examples: Improved human factors integration design and assessmentmethods and tools, including human-machine interface design andevaluation, training needs analysis, human performance and workloadprediction, complement validation, cooperative working environments,decision support facilities.

3.28 Aircraft Propulsion. Improved gas turbine propulsion technology is essential for aircraft performance improvement. These improvements will also feed intosurface ships which utilise aeroengine-derived propulsion. Enhanced thrust toweight ratio, lower fuel burn using variable cycles, and thrust vectoring, willimprove combat aircraft performance.

Examples: Higher temperature cycles, increased loading and efficiencyturbomachinery, vectored thrust, ASTOVL, reduced signatures.

3.29 Energy Conversion. Improved non-air-breathing propulsion will benefitunderwater vehicles and torpedoes. Hybrid electric drives and turbine enginescould offer significant benefits to helicopters. Future fighting vehicles are likely toutilise hybrid propulsion systems combining electric drives and internalcombustion engines in order to achieve optimal combination of range, speed andminimal emissions while stationary.

Examples: Intercooled and regenerative cycle engines, integrated electricdrive, AIP systems, fuel cells, batteries, reduced emission power sources.

3.30 Guidance & Control. In many military systems, the control of a platform orweapon path to either follow and attack a target autonomously, or follow flightinstructions accurately is an essential part of achieving the overall weapon orplatform mission. There is a need for significant cost reduction, improvements inaccuracy and higher responsiveness in precision-guided munitions.

Examples: Faster processors, improved algorithms and architectures, smartstructures and actuation, precision guidance and navigation, intelligent andsmart controls.

3.31 High Performance Power Transmission. In many weapons systems andplatforms, there is the need to transmit mechanical power, usually at high levels,through highly reliable, robust, lightweight transmission systems. Often thetransmission is safety critical, particularly on helicopters. Improvements in thesetransmission systems would provide a major performance improvement andhence competitive edge.

Examples: Fluid, electric, mechanical, integrated propulsion and powercontrol systems.

3.32 Command, Control, Communications and Intelligence(C31). Indefence, there is a need for a Communications and Information System (CIS) to representaccurately all forces in the theatre and to provide robust, secure communicationsthroughout the theatre of operations. There is also a need to present suchinformation for commanders, through a Command and Control (C2) process, in atimely fashion, and in a form which enables prompt decision making. The CISsupport infrastructure will need to deliver information over robust, interoperableand secure networks of both local and global scale. c2 and CIS, together with theirassociated technologies, are vital to all Services.

Examples: Secure and survivable communications, command decisionaides, information fusion, SATCOMMS, IT networks, local and widearea networks.

3.33 Robotics and Automation. The introduction of partly or fully autonomousvehicles or systems will provide a valuable force multiplier, whilst at the sametime reducing the risk to own forces. It will respond to public concern about conflictcasualties whilst also offering the possibility of some platform performanceimprovements by removing human environmental limitations and vulnerabilities.

Examples: Machine perception, machine intelligence, data fusion,intelligent guidance, control and actuation, systems planning andmission management, artificial intelligence, automated support systems.

3.34 Non-Lethal Weaponry. Emerging technologies offer scope to develop a newgeneration of weapons to deter, contain or defeat hostile forces from action whileminimising loss of life and collateral damage. Weapons which achieve this willincrease own forces capability and survivability, particularly under restrictive rulesof engagement.

3.35 Ordnance Disposal, Mine Counter Measures and Clearance. There is agrowing requirement to provide capabilities for tactical mine counter measuresand for the safe disposal of ordnance, and the clearance of mines (both land andsea) - 'demining' - when hostilities have ceased.

Examples: Detection of mines, robotic handling and vehicles, remotedetection of minefields.

3.36 Electronic Warfare Systems. This includes surveillance, monitoring andgathering intelligence from enemy electromagnetic emissions, counter-measures(eg jamming, decoys) and protection of own sensors against such attack (countercounter measures). These technologies will be integrated in Defensive AidsSystems (DAS) designed to defeat enemy sensors and will lead to improvementsin platform survivability and mission effectiveness.

Examples: Electronic surveillance, electronic counter measures, sensorprotection, radar jamming, IR decoys etc.

3.37 Signature Control. Low observables or stealthy weapon systems have lowsignatures to avoid detection by enemy sensors, such as radar and infra-red. Theability, through stealth, to avoid being attacked during a mission will lead tosignificant improvements in mission effectiveness through improved survivability.

Examples: RF, IR, W, acoustics, active techniques, effectivenessmodelling, design integration, manufacturability, materials.

Policy Influences

3.38 R&D Investment Levels. Concern has been expressed that the planned onethird reduction in MOD R&D by the year 20007 is in contrast with the approach being taken by the UK's major competitors, France, Germany and the USA. Thispoint is covered more fully in Section 6.

3.39 Off-the-shelf Procurement. In contrast, the UK private sector is expected tofund an increasingly higher proportion of R&D expenditure, and then to competefor MOD production contracts. This is not sustainable. Unless remedial action istaken, UK industry is likely to be forced out of a number of important marketsectors. There is further concern that UK budget pressures are likely to lead to agrowth in off-the-shelf procurement, which places the principal risk on industryand will, in time, preclude a home-based product being offered. This puts at riskthe UK's technological capability, and hence its ability to participate in subsequentcollaborative projects or to compete in the world market.

3.40 Collaboration. Responding to market pressures, the UK Defence sector hasincreasingly engaged in transnational collaboration. Commercial risks and adeclining domestic market are likely further to encourage this process, particularlyin relation to other European countries. Cost-effective collaboration demands thata partner's position in a project depends to a large extent on his technologicalcompetence and cost effectiveness. Therefore, it is vital that UK industrymaintains a full complement of key technology skills in order to win a leadingposition in such collaborative programmes. UK success requires a long-termstrategy to identify those future collaborative programmes in which the UKwishes to play a role, and specify all relevant means to maximise the benefit to theUK

3.41 Requirement Commonality and Open Markets. A further form ofinternational collaboration can be based on the rationalisation of requirementsbetween nations, especially in Europe, and open procurement. It is critical,however, that any such opening of markets is based on full reciprocity of marketaccess, both among initial partner countries and with any third country to whichcollaboration is extended.

3.42 Systems Integration Capability. Often, the ability to present a totalsystems solution in response to a customer's needs is critical both in winning the primecontractor role and in maximising the economic benefit to the UK The capabilityto offer the prime products or major platforms can be another important key tothis prime contractor business. It is vital that the UK retains and extends itscapability to design, develop and integrate total systems, rather than lapsing intosupplying equipment and components for other nations' programmes. Theproduction of large platforms or systems nationally has given the UK a focus fordevelopment of many other sub-systems and has been essential for sustainingsystem integration skills and strength in a wide range of defence products andtechnologies. In the future it is likely that many large platforms and systems willbe developed in collaboration rather than nationally, due to the high costsinvolved. In such collaborative projects it is vital for the UK to secure a leadingposition, preferably as prime contractor or leading in those areas whereparticipation maintains core skills for the UK that also add maximum value, egsystems integration. If not, much of the skill and expertise built up by the UK inthe past will atrophy, and with it industry itself

3.43 Exportable Equipment. Continuing recent export success will depend on the development of a broader product and customer base. Export marketing supportfrom MOD, and from DESO in particular, is greatly valued by industry, butreductions in UK MOD programmes will oblige industry to seek markets forsome of its defence products without the advantage of prior procurement by UKArmed Forces.

3.44 Launch Aid It is suggested that a system of governmental launch aid isconsidered for defence product developments aimed solely at the export market.This would emulate the scheme available to the civil sector with funds beingrepayable from export sales. Thus the aim must be to strengthen the UK'scompetitive position in the global market and maximise the benefits derived fromcollaboration.

Key Recommendations

3.45 The Defence sub-group has completed an analysis of the market and product opportunities, at home and abroad, and has identified **18 technology areas** that are important to underpin wealth creation in this sector. Only the last four of these are defence-specific. The others are relevant across the Defence andAerospace sector, and many are key technology areas for applications in othersectors. These have been integrated with the work of the Civil Aerospace subgroup to produce the seven key common technology areas identified at Chapter 8.Programmes funded under these technology headings could prove to be dual-use,bringing benefits across a number of sectors. **The Panel recommends thatthese technology areas are used to guide research and technologyfunding decisions by Government, Academic and Industry bodies.**

3.46 The Defence Industry benchmarking study highlighted the disadvantage UK industry will face if it loses the capability to design and integrate whole systems orplatforms. This capability is vital if UK companies are to act as prime contractorson indigenous or international collaborative programmes. It is essential thereforethat the underpinning technologies are fostered. Technologies associated withsystems integration, cost reduction and modelling have therefore been given ahigh priority by the Panel. **The Panel recommends that technologies andprocesses associated with supporting a prime platform capabilityare given particularly high priority when research funding decisions arebeing made.**

3.47 But technology and improved processes alone are not enough for industry to keep its prime platform capability skills sharp. Companies must have programmeswhich allow systems integration skills, revised business and the latest technologyto be brought together under programmes representative of service conditions.Technology demonstrators offer the ideal vehicle to meet this objective andprepare companies for later low risk product development programmes. **ThePanel recommends that technology demonstration projects, mainlyaimed at improving industrial capability, be treated as vital to thefuture of the industry. Issues impinging on this vital area, such asprocurement policy and international collaboration, will be discussed in moredetail under Barriers to Progress in Section 6.**

4. CIVIL AEROSPACE TOPICS

Background

4.1 Civil air transport has seen dramatic growth since the end of the Second World War and the UK has always secured an important part of the market. Travellingby air was a rarity, just for the rich and famous, but is now an everyday occurrencein the developed world. Passenger numbers have risen from 18 million in 1946 toover 1.1 billion in 1993, enabled by reduced fares: in real terms a ticket across theAtlantic today costs only a half to one third the price at the dawn of jet transport in1958 (Figure 4.l).

4.2 The growth in average distance flown has been even more remarkable with the longest flights now exceeding 12,500 km. Over 2,000 billion passenger-km wereflown in 1993, carried by a fleet of 14,700 commercial aircraft offering 3,000billion available seat kilometres (ASKs) (Figure 4.2). This is a fifteenfold increasein ASK since 1960. The modern long-haul aircraft can be expected to spend moretime in the air than on the ground, covering over 100 million km and generating45 billion passenger-km in its 30 year life.

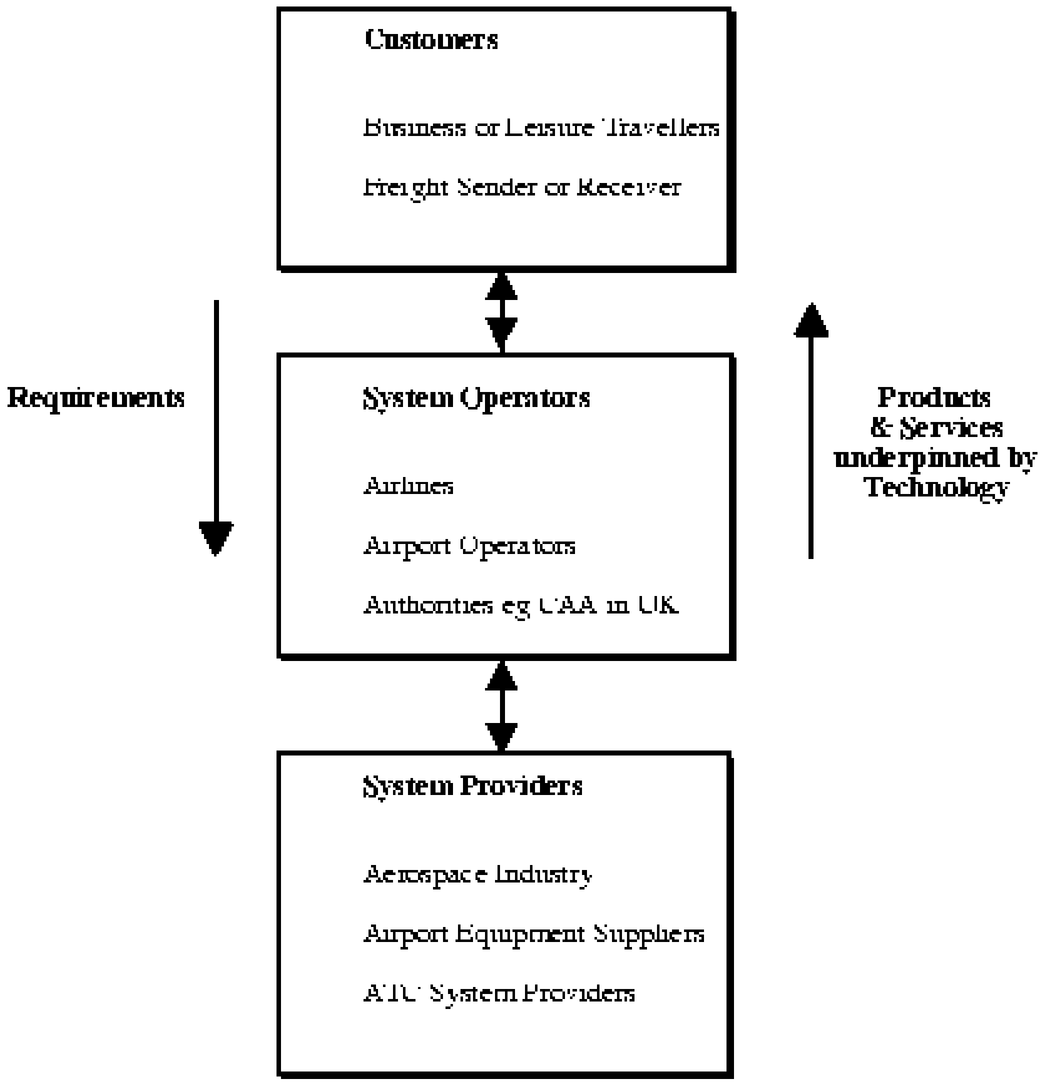
4.3 These achievements have resulted from a combination of world economic growth and increased capability of the aircraft and their associated operating systems.Technology has been the prime enabler throughout this period, leading to reducedrunning costs, greatly improved productivity and enhanced safety and reliability.

4.4 The scope of this study is the civil air transport system including all theequipment and systems required to transport passengers or freight - from arrivalthrough the airport doors at the start of a flight, to exit at the final destination.Systems that lie beyond the airport fence, such as booking systems and transportlinks to airports, have been excluded because they are better covered by otherpanels such as IT&Electronics and Transport.

4.5 In order to assess the most relevant technology requirements, it is first necessary to understand the customer/supplier relationships in the supply chain thatsupports the Civil Air Transport sector (Figure 4.3). This supply chain relates thetechnologies to the market-pull.

4.6 The customers, at the top of the supply chain, are business and leisure travellers and freight carriers. They are served by the operators of the air transport system:the airlines, airport operators and air traffic controllers. Products and services areprovided to the operators by the air transport industry in the form of aircraft, airtraffic control systems and airport equipment. The customer requirements flowdown through this chain, and products and services which meet them flow backup. Technology, whether embedded in the product or used as an enablingprocess, must be targeted to meet these requirements at all levels of the supplychain.

Figure 4.3 - Supply Chain of Customer/Supplier Relationships



Current Markets

4.7 The current total global value of civil air transport products is huge: in excess of 00B per annum (Figure 4.4), of which about 30% is after-market business(which includes spares, repair and overhaul). The UK currently wins around 10%of the civil business: its performance is detailed more fully in the benchmarkingsection below. The market is dominated by aircraft systems which account forabout 75%, including lifetime spares, divided approximately equally betweenairframe, propulsion and equipment. The remainder constitutes ground-basedsupport equipment.

4.8 The current fleet has grown to 350,000 active aircraft. Around only 4% of these are in the commercial air transport sector (Figure 4.5), and yet they represent 95% by value of aircraft deliveries (Figure 4.6). Aircraft above above 120 seats dominate, representing about three-quarters by value.

4.9 Commercial Air Transport Sector

4.9.1 Although the US currently accounts for 40% of world air traffic, the fastest growth is occurring within embryonic markets within SE Asia (Figure 4.7).

4.9.2 Worldwide air traffic has grown at a high, although decreasing, rate sincethe Second World War (Figures 4.8 and 4.9), punctuated only by shortterm, periodic recessions. The industry is currently just emerging from asevere downturn, during which year-on-year world traffic actually fellfor the only time since records began in 1929. This recession wasprincipally in the US and European regions; other regions, notably SEAsia, continued to grow. In turn aircraft orders fell dramatically, withmany cancellations, but the worst now appears to be over.

4.9.3 Growth in traffic has resumed and a pick up in orders is expected thisyear. With continued recovery in the world economy, significant growthis expected over the next 20 years; particularly in the developing regionswhere the majority of the world's population have yet to fly.

4.10 Airline Profitability

4.10.1 A key issue in the civil air transport sector is the lack of profitability.There is a good correlation between airline operating results and civil jetairliner orders. Historically, rising aircraft orders have coincided withearnings growth. This also tends to correlate with GDP and hence trafficgrowth. Profitability has therefore been cyclical but with returns rarelyhigher than 2%-3% even in times of relative prosperity (Figure 4.10).

4.10.2 Airlines are addressing this problem within their own operations throughrationalisation, dramatic cost cutting and improved productivity. Themanufacturing industry that supports them is responding to thechallenge by reducing the prices of its products and services, andlowering its costs to restore profit margins. This effect is then cascadingthroughout the supply chain leading to restructuring of the industry withonly the fittest surviving.

4.11 Airports

Although the data are less reliable for ground-based infrastructure, conservativeestimates of the total global airport business put its worth in excess of 0B perannum, and this excludes US domestic airports, China and the former SovietUnion. Construction dominates and is valued at 0B. Airports in the US andEurope are being stretched to capacity and passengers increasingly annoyed byfrequent queuing. Major improvements will be needed if this infrastructure is tocope with the forecast doubling of passengers over the next 15 years.

4.12 ATC Equipment

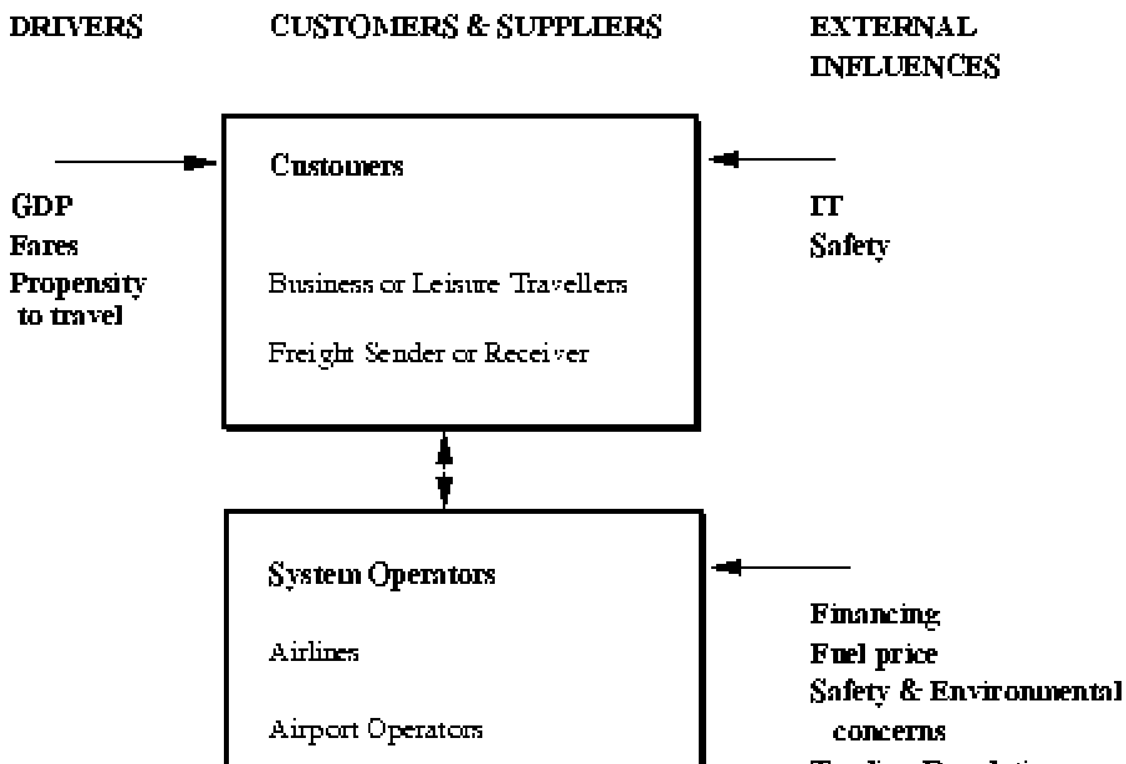
Delays on the tarmac and in the air, waiting for take-off and landing slots, are afrequent reminder for today's air traveller of the inadequacies of worldwide ATCsystems and congested airports. Such delays are costly to airlines and frustratethe passenger: some estimate the cost of delays at B each year in US andEurope alone. The existing worldwide ATC infrastructure faces the most radicalchange of all the elements of the air transport system over the next decade.

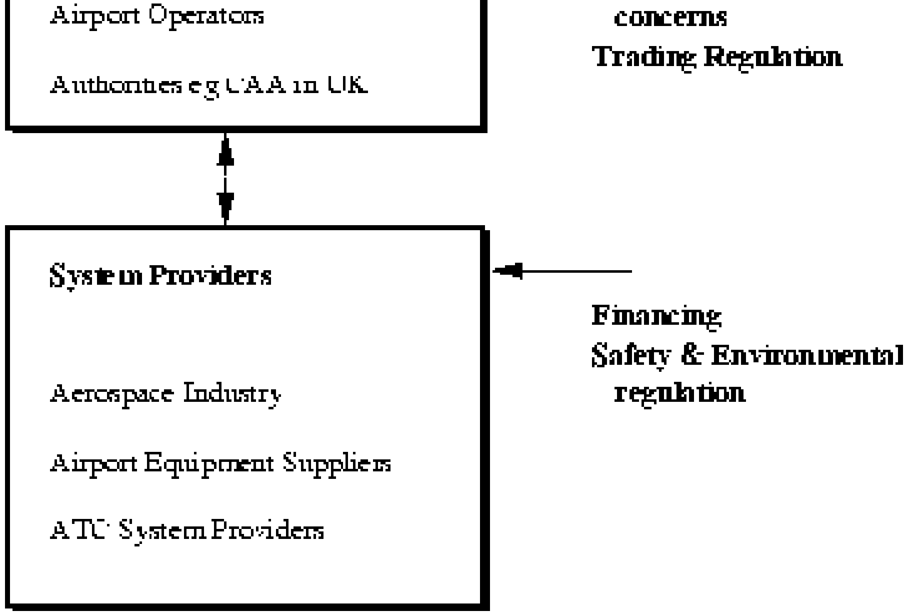
Future Market Scenarios

4.13 Forecasting is fundamental to the civil aerospace industry and world wideexpertise has been developed over the last 20 years. Widely agreed models have agood track record in predicting total traffic growth but are less reliable inpredicting near term trends in regional growth and aircraft size requirements. TheForesight study has used the Aviation Committee Market Panel models to assistin its scenario analysis.

4.14 In order to assess suitable market scenarios, the external influences which affect the dynamics of the supply chain have been identified (Figure 4.11).

Figure 4.11 - Supply Chain showing Drivers and External Influences





4.15 There are three main drivers for growth in air travel.

- **Gross Domestic Product** is the dominant driver, having up to four times the leverage of fares. Growth of GDP stimulates business activityand increases disposable income per head, which promotes leisure travel.The baseline scenario used in the report assumes an average 3.0% perannum, a consensus view for worldwide GDP growth.
- **Fares clearly influence traffic growth, particularly in the tourist sector.The historic** trend of reducing fares is expected to continue, but at a muchslower rate of 0.1% per annum compared with 2% per annum over the last30 years.
- **Propensity** to travel reflects the maturity of the market. In the US,which is mature, travel is largely determined by GDP and fares, since alarge proportion of the population are frequent fliers. However in lessdeveloped regions, such as China, very few people have flown and hencethe desire to fly itself promotes market growth. The forecast includesfactors to represent this effect. **4.16** Growth can also be affected by other factors - economic, social or political - which either directly or indirectly influence the customers and suppliers. For example,an adverse change in the price of fuel or the proportion of business travel willincrease fares and so reduce growth. More strategic legislation on emissions in theform of a 'carbon tax' would drive up fare price and produce the same effect.

4.17 The panel has examined the major influences shown on Figure 4.11 andconcluded that the only likely major changes are fuel price, perhaps caused bypolitical unrest or environmental issues, and a greater reduction in the proportionof business travel, due to the impact of Information Technology (IT), although ITcould have a positive effect on demand by stimulating international economicactivity. These two effects, together with a range of assumptions for GDP growthand fare changes for other reasons, were analysed to give the baseline, high andlow scenario cases over the next 20 years. The variations considered are shown inthe Table 4.1.

Table 4.1 - Variations in Main Drivers and Influences

Major Influences	Baseline	Low Case	High Case
World GDP growth per annum	3%	2.1%	3.9%
Fares variations per annum	-0.1%	+0.3%	-0.5%
Fuel Costs per annum	0.8%	0.8%	0.8%
Fuel Costs - Carbon Tax step change	0%	100%/300%	0%
Proportion of business travellers in 20 years	25%	15%	25%

4.18 The combined effect of the various influences can produce significant variations from the base case, but the combination used in the models covers the mostplausible eventualities. The resultant growth forecast over the next 20 years isprojected to be between 4% and 6% per annum, expressed as Available SeatKilometres (Figure 4.12), with highest growth rates occurring in the Pacific Rimand Asia (8%). Even the low case provides substantial market opportunities.

4.19 There is also a substantial market to replace old equipment which will be retired on age, economic or environmental grounds. Together with the requirements tosatisfy the growth demand, this gives a sustained requirement for new aircraft wellinto the next century. It is expected that 60% of demand will be to satisfy growthand 40% for replacement aircraft.

4.20 Throughout the industry's history there has been a trend towards larger andlonger range aircraft. Recently this trend has become more complex, withdownsizing across the North Atlantic for example, but with continued stronggrowth in both size and range in other regions. This dichotomy is having theeffect of encouraging greater range for the smaller wide-bodied aircraft, forexample, whilst leading to demands for an aircraft substantially larger than theBoeing 747, particularly for Asian markets.

4.21 For trans-Pacific, trans-Atlantic and the other long haul routes, pressure isbuilding for a supersonic successor to Concorde. It is worth noting that ifdeveloped, this can address only a portion of the long-haul market which in totalis expected to amount to around 35-40% of the total traffic. Overall, the bulk ofthe new aircraft deliveries is expected to continue to be in the current largernarrow body and wide body categories.

4.22 The table below (Table 4.2) summarises the base case forecast for civil airlines along with the other civil categories (Figure 4.13). The total new aircraft marketover the next 20 years is between 00B and 100B, to which must be added 50-400B for after-market sales giving a total aircraft and equipment market of50-1500B, some 0B to 5B per annum. The additional after-market, whichis an important source of income for the industry, will reduce as a percentage ofthe new aircraft sales because of the ever increasing reliability of products.However this market segment is the most profitable, again underlining the longterm nature of the business.

4.23 Growth in demand for airport and air traffic control equipment will followpassenger growth. It is forecast at around 8-10% per annum and is worth about70B over 20 years. Substantial regional variations exist depending on whethernew airports are required or existing airports are increased in capacity: China forexample is growing at around 25% per annum.

Table 4.2 - Current Fleet and Forecast Over the Next 20 Years

Category	Current Fleet	Forecast Deliveries	Delivery Value ()
Turbofan Airliners	9680	12100	725
Turboprop Airliners	5000	3900	50
Business Jets	8000	7200	75
Turbine Helicopters	12000	9000	80
Light aircraft	300000	20000	3
Civil Aircraft (Total)	344180	58200	963

4.24 The grand total for the air transport industry is 120-1670B. Presently the UK civil air transport industry has 10% of the aircraft and equipment and about 10%of the combined airport and air traffic control system markets. Provided it canmaintain this position, there is a potential UK market opportunity of 10B 70B in the next 20 years, of which about 60% will be exports. It is therefore ahuge opportunity for UK wealth creation and a major contribution to the globalquality of life.

4.25 The challenge facing the whole industry, if it is to satisfy this tremendous market opportunity, is how to finance the developments necessary to satisfy the growth.As we have seen, airline profit margins are under severe pressure and yet theyneed to invest 5B each year. This investment can only be met by fundamentallyincreased operating margins throughout the supply chain. Therefore cost willneed to be reduced through improvements in productivity, thereby determiningthe priority of the technologies. It is important that the UK sustains World's Bestcapabilities in key areas, to secure leading positions within collaborative ventures.

4.26 Further details of the scenario development work is given in the Market Panel's Report[8] and Manufacturers' own forecasts.

Industry Benchmarking

4.27 The UK aerospace industry, both civil and military currently achieves sales of around 6B, representing about 10% of the world aerospace market (Figure4.14), equally split between the Civil and Military sectors. Civil sales have grownsteadily over the last 15 years, and are retaining market share, as a result of goodpast technological investment. Because of the linkage between the industrialinfrastructure and the technologies, there is an inter-dependency between the civiland military sectors in terms of their capabilities and particularly in certainproducts such as propulsion, helicopters and avionics.

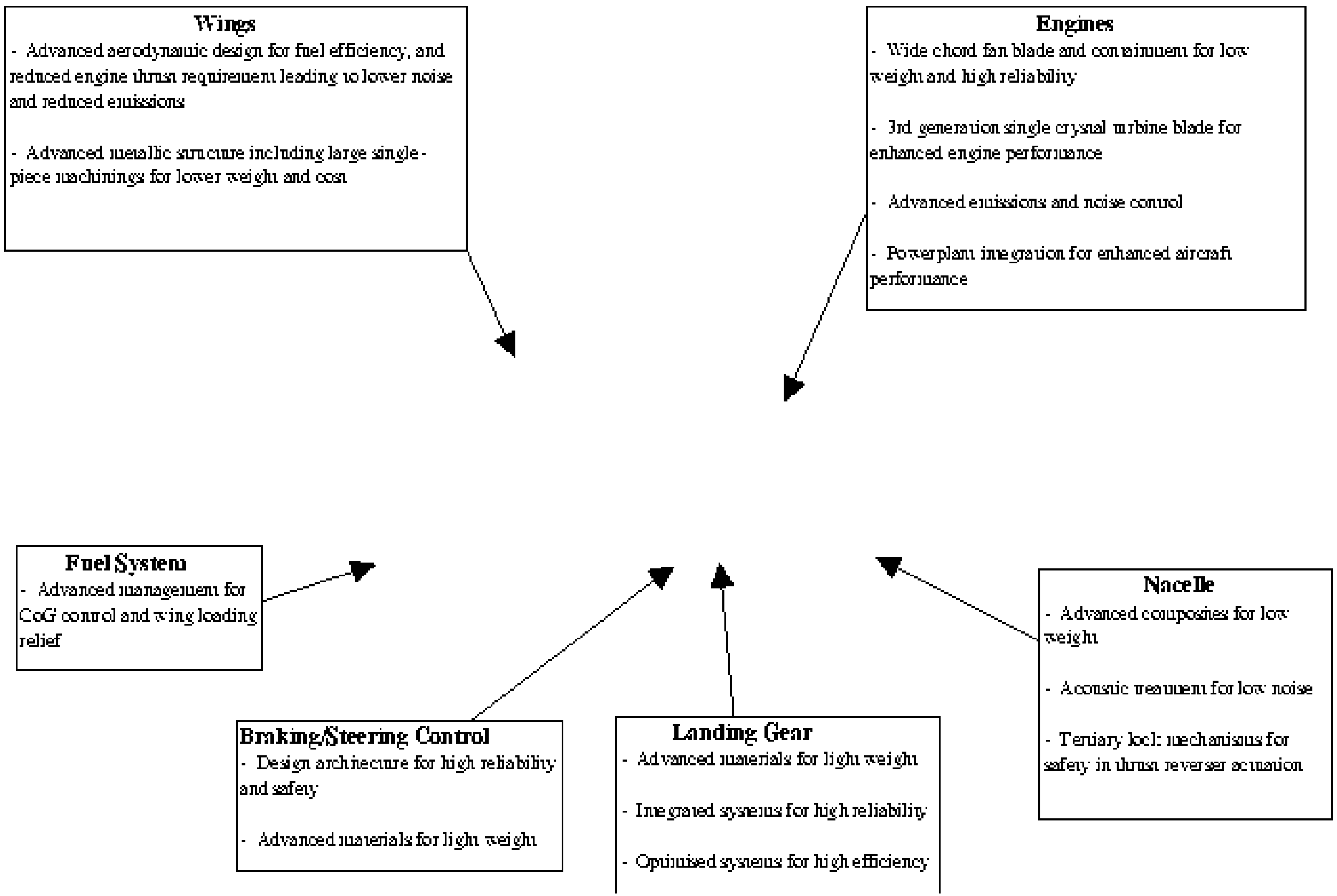
4.28 Two principal sources have been used to support the conclusions onbenchmarking: a report by DTI consultants which benchmarks the critical successfactors using a survey of almost 90 civil aerospace companies worldwide, and theinitial results from a UK competitiveness survey commissioned by the panel.

4.29 Lack of profitability throughout the industry is forcing both the systems operators and providers to reduce costs and improve productivity. The UK is well placed in this respect because of its low average wage rates relative to its competitor nationsof Europe and the USA. However, it is important that the UK manufacturingindustry continues to improve productivity to world's best standards in order tomeet the challenges that lie ahead. Whilst, in the past, the UK has been slow torespond to this challenge, there is good reason to believe that this issue is nowbeing properly addressed within the UK aerospace industry through total quality/business re-engineering initiatives. The success of the SBAC's CompetitivenessChallenge initiative is a good indicator of the importance which industry is givingto these areas.

4.30 UK companies have been winners in worldwide aerospace where markets have been open, competing primarily through superior technology (based mainly onpast R&D investments), but increasingly through their operating performance, todeliver high value, more cost effective solutions. Because of this, the UK has astrong customer base in the civil sector which is important when looking to thefuture.

4.31 The UK industry has the major asset of world-class capability in a wide range of areas: airframes, engines and equipment, together with a well developed supplychain at various levels. It also has a competitive advantage in its capability tointegrate systems at several different levels: wings and aerostructures for aircraftabove about 120 seats, total aircraft for regional and turboprop segments,propulsion across the total thrust range, light and medium helicopters andequipment. A prime platform capability is important since this provides customersfor equipment, components and materials at all levels. This capability isexemplified by the A330 aircraft (Figure 4.15) . Of the aircraft ordered by CathayPacific, almost 50% weight/$ value content is sourced from the UK

Figure 4.15 - UK content of Airbus A330



4.32 Airframe

4.32.1 UK airframers have capability across the range of aircraft sizes. BAe is theworld leader in large transport aircraft wings, through Airbus, and hasworld-class capability in aerostructures, regional jets and turboprops; itwas the top UK exporter in 1993. Other companies such as Shorts have aworld-class capability in aerostructures, including turbofan enginenacelles, and supply a range of aircraft programmes from Boeing 747 tosmall business jets. Westlands have a capability in turbine helicoptersand turboprop engine nacelles and aerostructures.

4.32.2 Large transport wings form the largest sector by value and their majorinfluence on the performance of the product make them the criticalairframe technology. The whole aircraft capability is also important tothe UK and supports an essential ability to integrate systems at alllevels of the supply chain.

4.33 Propulsion

4.33.1 Propulsion is an important sector of the aerospace market and accountsfor a third of the total value. The UK has a strong propulsion industry:Rolls-Royce is one of the world's largest gas turbine companies with agrowing market share and potential to reach 30-35% within thetimeframe of Foresight. It has system integration capability and keytechnologies in all aspects of propulsion.

4.33.2 The UK has capability in the total thrust range, including the only civilSST engine. Propulsion technology also spins-off into the industrialsector where Rolls-Royce is market leader in gas pumping and power foroffshore oil platforms, and is now penetrating the utilities market withthe Industrial Trent engine and marine, markets with the WR21 (RB211-based) engine under development for the USN.

4.34 Equipment and Systems

4.34.1 In the aerospace equipment sector, the remaining third of the market, theUK has a strong and growing world presence in fields as diverse asavionics, secondary power supplies, landing gear, propellers, fuelsystems and fuel management systems, and engine and flight controlsystems. UK companies such as GEC, GEC-Marconi, Lucas Aerospace,Dowty, Smiths Industries, Racal Avionics, Fairey Hydraulics andNormal air Garrett are all world-class companies operating in theequipment sector. Although the position of the equipment industry seemsless dependent on specific projects, the UK's pre-eminent position wouldbe threatened if the UK did not have significant prime contractorshiproles in airframes and propulsion.

4.34.2 UK prime airframe and engine programmes have significantly greaterUK equipment content than airframes or engines with no direct UKinvolvement. However, it is important for UK equipment suppliers tobuild on this base and to win business on a wide range of platformsincluding those led by overseas companies. A current threat is thedeveloping trend towards off-shore manufacturing, encouraged by theextra state support and incentives offered abroad, and hence reducedwealth-creation for the UK Ultimately UK competitiveness in itswidest sense will determine where future projects are located.

4.35 The cost of financing new development increasingly necessitates collaboration with overseas industries. Examples include BAe's involvement in Airbus,Westland's role in the civil EH101 and Eurofar, Rolls-Royce's partnership withBMW in the BR700 engine series, Short's link with Fokker on the Fokker Jetlinerand with Lear on the L45, and Dowty's involvement with Messier in the Airbuslanding gear. Future regional aircraft, extending the Avro and Jetstream ranges, arelikely to be collaborative. Collaborations such as these also help to improvemarket share, of which the Racal/Honeywell Satcom development is a good example.

4.36 The market has historically been dominated by US and European suppliers.However Asian nations, such as the Japanese and Koreans, are hungry for a shareof the market. They are becoming a threat to the traditional suppliers, and theirimmediate ambitions for regional jet and turboprop aircraft need particularattention. Retention of a systems integration capability and hence a quality sharein future programmes, is therefore essential for UK industry to survive.

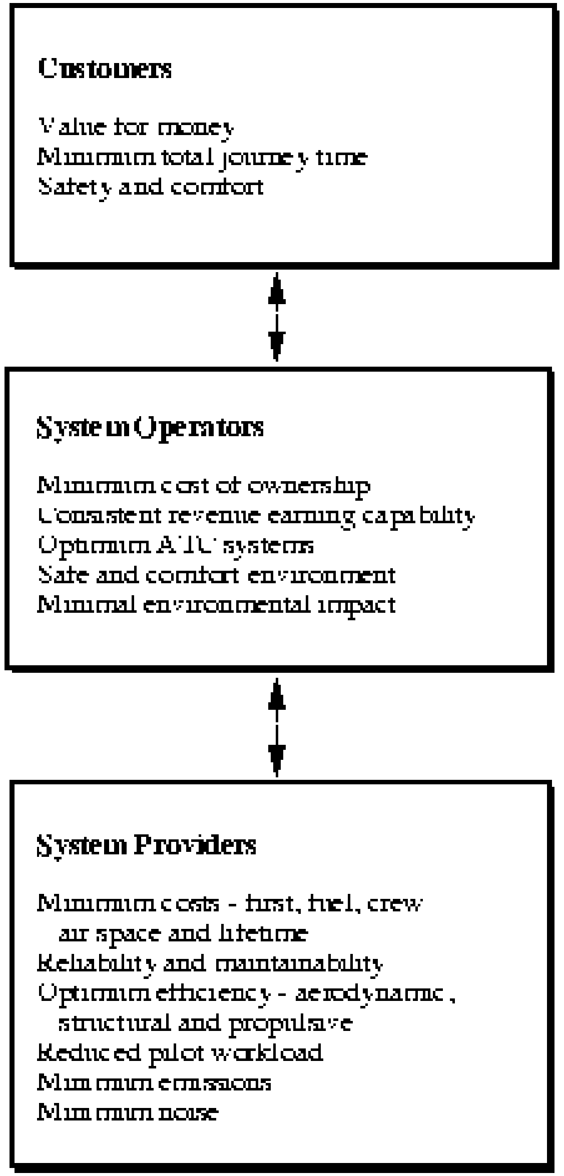
Product and Technology Opportunities

4.37 The products covered in this section are those which are most likely to meet the future market requirements and where the UK presently has above average orworld-class capability and is therefore well placed to exploit the futureopportunities. The market to be satisfied is extremely competitive, as alreadydiscussed, and therefore all the products in the sector will need to satisfydemanding performance and cost requirements, the balance between the twobeing dependent on the particular market sector.

4.38 Some of the major market requirements are shown in Figure 4.16, and have been derived by considering the needs of the airlines' customers and how they will besatisfied by the operators and the system providers.

4.39 The large fixed wing commercial transport sector is the most significant in terms of revenue and the demand for technology. The incremental technologiesrequired to service other fixed wing products are relatively small, once thiscommercial transport sector has been satisfied. Failure to satisfy the needs of thelarge fixed wing commercial transport sector would weaken the UK aerospaceindustry as a whole and threaten its survival. Therefore, this section identifiestechnologies needed by the commercial transport sector first, and then gives theincremental technologies against the other sector headings. For example, rotarywing aircraft require some special technologies such as rotor and transmissionsystems. Each of these sectors will be underpinned by the key technologiesdescribed in Paras 4.75 to 4.86.

Figure 4.16 - Examples of Customer and Supplier Requirements



4.40 The severe financial constraints faced by the system operators make minimum cost of ownership and consistent revenue earning capability fundamental, asconfirmed in the Delphi survey response (Statement 5 - Halving of subsonicaircraft Direct Operating Costs). They also dictate that purchases of newcommercial transport aircraft will tend to be further upgrades and replacements ofexisting aircraft types rather than radically different aircraft. However theapplication of new technologies, particularly advanced wings and fly-by-wire, hasalready enabled Airbus to displace McDonnell-Douglas and to become a seriouschallenger to the market leaders Boeing in the large commercial aircraft market.

4.41 The customers' requirement for low cost drives the need for effective business processes, including lean manufacturing technologies. It is essential that theknowledge base in aerodynamics, structures, manufacturing, propulsion andcontrol technologies is developed sufficiently to enable a holistic approach todesign and manufacture.

4.42 For long haul operations, fuel burn will always be relatively more important than in short haul operation: this represents a larger proportion of operating cost asrange increases, and competitive fuel burn translates into range capability. Moreefficient aerodynamics leading to drag reduction and high lift, airframe-propulsionintegration, and the cost-effective application of new structurally-efficientmaterials such as composites, are all important technologies to achieve this.

4.43 Reliability is also extremely important since increased airline utilisation rates accentuate any disruption costs. Maintenance costs must be minimised, requiringnew materials and improved life prediction and design techniques. Non destructiveevaluation and health and usage monitoring systems offer improved in-serviceoperation.

4.44 The increase in air traffic over the next two decades will create specialenvironmental challenges which will need to be addressed. The effect of existingaircraft and the potential effect of new aircraft must be controlled. There will bestrong pressure to reduce aircraft noise. The Delphi responses ranked Statement 38(Large subsonic aircraft quiet enough to take off and land at night) as the largestwealth creator.

4.45 Huge growth on high density routes, together with pressure to reduce operating costs, will create demand for a very large (500-1000 seats) aircraft, aimed ataddressing the growth in air traffic within the constraints of the existinginfrastructure capability, as responses to Delphi statements 37 (Large 600-800 seattransport aircraft) and 39 (Very large subsonic aircraft, > 1000 seats) demonstrated.

One such potential project, VLCT, is proposed to enter service about 2005. Newtechnologies will be key enablers to its introduction; their affordability will beparamount since first cost and cost of ownership will again be extremelyimportant. The aircraft will be constrained to operate from existing terminals andairports, and to conform to continuing pressures to reduce environmental impact.

4.46 Another potential project, in a similar timescale, is a new regional jet. Shorter routes serviced by regional jets, turboprops and helicopters could meet increasingcompetition from improved ground transport systems.

4.47 UK participation in all new aircraft projects is expected to be throughinternational consortia, hence it is essential that UK industry maintains anddevelops world-leading capabilities in key areas to win a "seat at the table". Theseare all aspects of wing technology for all aircraft sizes, and whole aircraft designand integration for regional jets. A level of whole aircraft capability is also requiredfor large aircraft in order to participate effectively within internationalpartnerships.

Supersonic Transport

4.48 Concorde has demonstrated that a supersonic aircraft for commercial transport is technically possible, provided that the economic and environmental problems can be overcome. The market opportunity is largely in the Pacific Rim for long rangeoperation with supersonic flight over water and subsonic flight over land, since acomplete solution to the sonic boom over-pressure problem appears unlikely.

4.49 In order to improve the economic viability compared with Concorde, advances in aircraft aerodynamics - lift/drag ratio increased by 20% - combined with a 40% reduction in structural weight per seat and a 5-10% improvement in specific fuelconsumption are necessary. These are considered to be achievable with the use ofadvanced supersonic aerodynamic analysis and design techniques, and theextensive use of composites and titanium in advanced structures. Noise andaltitude emission of NOx will need to be addressed by using a variable cyclepropulsion system with ultra-low emissions combustors.

4.50 These advances would enable a 5000 - 5500nm Mach 2.0 to 2.4 aircraft to bedeveloped with a seat mile cost 15% more than today's Boeing 747, or 30% greaterthan the subsonic aircraft of the future. At this level of economics, it is judged thatthere could be a market of between 500 and 1000 aircraft.

4.51 The existence of such an aircraft will change the long term structure of airline operations, and future equipment requirements, for the long range routes. Themost likely in-service dates, confirmed by the Delphi survey (Statement 40), is2015 and certainly not before 2010.

Novel Shaped Aircraft

4.52 Current airline economics are marginal, prompting little or no interest in high risk high cost, aircraft. New aircraft need to be able to use current airport facilitiesand to be interoperable with existing fleets. The introduction of radical technologywill require assurances of minimal risk, hence aircraft in the foreseeable future areunlikely to see radical changes in configuration or shape. The Delphi surveytimescale responses to Statements 42 (low cost, personalised air transport) and 55(novel-shaped or ground effect aircraft) confirm this.

4.53 Significant changes in aircraft design will only come about either when forced by external influences such as a shortage of carbon based fuels, severe changes inenvironmental regulations, or when enabled by a step change in underlyingtechnologies which contribute to economic benefits. Such radical possibilitieswould include: flying wings, multi fuselage, joined wings, slewed wings,cryoplanes (liquid hydrogen, liquid natural gas as fuels) and integrated/blendedwing fuselages.

4.54 Radical configuration studies must continue at a background level to ensure that UK is well placed, should events and technological breakthroughs combine tomake them economically beneficial.

Rotorcraft

4.55 Rotorcraft are likely to stay dominant in the offshore oil and gas support role and specialist emergency and rescue roles where a VTOL capability is required. Thereis also a possibility that they will create a significant niche market in scheduledpassenger operations, given pressures to reduce runway congestion at some majorairports, and the attraction of city centre to city centre operations (Delphistatement 43 - Civil rotorcraft with tenfold increase in safety). The developmentof this market requires improvements in safety, operating economy and ridequality, together with a significant reduction in noise. In addition, action will berequired to integrate rotorcraft into the developing air traffic management system,taking into account their unique VTOL capabilities, which in turn could be usedto minimise the noise footprint.

4.56 Such use will be dependent on a reduction in operating costs through theapplication of lightweight materials, improvements in rotor aerodynamics, and theuse of smart structures. Transmission system reliability must be increased as mustthe time between overhauls. Improved safety is crucial to extensive scheduledpassenger use and will require advanced health and usage monitoring for rotorand transmission systems, together with more effective de-icing. Easier handling,through integrated flight and engine control systems, will help ease crewworkload. Environmental acceptability needs to increase and this, particularly fornoise reduction, represents a considerable technical challenge. Advancedderivatives of conventional rotorcraft are also foreseen. These will include lift andthrust compounding, and tilt rotor developments.

4.57 The UK has a recognised capability in this sector, notably with rotors andgearboxes, and should look towards retaining its presence to benefit from thesemarket opportunities.

Turboprop Aircraft

4.58 The technology for turboprop aircraft depends largely on those developed for larger aircraft, and many of the fundamentals are common. There are exceptionssuch as propeller capability, noise reduction and ice protection. In gearboxtechnology there is some commonality with helicopters. The application cost ofsome of the technology from larger aircraft developments can make themuneconomic to use directly on the lower priced turboprop aircraft. However,requirements such as lower cost and increased structural efficiency are shared byturboprop, regional jet and rotorcraft.

Propulsion

4.59 Propulsion system configurations for subsonic aircraft will continue to evolve for the foreseeable future. There will be a steady upwards growth in size to wellbeyond 100,0001b thrust. By-pass ratio, pressure ratio and turbine entrytemperatures will all increase in order to reduce specific weights and specific fuelconsumption, since they both improve the earning capacity of the aircraft andreduce CO_2 emissions. Ultra low emissions combustion chambers will bedeveloped to reduce the oxides of nitrogen, whilst there will be widespread use ofadvanced materials to improve structural efficiency and permit the use of higherrotational speeds to reduce the number of parts. Above all, however, there will besignificant reduction in cost resulting from the use of fewer components made inlean manufacturing facilities to yield reductions in cost of between 35% and 50%per lb. of thrust.

4.60 The success of the second generation supersonic transport depends largely on the ability of a new engine to satisfy performance, weight, noise and emissionrequirements. Those technologies which are unique to this requirement are noiseand emissions reductions, the remainder being common to future civil andmilitary engine needs.

Equipment and Systems

4.61 Aircraft equipment and systems include all aspects of avionics, electromechanical systems and the features and facilities of the cabin environment. The airlines willrequire increasingly efficient and reliable systems at lower cost reducing bothinitial costs and recurrent crew and maintenance costs with modularity and inbuiltupgradability.

4.62 Passenger appeal will be influenced by the cabin facilities: comfort, an office in the sky in contact with the base office, and a wide choice of personalentertainment. On board avionics will undergo a dramatic change with theworldwide acceptance of satellite based navigation and communication.

4.63 Developments in electronics, sensors, displays, high speed data exchange and human-computer interaction technologies will contribute to improvements inaircraft control, integrating all aspects of performance and improving the crew/computer interface whilst reducing crew workload. From these technology areaswill also come the required improvements in flight deck workload, office andentertainment facilities. The Delphi responses to Statements 61, 62, 64, 65 and66 showed that these technologies have large exploitation potential for platforms.

4.64 Future electromechanical systems include very large multi-wheeled landing gears and novel actuation systems. Product optimisation will be achieved principallythrough improved design and manufacture processes. It will also involvedevelopments in materials, smart structures, power optimisation, controlelectronics and power transmission systems.

Air Traffic Management

4.65 Air Traffic Control (ATC) systems are a critical element in the air transportation system. Future ATC systems must cope with an expected doubling of traffic over the next 15 years; enhancing safety will be a key requirement, whilst cuttingdelays and reducing airline operational costs. The trend to even larger aircraft willexacerbate some of these problems. Current systems have evolved over the last 30years in a somewhat piecemeal fashion and will not be able to cope with thislevel of traffic growth. There is clearly a significant upgrading market to service,and the UK has the potential to lead in the provision of technical solutions andsetting of standards.

4.66 The main current problem is the lack of suitable equipment in some parts of the ATC network. In Europe, there are 31 different systems in the 51 ATC centres,using computers from 18 manufacturers with 22 different operating systems and33 different programming languages. The initial strategy being pursued by Europeaims to bring about a substantial increase in airspace capacity through adoption ofsystems capable of comparable levels of performance, complying to commonstandards, specifications and procedures, throughout Europe. Interface problemssuch as lack of integration between ground and air ATC systems, and a dearth ofstandard interfaces between different systems must be solved. The introduction ofcommon standards for on-line data exchange between all computers will improveco-ordination between ATC centres. The need for harmonisation with militaryrequirements is likely to remain.

4.67 In the longer run, European ATC can take advantage of the fact that technologies for air traffic management, communications, navigation and surveillance areadvancing at an unprecedented rate and can help to enhance air safety, cut delaysand reduce operating costs. The integration of ground and air systems, involvingthe automatic datalinking of flight information, will probably be based on acombination of ground-based secondary surveillance radar and a network ofsatellites. In the Foresight timeframe, the growing use of satellites for airnavigation will produce a large increase in the number of aircraft fitted with onboard satellite navigation equipment.

4.68 Technology itself is probably not the key issue in achieving this goal - it is itsusage which is critical. However, progress is determined by the essential process ofbuilding international consensus, on the standards and procedures that pilots andcontrollers will follow whilst using the new technologies. This has to be done verycarefully to ensure system safety. There will be a vital need for realistic simulatorsystems and demonstrators - including technologically advanced aircraft avionicssystems as part of an integrated air-ground ATC system - so that decision makerscan be convinced of the cost benefit cases to underpin the major capital investmentrequired. The UK must ensure that it is fully involved in defining, andparticipating in, these programmes: if necessary, Government funding supportshould be provided to ensure the UK takes a leading role.

4.69 It cannot be stressed enough that safety must remain the paramount ATCconsideration, because of the catastrophic consequences of an aircraft collision.Collision warning systems will need further development, probably using airground datalinked data. Improved safety for ground operations at airports willrequire work on integrating sensor information, and possibly artificial visionsystems.

4.70 Product developments include: advanced flight management systems, approach, en route, landing and ground movement management systems based on satellite communications, navigation and surveillance systems. There will be a substantialmarket for 'hybrid' systems (old with new) and open systems interconnectionssuch that digital information can flow between dissimilar networks.

4.71 People will remain a vitally important part of the overall ATC system. It istherefore imperative that the human-machine interface is improved to achievehigher productivity, reduce human error and increase overall reliability and safety.Computer assistance to controllers, to prevent task overload, and betterergonomic displays are instances where this focus is particularly important(human error is still cited as a major causal factor in aviation accident).

Airport Systems

4.72 Air traffic growth has led to the increased physical size of aircraft and passenger throughput and the need to make the airport element of air travel a more pleasant experience for the customer. These factors combine to create a substantial airportsystems market over the next 20-30 years. The overall market consists of upgradesof existing facilities, which are mainly found in the mature areas for air travel, i.e.US and Western Europe, and provision of all new facilities which are primarilyrequired in developing world regions such as the Far East. Faster check-in,increased security, less time with baggage, automatic baggage reconciliation, andbetter inter- and intra-terminal passenger flows are some of the requirementsdriving airports to automated systems for passenger processing.

4.73 Common User Terminal Equipment (CUTE), utilising fibre opticcommunications, will be a key element. Increased utilisation of already congestedairports will necessitate smarter scheduling to utilise existing runways andtaxiways, better manoeuvrability of aircraft, precise tracking and, perhaps,automation of all airport vehicle ground movements.

4.74 Environmental protection is another key element of airport infrastructuredevelopment. Air quality, noise, re-cycling of waste will all demand increasedattention in the future. Green field site airport developments will be built on amodular basis, if space permits, so as to allow flexibility and expansion.

Key Technology Areas

4.75 There are five key technology areas which underpin all aerospace products. It is therefore essential that the UK maintains its capability in these areas in order thatit can fully exploit the market opportunities. These areas are:

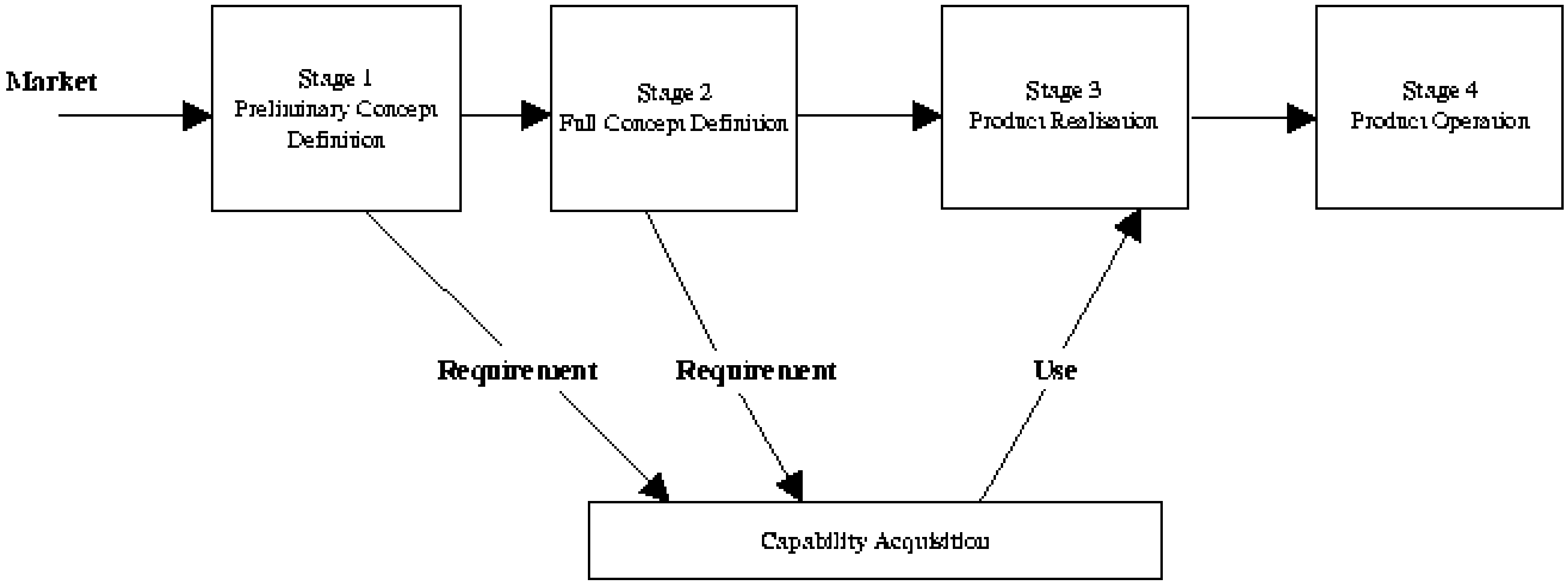
- Systems integration
- Product and factory design systems
- Structures, materials and manufacturing processes
- Aerodynamics (including emissions and noise)
- Avionics and high integrity software

4.76 These are 'Dual-Use' technologies, fundamental to other market sectors as well as Defence and Aerospace. However, it is likely that progress within the UK onmany of these technologies will be led by the civil aerospace sector. For example,materials developments (particularly high temperature) will be driven by civilrequirements because of the short product development timescales. The businessprocesses of product and factory systems integration will also be led largely bycivil aerospace because of market pressures to reduce costs and time to market inan extremely competitive market.

4.77 Competitive advantage in the Civil Aerospace sector in the future will be critically dependent upon enhanced product performance, combined with dramaticreductions in the costs and timescales associated with product development,production and operation. The systems used to design and operate the productand the factory in which it is to be made will therefore be essential to the successof the product. The integration of all of these systems is a key skill for UKindustry.

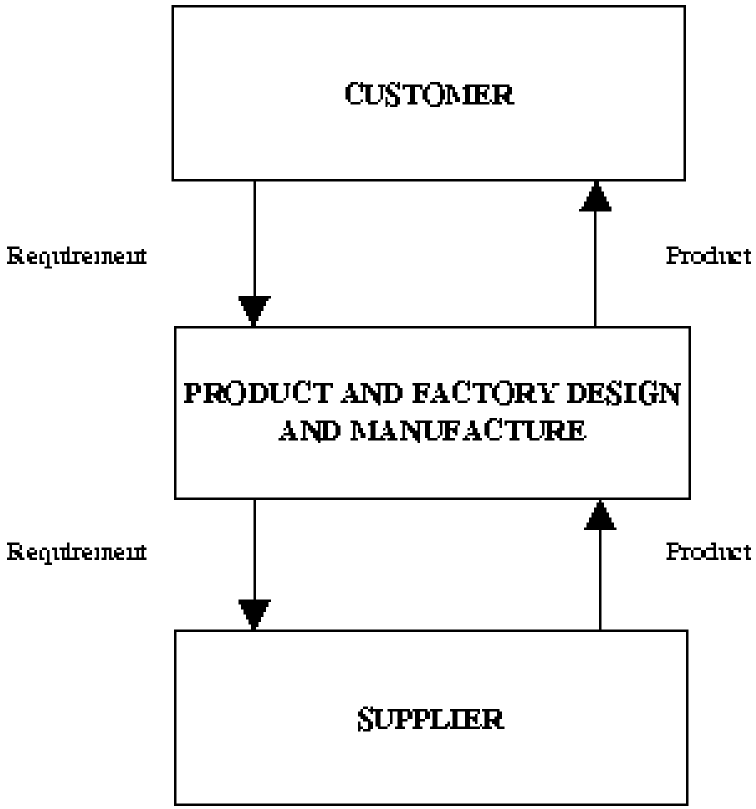
4.78 There are four basic stages to the life cycle of any product, covering preliminary concept definition, full concept definition, product realisation and productoperation. These phases apply whether the product is an aircraft or the factory inwhich it is manufactured (Figure 4.17). Competitive advantage will be secured byacquiring capability that enables these products to be designed, manufactured andoperated at lowest cost and taken to market in the shortest possible timescale.Therefore technologies associated with these processes are critically important.

Figure 4.17 - Product Life Cycle



4.79 There are three basic processes involved: selling of the product/system to the customer against specified requirements; design and manufacture of the productto satisfy the requirement; and buying of sub-systems or materials from lowerlevels in the supply chain (Figure 4.18). Concurrent engineering is needed tooperate the above business processes in parallel rather than sequentially, during allfour stages of the product life cycle and involving all parties in the supply chain.Systems Integration encompasses all activities described above, from end user tomaterials supplier and throughout the product life cycle.

Figure 4.18 - Product Supply Chain



4.80 Product Design Systems. The product design systems are all those designsystems and tools associated with product definition and its subsequent operation,including those pertaining to its method of manufacture.

Examples: Requirements capture tools, CAD/CAM, computermodelling of aerodynamics (CFD), structures (finite elementanalysis), product functionality, materials (fracture mechanics), manufacturing(process modelling), data acquisition (sensors), rapid prototyping.

4.81 Factory Design System. The factories convert material, using the definedproduct and manufacturing processes, into the final product. This will include themanufacture of materials and components and their assembly into completeproducts. These factories are systems requiring tools which are common to theproduct, and others which relate to factory operation. They use leanmanufacturing technologies aimed at reducing product costs and inventory levels.

Examples: CAD/CAM, reconfigurable manufacturing cells, shopcontrol systems and advanced machine tools, product cost modelling, production scheduling systems.

4.82 Enhancement of these processes by technology, notably information technology, will yield substantial benefits to the Defence and Aerospace sector as it responds to the challenge of designing and manufacturing highly complex products ataffordable costs in short timescales. For the reason stated, these technologies willhave been identified in greater detail by the Manufacturing Panel. Defence andAerospace, however, may well spearhead developments of these technologies,although they will have widespread use throughout UK manufacturing industry.

4.83 Concurrent engineering practices are essential to integrate the design, systems and lean manufacture technologies into a single holistic design approach whichdelivers the airline customer the right product on time at the right cost. Key skillsand training in this way of working are also an important requirement. Onlythrough this holistic approach will the Civil Aerospace sector meet the challengethat lies ahead.

4.84 Structures, Materials and ManufacturingProcesses

4.84.1 The competitiveness of aerospace products is critically dependent on thedevelopment and application of advanced materials in efficient, low coststructures, to reduce weight and improve in-service operation. Inaddition, future exploitation of smart materials and structures will havemany potential benefits, for example continuous in-situ damagemonitoring to prompt on-condition maintenance, and condition sensingstructures and components with the ability to change shape, henceoptimising aerodynamics and engine performance.

4.84.2 The ability to design for both cost effective manufacture and efficientoperation in all types of material will be essential. The application ofaccurate life prediction methodologies for complex materials andcomponents will contribute to the control of life cycle costs, whilstmanufacturing technologies which deliver consistent high quality willimpact on first cost. All aspects of design must be integrated to assessthe trade-offs between cost and performance, and hence achieve theoptimum balance.

4.84.3 Important areas for materials and processing developments include:

- Metal and ceramic matrix composites: developments inprocessing and behavioural modelling;
- Ceramic matrix composites: developments in oxidation resistant systems forhigh temperature operation (> 1400°C);
- Ni-based superalloys:improvements in temperature capability, lower density, reducedcost;
- High temperature coatings;
- Corrosion-resistant steels for undercarriages;
- Advanced structural alloys including Al-Li for aircraft structures;
- Polymer matrix composites, in particular low cost processingroutes and manufacturing, and damage modelling of 3-D fibrearchitectures;
- Microstructural, thermodynamic and behavioural modellingtechniques for materials development;
- Process modelling for optimisation and control of materialsprocessing;
- Machining and joining of advanced materials;
- Surface engineering;

- Non-destructive evaluation, especially for advanced materials andcomposites;
- Repair techniques, especially for composites.

4.84.4 Advanced aerospace materials constitute a small and highly specialisedmarket. The UK is losing high technology aerospace materialsproduction capability as indigenous materials suppliers find ituneconomic to compete in this investment-intensive, but low volume, area. The UK aerospace industry is therefore becoming increasinglydependent on foreign suppliers. Reliance on procurement from overseascauses problems where access to a critical material is restricted, forexample through export controls.

4.84.5 In order to exploit the latest materials technology, and to overcomeproblems of restricted access where necessary, the UK aerospace industrymust be able to define and develop manufacturing processes for vitalmaterials, in many cases without the help of an indigenous productioncapability. This will enable design and lifing studies to be undertakenand demonstrator components to be produced.

4.84.6 Several requirements underpin such activities: a broad-based materialsresearch capability in the UK science base closely linked to industry'srequirements; good intelligence on worldwide materials developments;and a community which can respond quickly when a materials-basedcapability gap is perceived.

4.85 Aerodynamics (including emissions andnoise)

4.85.1 Aerodynamics is an essential underpinning technology for aircraft, rotorsand propulsion systems. Improvements in engine and aircraftaerodynamics reduce fuel-burn and lead to lower running costs.Significant reductions in product design times and costs can be gainedfrom improved modelling techniques based on CFD, as fewer optionsneed wind-tunnel testing. A better understanding of flow phenomena willreduce development risk and allow performance optimisation to becarried out will enhanced confidence.

4.85.2 The ever-growing awareness of the environment and consequent legislation is leading to increased requirements for reduced emissions, improved fuelefficiency and lower noise from both engine and airframe.

4.85.3 Advances in aerodynamics need accurate, reliable CFD codes, togetherwith enhanced theoretical approaches and experiments. Important areas

- total aircraft performance prediction;
- improved understanding and modelling of complex viscous/unsteady flow phenomena, eg turbulence, transition, shockboundary layer interaction;
- active and passive drag reduction for wings and nacelles (eglaminar flow);
- design and off-design aerodynamic and heat transfer analysis ofturbomachinery components;
- prediction and control of aeroelastic behaviour;
- development of CFD codes with chemical reaction kinetics;
- improved aeroacoustic models for prediction of noise, generatedby engines, propellers, rotors and airframe.

4.86 Avionics and High Integrity Software

4.86.1 The avionics content of civil aircraft has steadily increased, firstly throughthe provision of communications, weather radar, landing aids and flightcontrol and, more recently, the provision of communication and in-flightoffice facilities and entertainment. New aids to landing in difficultconditions are being developed, utilising a number of technologies suchas GPS, high frequency imaging radars, collision avoidance systems, 4-D flight management systems, head-up displays and terrain contournavigation.

4.86.2 Managing these large amounts of incoming information from differentsystems and sensors will require new integration approaches and realtime data fusion techniques with faster signal and data processing.Software for aircraft and air traffic control systems will demandimprovements in development/testing/validation tools, and tools forverification and maintenance, particularly fault detection. At the humancomputer interface the implications will be a need for displays whichoptimise understanding of information, features which limit pilotworkload and the integration of voice actuated systems.

Key Recommendations

4.87 The Panel makes the following recommendations concerning Civil Aerospace products and technologies:

4.87.1 It is essential for the UK to invest in capability in commercial transportaircraft products: notably airframe wings, primary aircraft structures,propulsion and equipment sub-systems, since this is the dominant sectorby value and drives the technology requirements which then spin off intoother aerospace sectors and the remainder of UK industry. A limitednumber of technologies specific to turboprops and rotorcraft, such asnoise and vibration reduction, will also require UK investment in orderto improve competitiveness in these wide market areas.

4.87.2 The basic technologies of the Aerospace sector are aerodynamics,structures, materials, manufacturing processes and avionics. It isessential that the UK retains and enhances its capability in these areas.

4.87.3 Cost and time to market are rapidly becoming the dominant drivers insecuring the competitive edge. Systems integration, product and factorydesign should therefore be given greater emphasis than in the past, asshould the training of the workforce and students in concurrentengineering principles.

4.87.4 The UK currently has a lead in supersonic transport with Concorde andneeds be involved in sufficient research and technology acquisition toparticipate in any future collaborative programme. In the first instance,Government should actively promote and support a Europeantechnology acquisition programme similar to that presently beingfunded by NASA.

4.87.5 There are significant opportunities for the UK in a worldwide satellite-based air traffic management system. However, progress is being hampered bya lack of inter-governmental agreements on how to achieve this long-term objective. Information from European research and demonstrationinitiatives in ATM should enable progress to be accelerated. The UKGovernment, in conjunction with CAA, should aim to lead in such aninitiative within Europe, with funding assistance provided wherenecessary.

5. SPACE

5.1 Space applications span the civil and military aerospace sectors, and in somecases serve both. A number of such applications, eg space-based defencesurveillance systems and air traffic control, have been covered within the separateDefence and Civil Aerospace sections. This section seeks to draw together underone heading the Panel's findings on Space-related issues.

5.2 In addition to the work on space-based systems that arose during the work of the two sub-groups, the Panel received valuable input from the UK Industrial SpaceCommittee (UKISC) on sector characteristics, the major issues in Space and howthe UK might be involved in market developments in this important sector. ThePanel also held a specific workshop on Space-related issues involving Industry,Academia and officials from the British National Space Centre (BNSC). Amini Delphi exercise based on space-related topics from four of the sector panelswas also held. This section incorporates the results of these consultations.

5.3 The Panel is conscious that in the time available, this important area has notreceived the attention it deserves. Continuing Foresight work by the Defence andAerospace Panel should focus on Space as a sector and conduct a morecomprehensive analysis of the factors affecting wealth creation.

Sector Characteristics

5.4 UK industrial involvement in Space is closelybound to European activities, particularly those conducted through the EuropeanSpace Agency (ESA). The total turnover of the European space industry isestimated at 6B ECU[9], with the total value of European space activities,including value added business and services in television andtelecommunications, estimated to exceed 18B ECU. The total turnover of theUK space industry is about £500M, with total turnover at around £1B when theservice sector is included. Some 6000 people are employed in UK industry.

5.5 Government funding of space science and engineering is directed through the DTI, specifically the British National Space Centre (BNSC), and the ResearchCouncils, SERC/PPARC and NERC. Table 5.1 summarises past and plannedGovernment expenditure on Space science and technology activities.

Table 5.1 - Sources of Funding for Space-related Activities

ACTIVITY	1991/92 (Outturn)	1992/93 (Outturn)	1993/94 (Estimate)	1994/95 (Privision
SERC/PPARC/NERC				
Astronomy/Planetary Science	26.5	29.4		
Space Science	40.5	50.8		
Earth Observation	9.2	8.8		

Astronomy/Astrophysics			53.7	55.4
Solar System Science			44.6	35.8
TOTAL	76.2	89.0	98.3	104.3
Of which:				
ppA - General Support for Research	65.8	78.4	88.7	95.8
ppD - Technology Support	10.4	10.6	9.6	8.5
DTI/BNSC				
National Space	20.4	20.2	14.6	9.0
ESA	75.5	75.6	77.0	78.21

Source: Forward Look 1994
Notes: Earth Observation transferred from SERC to NERC in 1993
Astronomy and Space Science became PPARC responsibility from April 1994
pp = Primary Purpose

Main Issues

5.6 The submission from UKISC and the results of the special Space workshop have been used in compiling the following brief summary of the main issues.

Competitiveness

5.7 In science and technology, the UK is viewed as being level with our maincompetitors. As in the Defence and Civil Aerospace sectors, however, the UK isseen as being poor at exploiting good ideas from the S&T base into successfulproducts. This was confirmed by the analysis of the Space topics within the mainDefence and Aerospace Delphi, and the mini-Delphi held at the Space workshop.

5.8 In common with the rest of the Civil Aerospace sector, Space needs radicalimprovements in cost and timescale if the UK is to be competitive in worldmarkets. Innovative manufacturing methods and new business processes such asconcurrent engineering must be introduced.

5.9 The European approach, whereby each nation tries to do everything, is considered wasteful, and puts Europe at a disadvantage compared to our US and Japanesecompetitors. The 'juste retour' principle is not appropriate: there must be moreopen competition with work being placed where the real competencies reside.This echoes the findings of the Defence sub-group with respect to defencecollaboration in Europe.

Technology Transfer

5.10 The workshop highlighted a large gap between Government laboratories and academia, and Industry, in terms of the understanding of what Industry wasseeking, and a lack of appreciation by Industry as to what academia was capable ofproviding. It was suggested that there may be a role for BNSC in fostering closerlinks between these groups, and there was a strong call for better dissemination ofknowledge of core competencies within UK research groups in academia andindustry so that decisions on teaming can be taken on the basis of matchingcomplimentary capabilities.

5.11 A specific area highlighted as ripe for exploitation in other industrial sectors was instrumentation developed for space applications. The warning was sounded,however, that technology transfer per se does not create wealth: it is important toget the science and technology from the science base into industry, but wealth iscreated by exploiting the S&T through getting products to market. Here, UKweaknesses in project management and the marketing function were highlightedas placing the UK at a competitive disadvantage.

Management/Organisation

5.12 Globally, the space industry is consolidating to correct over-capacity, and this process is likely to continue for some time yet. In the UK, the spacemanufacturing industry has contracted considerably and further rationalisation islikely. Factors such as the level and direction of Government funding, deregulation and access to overseas (particularly the US) markets will play animportant role in determining the competitiveness of the UK space industry in anincreasingly competitive worldwide market. The role and policy direction of ESAare important in determining how Europe will fare in the global marketplace there is a strong feeling from UK industry that Europe needs a co-ordinated longterm policy for space, and ESA must develop new mechanisms which focus moreon competitiveness and market requirements.

5.13 It was also felt that there was scope for reducing bureaucracy and administration costs associated with ESA, so releasing more funding for science and technology.There was strong advocacy for strengthening the role of BNSC, perhapsconferring agency status with a dedicated budget drawing together the variousstrands of the UK space effort under this one group.

5.14 In terms of space missions themselves, there was a view that Europe should be moving from few, large missions to many but smaller, for the same funding. Thelatter approach made the overall programme less vulnerable to failure of anindividual mission, and made it easier to maintain the skills base, but there wassome pressure from other nations within ESA to resist this change. The 'many butsmaller' approach would probably favour the more flexible characteristicsattributed to UK scientists and engineers.

Funding

5.15 The UK Space community is concerned about the extent to which UK funding for technology support to national space activities is being reduced. UK fundingfor ESA programmes is being sustained, but national spend will be more thanhalved over the next few years (see the DTVBNSC entry in Table 5.1). Theworry is that the UK is providing insufficient funds to support national activity inkey areas such as instrumentation at a level which enables the UK to get the bestvalue-for-money from its membership of ESA. There was a strong call for thisbalance to be adjusted.

Role of Government

5.16 Investment in space science and engineering needs a long term view, and some issues have levels of risk and cost which industry cannot justify dealing withdirectly. There are examples, however, where industry overseas, particularly in theUS and Japan, are prepared to invest large amounts of their own funding inlongterm space projects, in which the revenue stream can be ten years hence.

TheUK financial culture does not favour long term, high risk investment, and Spacewas perceived as absorbing large development funds with poor rates of return. Thelack of investment by large UK communications companies in satellites,favouring instead terrestrial systems, was seen as a reflection of this risk-aversionapproach.

5.17 There was a strong plea for maintaining and developing a space capabilitywithin Government R&D establishments and introducing methods to facilitatetransfer of technology into industry (see technology transfer section above).

5.18 In common with the Defence sub-group, there was concern over reciprocity of market access, with the Space community calling on Government to work withother European nations to establish full reciprocal access to the US market.

Skills

5.19 Downsizing of the Space industry has resulted in the loss of key skills inmany specialised areas. Uncertainty over the future and better conditions inother sectors means that although Space attracts good graduates - the sectorstill has a glamorous image which helps draw in good people - retaining themfor longer than about three years proves difficult. Concern was also expressedabout the falling number and quality of students entering science in schools.

5.20 As in the Defence and Civil Aerospace sectors, the important part technology demonstrators play in maintaining the skills base was emphasised.

Market Opportunities

5.21 Civil space system applications will grow withthe replenishment of existing satellites and deployment of new systems innavigation, communications, earth observation and meteorology. The growingconvergence between military and civil space technologies may also presentfuture opportunities, and economic benefits would flow from closer coordinationof military and civil space programmes. As an example, the synthetic apertureradar imaging capability developed for earth observation satellites hasapplicability to military surveillance.

5.22 An important factor in the development of competitively priced space systems will be low cost launch capabilities, and UK industry feels the UK shouldstrongly support ESA studies into future launcher concepts. The Delphi surveygave the topic on low cost (implied Single Stage to Orbit - SSTO) launcher ahigh ranking for wealth creation. It was noted at the workshop that launch costsare currently dictating the pace of system deployment and scientificexperimentation, and the US is addressing what it sees as a large market for LowEarth Orbit (LEO) at half the current cost. But the workshop doubted that it wassensible for the U1(to try and enter this market given the lead held by others inEurope.

5.23 Satellites are set to continue as the main commercial base for the space industry, with growth in applications such as mobile communications, interactivemultimedia and global navigation, initially for air and marine, but eventually forautomobile location/tracking, perhaps as part of road pricing developments. TheUK space industry views participation in the next stage of the Europeantelecommunications technology R&D programme (ARTES Element 5) as ofparticular importance if UK industry is to gain entry to future commercialsatcomm programmes.

5.24 The UK has strengths in conducting the total system integration task for satellite systems, and has proved successful in the European market. Outside Europe, UKindustry tends to be seen as a component/sub-system supplier. The growingmarket in the Pacific Rim may offer opportunities for UK industry.

5.25 It is likely that future Earth Observation (EO) applications will have to support industrial and commercial interests in addition to meeting the needs of regionalenvironmental management, and there is a number of product developmentsnecessary to establish this market link eg remote sensing instruments and datahandling and distribution technologies. Provision of complete end-to-end spacesystems, including the ground-based element, is likely to be important inpenetrating world space markets.

5.26 Component technologies are fundamental to the successful development of new space systems, and the UK has achieved worldwide market success largely as aresult of earlier prudent government investment. Meeting the requirements of thenext generation of communications satellites will demand new semi-conductortechnologies to be developed. Funding of these expensive programmes and thedevelopment of strong partnerships between semiconductor supplier and systemuser will be key issues if the UK is to maintain its strong lead in this area andbenefit from the market growth represented by the next generation oftelecommunications payloads.

5.27 Space tethers, materials processing in space, space-based power generation and waste disposal were potential longer-term market possibilities raised at theworkshop. Space tourism, based on access to low cost spaceplane concepts such as'Spacecab', was the subject of an additional topic in the workshop 'mini-Delphi'.A large majority indicated that this development was unlikely to occur until after2015, and would require global collaboration.

Technologies

5.28 From syndicate groups at the Space workshop, and consultations with UKISC and space companies, the following technologies have been identified asimportant for future market success in the Space sector:

- Systems integration;
- Innovative manufacturing processes and techniques;
- Sensors: improved spectral response and spatial resolution;
- Data fusion;
- Digital signal processing for channelisation and beam forming;
- On-board digital data and image processing;
- Multiple beam and contoured spot beam antennas, both lightweightconventional antennas and phased arrays;
- Electric propulsion for geo-stationary satellites;
- More efficient forms of energy storage and power generation;
- Techniques to increase spacecraft autonomy, in order to reduce groundcontrol station manning, and for military surveillance;
- Active thermal management techniques;
- Focal plane techniques.

Many of these have been identified as key technologies by the Defence and CivilAerospace groups. The Panel's key technical priorities are discussed in Section 8.

Key Recommendations

5.29 Based on the limited work done so far, the Panel makes the followingrecommendations. The first three coincide with recommendations made for thesector as a whole. The last two will require specific action in the Space sectoritself.

5.29.1 Links between Industry and Academia. The links betweenAcademia, Government Research laboratories and Industry should bestrengthened. Better information on core competencies within researchgroups should be prepared and widely disseminated.

5.29.2 Industry/Government Long-term Strategy. An industry withlong time horizons and high risk requires a long-term technologystrategy between Industry and Government. The Space sector should beincluded in the Panel's recommendation for dialogue with Governmenton a National Strategy for Defence and Aerospace technologies.

5.29.3 European Collaboration. The UK Government should considerworking within European institutions to change the basis on whichbusiness is placed to one of capabilities and cost, rather than on'juste retour' principles.

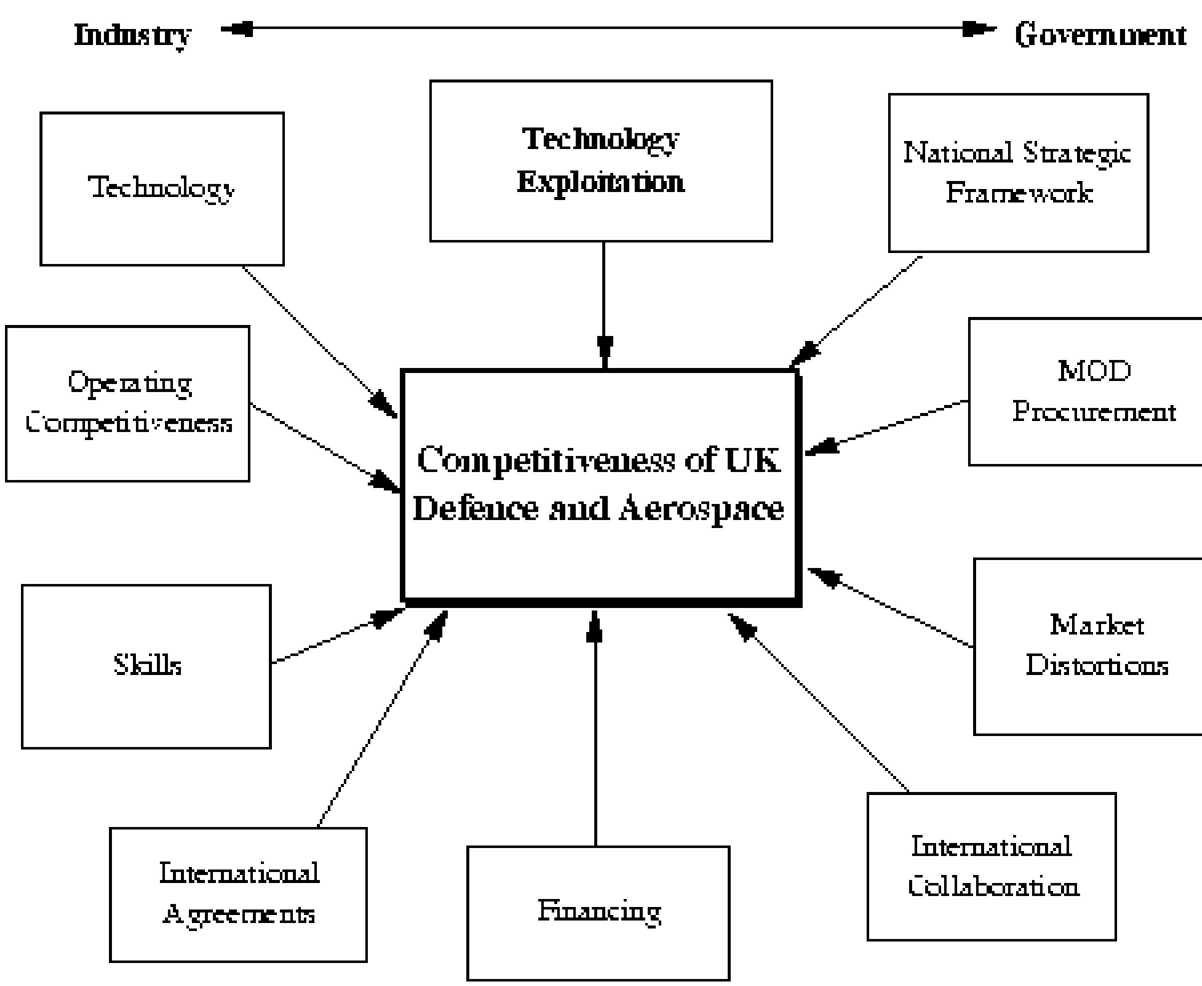
5.29.4 Funding. Consideration should be given to adjusting the balancebetween national and European funding for space activities.

5.29.5 Reforming Space Institutions. The UK should work towardsmaking ESA more efficient and to develop new mechanisms whichfocus more on competitiveness and market requirements. Considerationshould be given to creating a UK Space Agency with a dedicated Spacebudget.

6. BARRIERS TO PROGRESS

6.1 Defence and Aerospace is a sector in which science and technology is particularly important to competitiveness. However, success cannot be achieved throughtechnology alone. The Panel has identified a number of success factors (Figure6.1) which must be addressed if technological competitiveness is to flourish,based on a model developed by SBAC. Some of these factors are primarilyIndustry's responsibility, some are primarily for Government to address, and mostrequire effective partnership for success.

Figure 6.1 - Critical Success Factors



Using the above model, and based on the process of widespread consultationcarried out by the Panel, an analysis of the main barriers to progress hasbeen developed as set out below.

Technology and Technology Exploitation

6.2 UK Industry holds a lead in several key areas of technology such as large civilaircraft wings, aeroengines, fly-by-wire systems, STOVL combat aircraft,helicopter rotor blades, low level air defence systems and gun design. This successhas stemmed from past investment in research and technology demonstrationprogrammes, and future success is critically dependent on the continuing flow ofproduct and process technology. However, the Delphi responses highlight concernthat, whilst innovation is strong in the UK, there is considerable scope forimprovement of current mechanisms for the exploitation of new ideas developed atthe research stage. Linking the science base in a closer partnership with industryin market-led programmes is seen as a vital step in improving the technologyexploitation process, by providing a wealth creation focus for university-basedresearch. Historically, Higher Educational Institutions (HEIs) have been fundedmainly for basic discipline-based research rather than applied research, inhibiting more industrially oriented work technology transfer, mobility of industrial andacademic staff, and training.

6.3 The importance of these issues is such that the Panel has addressed it in a separate section of this report (Section 7), along with proposals for a new fundingmechanism for applied research.

Operating Competitiveness

6.4 Although the US Defence and Aerospace industry has scale advantages, UKindustry today is very competitive in operating performance (costs, quality, leadtimes), as regards both development and production. However, with the on-goingpressure on defence budgets and the strong pressure on civil aircraft prices, thebenefits of product developments will not be realised unless industry continues toimprove its operating performance in terms of costs, lead times, quality andflexibility. Furthermore, better margins are essential on existing products, ifindustry is going to reverse the serious decline in its R&D investment. It isessential therefore that efforts to improve competitiveness continue withincompanies and through industry-wide initiatives, including the science basewhere appropriate.

Skills

6.5 The Delphi survey highlighted only one area where Education/Skills was seen as being a significant constraint, this being the application of commercial business processes to defence procurement. An apparently contrasting result from the Delphi survey, however, showed that respondents believed technical feasibility is amajor constraint in realising many of the Defence and Aerospace topics.Furthermore, a recent DMA survey has highlighted the high rate at whichqualified scientists and engineers are being lost to the defence industry. It isunclear whether these apparent mismatches are due to a temporary surplus ofskills during a recession, a lack of recognition of the skills needed, or a lack ofhigh enough standards. But it is the panel's view, strongly supported by its wider consultations, that it actually underestimates the crucial role that educationand skills play in this sector.

6.6 There is a need for graduates with a broad view of design, manufacture andmanagement to contribute to the vital areas of Systems Integration, Design andBusiness Process re-engineering. This requires degree courses which encouragemulti- and inter-disciplinary activity.

6.7 Technology in the Defence and Aerospace sector is advancing at an everincreasing rate and maintaining up-to-date specialist knowledge will becomeincreasingly difficult. The funding initiatives described in Section 7 would assist inproviding support for centres of excellence in HEIs working closely with industry.This would help to encourage post-doctoral staff in universities to move toindustry, transferring up-to-date knowledge and skills, and so strengthening theindustrial base.

6.8 The pace of advancing knowledge means that continuing education will become essential. The provision and funding of short courses or 'modules' in the latesttechnology, specifically aimed at industry, should be given high priority.

International Agreements - Air Traffic Control

6.9 A specific barrier arises in the air traffic control field because of the lack ofinternational harmonisation in air traffic control. Improved interfacing betweenair and ground systems, and between different control centres, is needed ifairspace capacity is to be enhanced. The main barrier is not technological, but inthe building of an international consensus on the systems, standards, andprocedures to be used. In Europe, this consensus building will be informed byEuropean research and demonstration programmes in ATM. The UKGovernment must ensure it plays a leading role in these initiatives, if necessaryproviding additional funding.

6.10 The UK should take a pro-active role with its European partners, to drive forglobal harmonisation. This will not only benefit UK manufacturers of flightmanagement systems, communications, radar and satellite technology, but alsounderpin the expansion of the civil aerospace industry.

Financing

6.11 In the Delphi responses and at the regional workshops, funding was highlighted as the most serious constraint on the UK's ability to maximise the wealth creation potential of its Defence and Aerospace technology base. This is a key issue forboth Industry and Government to address.

6.12 Overall Trends

6.12.1 It is clear that UK Defence and Aerospace R&D expenditures have beenreducing significantly in recent years, as illustrated in Figure 6.2 below.

6.12.2 This trend is markedly different from the trend in overall UK civil R&Dexpenditure as shown in Figure 6.3. The figures below show expenditurein business on R&D, whether funded by government, other customers orintramurally.

6.12.3 This marked decline in UK Defence and Aerospace R&D is particularlyserious when it is seen that R&D trends in competitor countries do notshow comparable reductions. It is extremely important, both for nationalsecurity and for wealth creation in markets where the UK is strong, thatthe decline in UK Defence and Aerospace R&D is reversed. However,although the Panel believes that UK Government funding supportmechanisms need to be reviewed, the Panel considers that the initialimpetus to change the trends of recent years must come from UKIndustry - both in terms of developing strategies and proposals, and interms of allocation of human resources and funding. Unless Industry isprepared to lead, increased Government support cannot reasonably beexpected.

6.12.4 Industry's attitudes are also critical in terms of the partnership withacademia. Short-term financial pressures on companies often runcounter to the requirements of well-run research programmes to attractthe best people and to maintain consistent directions in research.

6.13 Civil Aerospace

6.13. 1 The 1980s saw startling growth in the turnover of the UK civil aerospacesector. This was the result of the successful coupling of CARADsupported research and demonstrator programmes during the 1970s,with well targeted launch aid support for projects such as the Airbusrange of aircraft and Rolls-Royce engines.

6.13.2 However, a key challenge for the future is the financing of R&D andmajor new programmes. UK companies perceive particular difficultiesin financing, for the following main reasons:

- the cost of sales price concessions to secure market access inthe current recession;
- the heavy costs of restructuring in recent years (a burden that hasbeen heavier in the UK than elsewhere in Europe, whererestructuring has either been deferred or has been supportedheavily by government);
- the reluctance of UK financial institutions to invest inrelatively long-term programmes;
- a lack of confidence by Industry in the Government policyframework surrounding the sector.

6.13.3 Aerospace companies worldwide have faced severe financial pressures inrecent years due to the simultaneous effects of unprecedented airlinelosses and a downward trend in defence programmes. Governments,recognising the financial market limitations but also the strategicimportance of aerospace, have assisted their industries' funding. Suchassistance generally takes two forms:

- **direct support** for near market developments, for exampleUK launch aid;
- **indirect support** for longer term research anddevelopmentcapability up to and including the technology demonstratorphase, for example the UK CARAD budget.

6.13.4 Though using both direct and indirect funding, European countries havetraditionally favoured direct support, in contrast to the US, which claimsto use only the indirect form. In reality, especially with "dual use"technologies, it is evident that some of the US support could becategorised under either heading.

6.13.5 Under the recent US/EU aerospace trade negotiations within the GATTframework a limitation of a third is now imposed on direct funding ofaerospace development. Such funding is to be in the form of loans,repayable via a levy on sales. This is providing additional stimulus forEuropean countries to switch emphasis from direct to indirect fundingmechanisms; Germany was recently reported to have allocated £492million in indirect support, and the French Government has justannounced R&D support of 85 million each for Aerospatiale andSnecma.

6.13.6 Over the last 10 years, CARAD funding in the UK has fallen steadily inreal terms from £40-45M per annum to around £20M, and is scheduledto continue falling for the next three years (Figure 6.4).

6.13.7 Over the next three years also, Launch Aid payments to the Governmentare likely to exceed disbursements (Figure 6.5) as levies from successfulaircraft programmes such as the Airbus A320 flow in. It is likely thatGovernment will eventually see a significant net income from projectswhose current success stems from prior investment in research andtechnology through programmes such as CARAD.

6.13.8 These UK trends are particularly disturbing when set against the levels of Government support now available in competitor countries (Table 6.1).

Table 6.1 - State Aids in (£M) for Civil Aeronautics Research and Technology Demonstration

UK	France	Germany	USA
(1995/96)	(1995)	(1995)	(1994)
20	103	123	646

Source: Analysis of Publications

6.13.9 Against the above background, it is the strong view of the Panel that UKIndustry's level of investment in R&D and UK Government fundingsupport for Civil Aerospace technology development must be reassessedif UK industry is to be competitive. This is essential if Industry is tocontinue to deliver the same level of contribution to the UK balance oftrade and wealth creation as it has achieved over the past decade.

6.14 Defence

6.14.1 In the UK Defence sector, where expenditure by UK MOD is verysignificant, there has also been a pronounced decline (Figure 6.6).

6.14.3 Again, it is disturbing that the decline in the UK is in marked contrast to trends in our main competitor countries (Table 6.2).

	UK	France	Germany	USA
Change from 1985 to 1992	-25%	+36%	+24%	+7%

Source: Analysis of information from Forward Look 1994, Table 1.6.6

6.14.3 Continuation of the significant reductions in the UK Government spend onDefence R&D, and the decline of UK Industry R&D investment,especially when compared with R&D investment levels in othercompetitor countries, will undermine the UK defence and aerospacetechnology base and international competitiveness. This view wasstrongly supported by the Delphi respondents and workshops. Recentcuts in R&D budgets arising from the 1994 Defence Costs Studyrepresent another step in a process which is likely to result in MOD'sR&D spend halving during the 1990s.

6.14.4 Reductions in research volume will limit the range of technologiesavailable in the UK This, in turn, is likely to threaten our ability toaddress complex, large scale system integration problems, and toexercise prime contractor functions, and could well lead to an eventualincrease in off-the-shelf purchases from abroad.

6.14.5 A further serious issue is that the planned large reduction in the UKDefence research spend is not matched by a reduction in the range orcomplexity of systems procured. Furthermore, there is likely to be asignificant reduction in the numbers procured of each type, which willlimit Industry's ability to sustain its funding at the level necessary. Thiswill be exacerbated by the difficulty faced by most companies ininvesting significant sums of money far ahead of defence procurementprogrammes which cannot be relied on to happen. The focus of financialmarkets on short-term financial returns reinforces this difficulty.

6.14.6 These financing issues, which should also include consideration of howEuropean collaboration can be used to ease the burdens, should beaddressed as part of the defence technology strategy work proposed bythe Panel.

International Collaboration

6.15 UK Defence and Aerospace markets and industries are too small to support the development of major new platforms or the maintenance of a completetechnology base, particularly in view of the need to compete with the much largerUS defence industry. The UK is not unique in this respect and it is clear that noEuropean country on its own can compete successfully with the US. There istherefore a pressing requirement to make progress towards collaboration, atplatform level, on a much wider range of European programmes. This should notpreclude co-operation with the US where this makes sense, as has been the caseon some platform programmes (eg Harrier/AV-8B and Hawk/T45) and is wellestablished on a two-way basis in the equipment sector. A trend towards moreinternational collaboration requires Government and industry to work veryclosely together on appropriate strategies, and, in the Defence field specifically, itrequires Governments to identify a much wider range of common Europeandefence equipment requirements.

6.16 A major barrier to increasing such collaboration is the need for efficientcollaboration structures. Although Airbus is proving its internationalcompetitiveness, collaborative defence programmes which have been establishedon the 'juste retour' principle have often suffered from inefficient managementstructures and sourcing policies. This has prevented the UK from exploiting itstechnology lead and operating competitiveness. Indeed, the opposite has occurred,with the UK companies forced to share their technologies with others, andprogrammes costs forced upwards. New procurement policies, with businessplaced with consortia on the basis of capabilities and cost, rather than on 'justeretour' principles, are essential to remove this competitive disadvantage. Therecent decision to develop the FLA under the Airbus organisation provides arelevant model.

6.17 The encouragement by Government of increased collaboration in Europe, on a basis which gives the UK industry the best competitive position, is essential if ourtechnological capital is to yield the best returns. This encouragement must includeestablishment of new arrangements with other European nations, andconsultation with UK companies on how they should respond to the newopportunities.

6.18 However, whilst Government policies and initiatives are important in this area, a major part of the responsibility for moves towards increased Europeancollaboration, particularly at the platform level, rests with Industry. Industrymust adapt its strategies to the realities of the market, and must rationalise, restructure,and form consortia where necessary, on a European basis.

Market Distortions

6.19 The return from technology is affected significantly by the economic/business environment. The UK technology base has benefited from some UKGovernment policies, eg an open and competitive market, support from MODfor the defence science base, and CARAD and launch aid from DTI. However,the UK is also seriously disadvantaged against international competition by marketdistortions in other respects:

- given the stated aim of the US Government to sustain long-term globaldominance in defence technology and in civil aerospace, and the similarobjective of the French Government to achieve leadership in Europe in thedefence and aerospace field, the lack of a clear UK national technologystrategy is a major concern;
- there are important differences between UK government procurementpolicies and those of other countries; these include:

  unlike its counterparts in US or France, UK MOD does not have aclear duty to foster the strength and competitiveness of the nation'sdefence industry;

  the UK's past lack of emphasis on securing high technologytransfer and maximum leverage from 'offsets', as compared topolicies in other countries;

  lack of genuine reciprocal access to defence markets, despite theopenness of the UK defence market to foreign bidders;

  UK MOD's low level of support for development of improvedbusiness and manufacturing processes;

  markedly lower levels of support for 'capability building'technology demonstrator projects (this is caused, in some cases,by Industry's inability to fund its share of such projects);

- less favourable UK Government support for Civil Aerospace, whencompared to our main competitors, as regards:

  Launch Aid terms;

  support for R&T and other indirect supports (addressed in moredetail in the Financing section).

It is important that these issues are addressed if the UK is to gain thefullest benefit from its technology.

MOD Procurement

6.20 In procuring defence equipment, the formal responsibility of MOD is to ensure that it obtains maximum defence capability from the funds available. From thePanel's consultations, it is clear there is a widespread view that the single-mindedpursuit of value-for-money through competition has prevented adequate attentionbeing given to the health of the defence industrial base. MOD has had no formalresponsibility to consider the competitiveness of the supply base or wealth creationissues. It is recognised that MOD does purchase around 90% of its equipmentfrom UK industry (US and France procure over 99 per cent of their equipmentfrom home-based companies), and that MOD does contribute significantly to themaintenance of the technology base and to technology transfer (through itsequipment programme, through the intramural research at DRA, and throughextramural research in Industry and Academia which MOD supports). However,there is a feeling that off-the-shelf purchases from abroad are increasing and a viewthat the technology in DRA is not being exploited for wealth creation as fully aspossible.

6.21 Defence Industry competitiveness and wealth creation are the responsibility of the DTI. However, without full MOD involvement and compatible end-objectives,this responsibility cannot be discharged effectively.

6.22 Although there are some areas where the lack of UK developed products prevents UK firms from competing, UK Industry is generally reasonably well placed tocompete for UK procurement and in the export market as a result of investmentin R&D over the last twenty years. In cases where there is no UK productavailable, overseas procurement "off the shelf' is an obvious option when foreignproducts are readily available to meet MOD requirements. There is concern thatcontinued budgetary pressures on MOD, coupled with the narrow responsibilitydescribed above, may lead to a further increase in off-the-shelf procurement fromabroad. As overseas suppliers will not always be able to meet UK requirementsbecause of technology export constraints, off-the-shelf procurement is not asustainable general policy in the medium or long term. Nor is it a policy which isbest for UK wealth creation, as it will inevitably lead to an erosion of both thetechnological capability and strength of the UK industrial base.

6.23 There is often a difference in requirements and hence equipment perfommance between the UK and export markets, leading to products developed for home use that are not best suited to export. Equally, there is a difficulty in selling equipment which is not used by the UK armed forces. Some competitors, eg France, appear willing to deploy small numbers of "export standard" systems in order toovercome this. Others adopt a policy of developing exportable derivatives of inservice equipment, or subsidise sales of export-only equipment, although neitherapproach is viable when the basic platform is signature-managed. The issue ofhow to facilitate UK defence exports, where the UK armed forces have eithermarkedly different needs or no significant requirement, should be addressed inthe interests of exports and wealth creation.

6.24 Overall, there is concern that a combination of the current and projecteddramatic decline in UK Defence R&D (both in Industry and MOD), the longerperiods between major projects, and an off-the-shelf policy, will reduce UKcompetitiveness and cause the national capability to decline.

6.25 In periods of relative peace, the tempo at which armed forces can procure or absorb new equipment (and with it doctrine, tactics, logistic support, training andorganisation) does not align with Industry's need to design, manufacture andsupport such equipment on a relatively continuous basis in order to maintain acompetitive capability. (In periods of tension, the two may align much moreclosely.) Unless the UK procurement tempo is consistent with Industry's needs,Industry's capability and viability will be threatened. The solution lies in moretechnology demonstrator programmes, more evolutionary acquisition, moremodular systems, and, possibly, the adoption of a process of staged 'technologyinsertion' through which platforms' electronics are updated to remain state-ofthe-art.

6.26 Similarly, UK Defence procurement strategies and processes must align with the rapid evolution of technologies, such as IT. This will avoid the danger ofequipment which is obsolete by the time it enters service.

6.27 The above barriers to the successful exploitation of UK defence technology need to be eliminated if the current and potential UK capability in Defence technologyis to be exploited to create wealth and quality of life for the nation. In saying that,the Panel recognises fully the support given to Industry by MOD andacknowledges that many of the above issues are currently recognised, and arebeing addressed, by MOD.

National Strategy for Technology

6.28 The UK Defence and Aerospace technology base needs the highest possible level of partnership between Government (MOD, DTI and OST), Industry andAcademia. This is essential if the UK is to meet the challenge of the much largerand massively restructured US defence industry, and to counteract competitionfrom countries such as France and Germany where government and industryactivities are more closely integrated. Discussions in the Panel and at theworkshops indicated areas where the level of co-ordination in the UK Defenceand Aerospace sector could be improved significantly, especially between majorcompanies, between these companies and their suppliers, and between theGovernment sector (particularly MOD, DRA, DTI and EPSRC), Industry andAcademia.

6.29 There is a widely held view that this lack of coordination stems from the absence of an overall strategic framework which could help Industry and the variousGovernment Departments involved have a common view of objectives, and of themajor strategic and policy issues governing the technological competitiveness ofthe UK Defence and Aerospace sector.

6.30 Despite various initiatives (eg NSTAP, and various MOD studies) there has been no coherent national framework for the identification, prioritisation andacquisition of technology. Indeed, some people are concerned that Foresight willmerely add confusion to the current situation. The Panel views the majorlimitations of previous initiatives as being the absence of shared goals, thecompartmentalisation of defence and civil research/technology requirements, andthe lack of mechanisms for prioritising and acquiring those technologies whichwill have the greatest impact on satisfying defence and aerospace requirementsand promoting wealth creation.

6.31 The Panel feels strongly that a national strategic framework for UK Defence and Aerospace technology should be developed. This must involve all relevant parties,in Industry and Government, reaching agreement on common long-termobjectives, agreeing the means to achieve them, and putting in place the necessaryresources.

7. PROGRESS THROUGH PARTNERSHIP

Improving the Technology Exploitation Process
The Technology Exploitation Process in Defence andAerospace

7.1 A key factor in the competitiveness of industry is a responsive and effectivetechnology exploitation process. In the Defence and Aerospace sector, UKindustry, informed by a broad view of market requirements and technologicalpossibilities, has achieved a strong market position. This has provided significant economic benefit to the UK by systematic and sustained exploitation oftechnology acquired from a variety of sources, the principal one being nationalresearch and technology demonstration programmes supported by industry andgovernment. Figure 7.1 gives examples of successful projects that have resultedfrom a process of applied research followed by technology demonstration, andwhich are now making major contributions to UK wealth creation. However,making technology exploitation even more effective is essential if best use is tobe made of available people and financial resources, including scientists andengineers in universities.

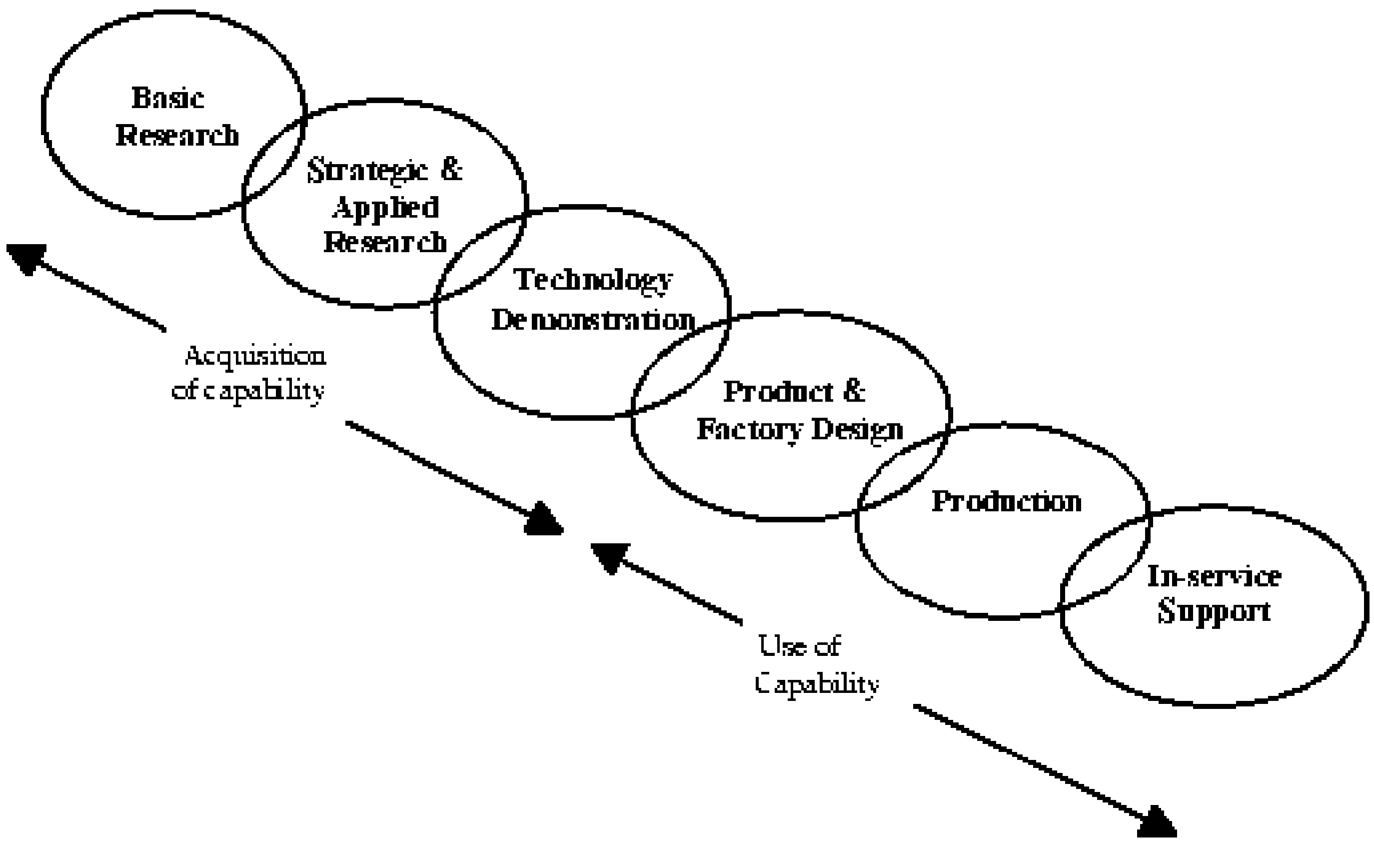
7.2 The technology exploitation process (Figure 7.2) has several elements. Capability is acquired through basic research, strategic and applied research, and technology demonstration. The capability is then deployed during the 'development' phase (encompassing: product definition, ie design and validation of the product, itsmanufacturing processes and production facilities), production and in-serviceoperation. It is important that this process provides technologies not only for theproduct and its manufacturing processing, but also for the design process and theproduction facilities. Furthermore, the production facilities design must beaddressed during the product definition stage in order to meet design-to-cost andlead time targets.

Figure 7.1 - Current Success from Past Research and Technology Demonstration

- Advances in transonic computational methods, developed in partnershipbetween the Royal Aircraft Establishment (now DRA) and industry, andthe UK High Lift Programme, were the foundations for the world-leadingAirbus wings;
- The EAP aircraft and XG40 engine demonstrator programmes wereessential precursors for the Eurofighter and EJ200 and which used theresults of applied research conducted by the RAE in the 1960s and1970s;
- The BERP Tip and Aerofoil Section Programme, which began as aresearch collaboration between the RAE and Westlands, has helpedWestland gain a worldwide capability in helicopter rotors now beingused on the EH 101 and on upgrades of the Lynx;
- The wide chord fan and instalied noise programmes form the basis of theRolls-Royce family of engines, and used advances in aerodynamics fromresearch in the late 1960s. The initial application was ten years ahead ofthat of its competitors;
- The composite nacelles developed by Shorts in conjunction with Rolls-Royce and supported by DTI are now installed on a wide range ofengines;
- The UK has established a world lead in IR imagers throughcollaborative work between the DRA and industry.

- The Condor high performance diesel engine, developed between DRAChertsey and Rolls-Royce, fielded in Warrior and Challenger, and selectedfor the US Army AFAS self-propelled gun programme.
- A family of weapon sights embodying Image Intensification (11)technology was originally developed by RSRE Malvern in conjunctionwith GEC Marconi. These sights are now fielded in a range of small armsapplications.

Figure 7.2 - Links in the Technology Exploitation Process



7.3 The costs associated with the acquisition of capability (Links 1-3 in the chain) are much lower - typically 10% to 20% of the costs of using the capability in productdevelopment (Figure 7.3); yet this investment has an enormous gearing on thecosts and risks of product development, production and in-service support. Also,the inherent competitiveness of the product is strongly influenced at this stage andhence its subsequent success in securing a significant share of the world market.

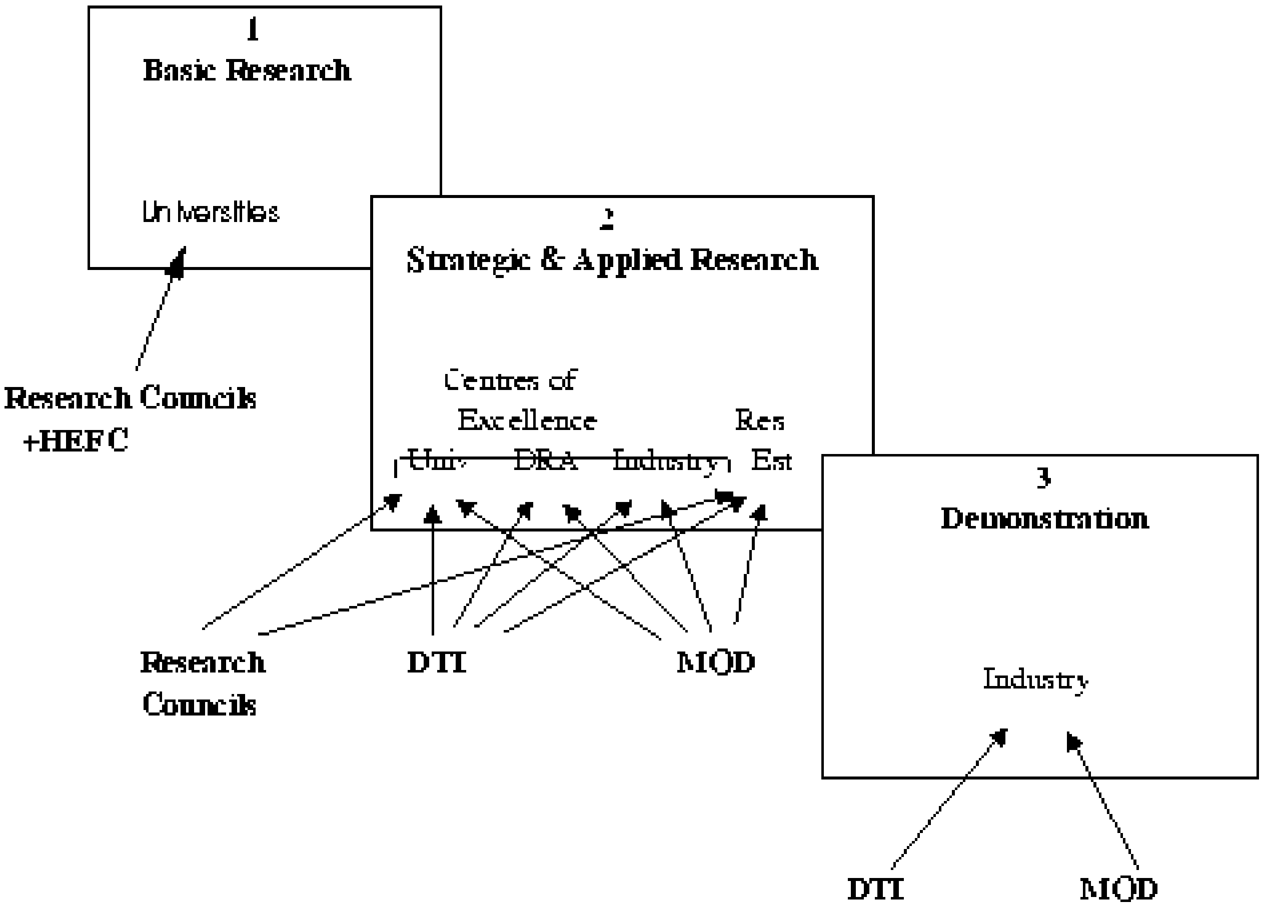
7.4 Recent military aero engine demonstrator projects have yielded savings of almost 50% relative to prior generation programmes. This, together with similarexperience on civil programmes, has enabled analysis of potential future savings tobe carried out. From this base, it is considered that an integrated approach totechnology demonstration programmes which involves product and processtechnologies could yield further cost and timescale savings. For example, a furtherreduction of 30% on civil and 60% on military aeroengine development costs areconsidered achievable, combined with shortened timescale from programmelaunch to operational service of 3'/2 years and 5 years for civil and militaryaeroengines respectively. It is considered that the same approach will produce costand timescale savings in other Defence and Aerospace product developmentprogrammes. It is therefore in the area of capability acquisition that government,industry and academia must work closely together in an integrated way tomaximise the benefits to be obtained from properly focused investment inresearch and technology demonstration.

Problems with the Current Operation of the Exploitation Process

7.5 Informed by its wide consultations, the Panel has identified the following factors that are hindering the effectiveness of the technology exploitation process:

- Much applied research conducted in universities funded by governmenthas no direct industry participation and therefore lacks market focus;
- Changing commercial priorities and lack of clear technology strategies incompanies hinders the support for, and exploitation of, academic workneeded to expand the number of world-class teams working in UK'centres of excellence';
- Co-ordination within and between Government Departments needsimproving to focus better their research investments (Figure 7.4); andthere are too many small funding schemes which lead to highadministrative overheads;
- Research and funding has been oriented towards product technologieswithout giving enough priority to technologies involved with design of theproduct, its manufacturing processes and its production system;
- There is an imbalance of government funds allocated to pure and appliedresearch and technology demonstration; the latter receives a completelyinadequate level of government support;
- Lower-tier suppliers are rarely involved in the demonstrator programmes of their prime contractors

Figure 7.4 - Some Government Funding Sources for Capablity Acquisition



Improving the Technology Exploitation Process

7.6 Investment in capability must be balanced between Basic Research, AppliedResearch and Technology Demonstration, with UK industry and governmentproviding guidance and making appropriate financial contributions to ensure thatmarket focus and prioritisation takes place.

7.7 University Basic Research

7.7.1 Basic, or 'curiosity-driven' research in universities should be of highquality, funded directly by the Research Councils and Higher EducationFunding Councils (HEFC) broadly along present lines, using Foresightpriorities to reflect the needs of the UK economy.

7.8 Customer-linked University Applied Research

7.8.1 The Defence and Aerospace sector must cover a considerable number oftechnologies if competitive systems are to be produced. Wealth creationdoes not therefore depend just on boosting research in a few key areas,but on having a better focus and exploitation of applied research across abroad range of technologies.

7.8.2 The panel has identified the key technology areas for future investment.However, the process for prioritising these technologies beyond the leveloutlined in this report, must be determined primarily by the customer(MoD and Industry) against their specific needs, be responsive to marketpressures and take into account the extent to which UK industry can andshould access technology from overseas sources (eg EC programmes).

7.8.3 The future demand for technology, in product and process, requiresindustry, government research establishments and universities to workmuch more closely and extensively together in high quality, customerled applied research programmes. There are several examples ofsuccessful bi-lateral arrangements between companies and universities inthis sector, eg Rolls-Royce's University Technology Centres (UTC),but the Panel believes that more must be done to expand and extend thistype of key partnership. To ensure that university applied research isbetter targeted at industry's requirements and that industry has thecommitment to exploit the technology, this category of work shouldprimarily be co-funded by the Research Council(s) and the customer.

7.8.4 To create much greater partnership and joint commitment betweenindustry, universities, Research Councils and MOD, two co-funded'LINK'-type schemes are proposed involving these groups with DTIsupport. The first scheme applies to the Defence sector and has theobjective of encouraging truly 'Dual-Use' technology programmeswhich maximise the value of the defence research funds. The secondapplies to the Civil Aerospace sector. These two schemes should bemanaged through a single management body comprising the ResearchCouncils, MoD/DRA, DTI and Industry.

Please note that the funding numbers shown below are ILLUSTRATIVE at this stage

7.8.5 Dual-Use Technologies. This new scheme would subsume theexisting Joint Grants Schemes (JGS) to which MoD and the ResearchCouncils at present each contribute £5M per annum. This would beaugmented by the allocation of an additional £3M from existingResearch Councils budgets, and a further £3M from the existing MoDfunds, which may be spent in industry or academia. The balance wouldcome from Industry and the DTI innovation budget to give a totalexpenditure of £24M per annum. The suggested funding split is asfollows (current funding in brackets):

FUNDING BODY, &M per annum

	Industry/DTI	MoD	RCs	Total
Dual-Use Technologies	8(0)	8(5)	8(5)	24(10)

In order to encourage frequent and productive interaction betweenindustry and academia, it is proposed that up to 50% of the funds fromindustry may support applied research carried out in industry, in whichcase these costs should be eligible for 50% support under the DTIinnovation budget. The maximum uptake of this budget would thereforebe £2M. Most of the remaining funding (£20M per annum) wouldsupport applied research in universities and/or Research Council groups.MoD might wish to increase its overall contribution to this newprogramme still further in due course because of the benefit of havingindustry participation. MoD/DRA has already announced that theyintend to launch an academic Pathfinder scheme along these lines. Whereappropriate, there could be a DRA partner (whose costs are not includedabove) who would provide a long term perspective.

7.8.6 Civil Aerospace. This scheme follows the same principles as theDual Use scheme and should be funded by the Research Councils andIndustry supported by DTI. Currently much industry funding ofuniversity research in this area (about £10M per annum) has noassociated direct government support. It is difficult to assess the currenttotal Research Council contribution to this sector because researchrelevant to aerospace is funded through a variety of panels. It isproposed that the Research Councils' expenditure on aerospace should becoordinated and that Research Councils should earmark £20M for CivilAerospace to be matched by an equivalent contribution by Industry/DTI. The suggested funding split is as follows (current funding, whereknown, in brackets):

FUNDING BODY, £M per annum

	Industry/DTI	RCs	Total
Civil Aerospace	20(10)	20	40

As in the previous scheme 50% of the funds from industry may supportwork carried out in industry and be eligible for 50% DTI support underthe CARAD budget. The maximum DTI contribution would thereforebe £5M. The remaining funding (£30M per annum) would supportapplied research in universities.

7.8.7 A major aim of these two schemes is to strengthen links between UKindustry, the DRA and academia. The significant funding input fromindustry and MoD will ensure market relevance and seriouscommitment to exploit the results.

7.8.8 University research would normally be conducted in university 'Centresof Excellence', which would focus on specific areas of technology.However, this should not exclude some work being carried out in otheruniversities where they have the requisite skills or capabilities. Jointprogrammes may also be carried out by industry, academia and DRA inthe Dual-Use Technologies Centres (DUTC) which are beingestablished by DRA (see Figure 7.5), to gain maximum benefits fromsharing facilities, knowledge and staff; or by industry-led dual-useinitiatives such as the Smart Structures programme (Figure 7.6), whichcreate joint teams of industry, government and university research staffin cross-sectoral co-development programmes. Teaming betweenuniversities should also be encouraged.

7.8.9 Industry and/or MoD would develop the project proposal jointly withthe university and/or Research Council group that would undertakemost of the work. The projects would be judged equally for scientificquality and value to Industry/MoD. A target should be set for amaximum period of six months between project submissions and releaseof funds.

Figure 7.5 - DRA Dual-Use Technology Centres

Dual Use Technology Centres (DUTC) are intended to facilitate the exploitationof defence-driven research for civil and commercial purposes and thus for thebenefit of the nation. Many of the enabling technologies that are important todefence, such as materials, software, communications, information processingand electronics are equally important to the successful development of civilproducts. Quite often, although the basic technology is similar, the regime inwhich they are used is different. The concept of DUTCs is that the research inthe DRA should recognise the potential for dual use from the outset, and allowindustrial, academic or other government departments with similar technologyneeds but different market requirements to join in as partners. Currently, MOD'sfunding can only be applied to meet defence objectives but, given the similarityin the basic technology, contributions from industrial and other partners canprovide significant leverage, to the benefit of all concerned. All DUTCs have thesame aim of enabling industry to exploit the facilities, technology, knowledgeand teams which exist for defence research. The armed forces benefit from suchcollaboration through cheaper and better equipment. The whole nation benefitsthrough the manufacture and sale of new products and services.

The Structural Materials Centre (SMC), formally launched in April 1994, is themost advanced of the DUTCs currently under development. Structural materialsare generally recognised as key technologies in a number of industrial sectors,including defence, transportation, energy and construction. The SMC is one ofthe largest structural materials research groups in Europe. Examples of thematerials involved are high temperature, high performance metals used in defenceand civil aeroengines, and corrosion-resistant, lightweight composites used onnaval platforms, which have uses in the offshore oil industry. A current SMCproject involves collaboration between DRA, Roils-Royce and SNECMAresearching high quality monofilaments suitable for manufacturing highstrength/ high temperature titanium metal matrix composites. These advancedmaterials will contribute to improved engine performance by reducing weight andhence fuel burn. These are crucial developments for future military and civilaeroengines.

Supercomputing is another key area with dual use potential. Many defenceapplications require the use of high performance computational techniques, butfew organisations can afford this technology individually and hence it is anatural area for national collaboration within a Dual Use Technology Centre. TheFarnborough Supercomputing Centre was opened in early 1995, its membersbeing BAe, Cray Computers, DRA and GEC Marconi. Supercomputers provide themeans to investigate previously intractable problems, thereby stimulating newideas and encouraging scientific advances. As well as defence applications,several commercial areas will benefit from access to super-computing facilities, including: the aerospace and automotive sectors for CFD, design and impactanalysis; the pharmaceutical and chemical industry in looking at molecularmodelling and drug design; and the oil industry in studying seismic modelling.The Farnborough Supercomputing Centre will help maintain UK competitivenessby enabling access to supercomputing facilities similar to those of our majorcompetitors in the US and Japan.

The **Marine Technology Centre (MTC)** aims to offer partners a range offacilities, test equipment and scientific knowledge built up by the DRA to meetdefence needs but which are available to meet civil requirements.

A **Software Engineering Centre (SEC)** has been established at DRA Malvern withthe aim of eventually forming a DUTC in software engineering.

DUTCs in **Information Technology, Electronics** and **Robotics** are also being developed or considered.

Figure 7.6 - The Smart Structures Dual - Use Pilot Programme

A further new development in the inexorable drive for technology advancement in Defence and Aerospace is a proposed dual-use pilot programme in Smart Structures. This programme will involve multi-skilled teams, using 'best-in-class' competencies and amenities, to generate genuine wealth creating opportunities and tangiblebusiness benefits across a number of industrial sectors.

The programme will adopt a seamless approach to integrating and migrating all stages of technology research and technology demonstration, aided by partnerships between industry, government, academia, supply chain companies and research institutions.

The focus for the smart structures work will be the proposed **National Smart Structures Demonstrator Facility** at DRA Farnborough. This will provide the physical entity for combining the component-level technologies needed for generic demonstrations of overall system capability.

The term 'smart structures' refers to sensors, electronics and actuators physically embedded in the structural material. These embedded components can be used to monitor the structural health of the material or change its physical shape, with consequent reductions in support costs and improvements in performance.

The associated technologies are at various stages of development. For example, the sensor systems required for periodic and/or continuous integrity monitoring (while they are embedded in carbon fibre composite material) are not yet mature enough for product implementation. Basic research, twinning the expertise in HEIs with the overall objectives set by industry, is needed to address this fundamental requirement. At the other end of the scale, some existing technologies and processes required by the integrated demonstrator are already available. Fibre optics, data fusion systems, manufacturing techniques and material technologies are sufficiently advanced for early adoption. Such work will result in industry and it s suppliers, academe and customers combining to bring the work closer to spin-off into multi-sectoral products. In between lie areas of varying advancement. For example, the embedded sensor system will change the properties of the composite material. Applied research with industry-industry collaboration and assistance from academic partners will be required to analyse and understand the implications of these changes.

The process can be illustrated as follows:

BASIC RESEARCH ...	APPLIED RESEARCH ...	TECHNOLOGY DEMONSTRATOR
Academe/Industry Teaming	Industry/Industry & Academe Teaming	Industry/Academe/Supply Chain & Customer
Embedded damage monitoring sensor system	Embedded sensors change the material characteristics	Consolidation of component level technologies and processes

There are barriers still to be overcome before the programme can get underway in earnest. IPR, the management problems associated with large consortia, funding and workshare, entry and exit mechanisms, academic participation and the role of SMEs are just some of the issues currently being addressed. Undoubtedly others will arise, but in many ways, the value of this programme and others like it lies as much in facing and dealing with these issues as in the problems of the technology itself.

7.9 Industrial Applied Research

7.9.1 As discussed in Section 6, DTI CARAD funding in the UK has fallensteadily in real terms over the last 10 years from £40-50M per annumto around £20M. Currently, only about £10M from the CARAD budgetis available for industrial applied research. The Panel believes that thismust be increased over the next two years to £25M, a figure whichIndustry would have to match.

7.9.2 The DTI contribution to industrial applied research should be set at 50%,irrespective of whether the proposal is from a single company or groupof companies, so as not to prejudice those companies with uniquecapabilities. However, wherever collaboration is practical this should bea requirement.

7.10 Exploitation of Government Supported Research

7.10.1 Government-supported research takes place in universities, Governmentresearch establishments (notably the DRA) and industry across allindustrial sectors. In the Defence and Aerospace sector, the technologyhas wider applicability across UK industry, particularly technologiesassociated with business process improvements. The Panel's review ofthe findings from related sectors within the Foresight process (Annex F)has clearly demonstrated scope for cross-sectoral initiatives. It wouldtherefore be appropriate for common technologies to be developedjointly, with other sectors where appropriate, to maximise the value ofthe investment in technology. Access to both the Dual-Use and CivilAerospace university research programmes should therefore be open tocompanies outside the Defence and Aerospace sector, who would teamwith Defence and Aerospace companies on the same funding basis.Equally, Defence and Aerospace sector companies should have access toschemes in other sectors, particularly the DTI Innovation budget.

7.10.2 The Defence and Aerospace sector conducts a significant proportion ofGovernment-funded research (around 20% in 1992/93 (10), although thisfigure has fallen consistently - see Section 6), much of this work takingplace within the DRA and the other MOD establishments. From April1995 these establishments are being combined with DRA to form theDefence Evaluation and Research Agency (DERA). It is clearly veryimportant to wealth creation that industry gains maximum benefit from this government-funded research.

7.10.3 Over recent decades, there has in the main been a close relationship andsuccessful technology transfer between the relevant Government ResearchEstablishments (such as RAE, RARDE, RSRE and ARE) and the majorUK defence companies, without prejudicing the MOD researchestablishments' ability to provide commercially neutral advice to MOD.At the same time they have been very important in pioneering much ofthe technology and equipment that industry has developed. Figure 7.1clearly illustrates this key role.

7.10.4 This good relationship was seriously upset when the decision was takenin 1989 to convert RAE, RARDE, RSRE and ARE into the DefenceResearch Agency, subjecting them to competition against industry.The teams that had worked together as partners suddenly becamecompetitors.

7.10.5 These problems have been addressed in the last two years. DRA hasestablished strategic alignments with most major UK companies inDefence and Aerospace and increasingly there is a very open exchange ofresearch and joint projects, whilst the DUTCs facilitate jointindustry DRA-academic research programmes. The Pathfinder scheme wasintroduced in 1992 by DRA as another way for companies to proposeprojects that meet their product needs and also meet MOD's defenceresearch requirements.

7.10.6 These are all valuable initiatives and need to be developed vigorously.DRA also needs to ensure that it places work with industry whereverappropriate. Competition should be avoided where it disruptscollaboration, or inhibits the transfer of technology or work with wealthcreating potential from DRA into industry.

7.11 Technology Demonstrators

7.11.1 Technology demonstration is an essential activity which enhancesindustrial capability prior to the launch of complex high technologyproducts. The size and nature of the demonstrator projects will varysignificantly in the different sectors of Defence and Aerospace, but theseprogrammes are particularly important at the present time due to thelengthening gaps between major new programmes. Technologydemonstrator projects must focus on all elements of capabilityacquisition, including process, thereby ensuring that UK industry will bewell placed to compete effectively in world markets as well as providevalue for money to the MoD as a major customer for Defenceequipment. Furthermore, the levels of downstream project expenditurewill reduce as a direct consequence.

7.11.2 The Panel considers that a substantial increase in TechnologyDemonstrator programmes is essential and that these should be morebroadly based, with strong involvement of all those in the supplychain in the development of integrated systems. This requires nationallevel initiatives to optimise wealth creation throughout the industryand, through the demonstrator programmes, to forge strong networksbetween UK companies.

7.11.3 The programme should be managed by industry and, where appropriate,involve the suppliers to that industrial sector. Overseas partners andsuppliers should be allowed to participate provided they secure their ownfunds. The criteria for selecting the projects should be based on the likelyreturn on investment and the capability of the industrial team to exploitthe technology in the market place on completion of the programme.

7.11.4 Taking into account what is happening in the US, France and Germany,and the broad estimates made at the time the original NSTAP report wasprepared, the panel assesses that DTI's budget for technologydemonstration in the Civil Aerospace sector must be increased to about£30M per annum immediately, rising to about £65M per annum,progressively over the next three years. Demonstration of processtechniques should be included and integrated with programmes whichcover the more traditional product related work Industry would beexpected to provide comparable levels of funding for these programmes.

7.11.5 The value of technology demonstrator projects has long been recognisedby the Ministry of Defence. However, expenditure on technologydemonstrators by MOD has reduced significantly in recent years (due notleast to industry's inability to fund its share of such projects) and theallocation of resources to this activity appears to be out of balance withother defence technology investments. Furthermore, the expectation thatindustry will contribute 50% of the funds is unrealistic for thoseDefence-specific projects where the opportunities for commercialexploitation are low or long-term. However, if enhancements toprocess related, as well as traditional product-related, activities wereadmissible in programmes, a higher industrial-contribution would belikely in such cases, with resultant benefits to both MoD and Industry.

Summary of Recommendations

7.12 In the increasingly competitive global Defence and Aerospace market, the UK will have to improve its capacity to exploit promising scientific and technologicalinnovations. Although the Panel has strongly recommended that R&Dinvestment by Industry and Government should be increased to match that of ourmajor competitors, the Panel recognises that it is equally important to ensure thatwhatever funding is available is directed in the most effective way possible.

7.13 The Panel has focused on two key links in the exploitation process: AppliedResearch, where technologies giving a market edge are often created; andTechnology Demonstration, where the potential of these new ideas is subjected torigorous evaluation in representative service conditions, and risk associated withnew concepts is reduced.

7.14 In the Applied Research area, the panel believes that a much stronger partnership between industry, universities, Research Councils and MOD is essential if thebest use is to be made of the available resources. To this end, the Panel hasproposed two new university-linked applied research schemes, covering DualUse Technologies and Civil Aerospace, and has recommended funding levels foreach. The significant industrial contribution to these two schemes (£21M perannum) will ensure market relevance and a commitment to exploit the results.The Panel also recommends that DTI significantly increases the level of fundingfor industrial applied research in Civil Aerospace through the CARAD scheme,where currently UK Government investment is well behind that of our majorcompetitors.

7.15 In these schemes, the Research Councils and MoD are required to allocate £28M and £8M respectively to university-linked research from existing budgets. DTI isrequired to allocate £2M from the Innovation budget and to increase the CARADbudget for Applied Research in industry to £25M. The level of industrial supportto its own research will remain at similar levels to today, whilst its contribution touniversity research will increase by £4M.

7.16 Finally, the panel recommends that Technology Demonstration activity should increase significantly. The Civil Aerospace sector, where there is littleGovernment funding currently available, should receive a particular boost. ThePanel proposes that DTI funding be increased to £30M per annum immediately,rising to £65M per annum progressively over the next three years. Industry wouldbe expected to provide a comparable level of funding. In Defence, considerationshould be given to expanding the scope of MoD-funded technologydemonstration programmes to include process as well as product technologies.Industry would then be more willing to fund a greater share of such programmes.

7.17 The DRA and the Defence and Aerospace Sector must work closely together to ensure that whilst respecting the sensitive nature of some of the work theresearch work carried out by the DRA is made available to UK industry for thepurposes of wealth creation.

7.18 The adoption of the above recommendations, which focus investment incapability in the form of Applied Research and Technology Demonstration, is themost appropriate way for Government to support this sector. Such support willlead to lower costs, including life cycle costs, and shorter timescales fordevelopment of new products in both the Civil Aerospace and Defence sectors,thus enhancing the industry's competitiveness.

8. CONCLUSIONS AND RECOMMENDATIONS

Key Technical Priorities

8.1 Using criteria from those suggested by the Foresight Steering Group, the Defence and Civil Aerospace sub-groups have identified the technologies which are crucial to have in the UK for success in their respective sub-sectors.

8.2 The Defence sub-group highlighted 18 technology areas (Paras 3.20 - 3.37). The Civil Aerospace sub-group worked in a different way. They identified the largecommercial transport sector as being the most significant in terms of wealthcreation and demand for technology. Therefore the range of technologiesunderpinning that sector should be the focus. In addition, a number of vital,underpinning, business process technologies and several key product technologieswere defined (Para 4.37 et seq) and grouped into five broad technology areas (Paras4.75 et seq).

8.3 The panel reviewed the technologies critical for success in the two sub-sectors, and identified seven technology areas which incorporate key aspects from Defence and Civil Aerospace, including the Space sector, and which because of theirgeneric nature are likely to feature in the priority lists of other sector panels. Thesedeserve special attention for these reasons. The following paragraphs set out thejustification for declaring these particular areas as key priorities and recommendwhat follow-up action should be taken.

8.4 A common theme from both sub-sectors was the importance of the UK retaining the skills and capability to design and integrate whole systems or platforms, either for UK developed systems or to ensure a significant role for UK industry oninternational collaborative programmes. However, the Panel has recognised thatthe UK cannot lead across the whole spectrum of Defence and Aerospace, butneeds to focus its strengths in the sub-sectors which are important for nationaldefence or where there is significant potential for wealth creation.

8.5 Many of the Panel's recommendations call for a re-focusing of science andtechnology investment. This section ends with a summary of the new fundingmechanisms described in detail at Section 7 and which are intended to enable thisobjective to be achieved.

8.6 Systems Integration

8.6.1 Probably the most important factor in the commercial success of a civilaerospace system, or the military effectiveness of a defence system, isto define the overall system concept and then ensure that the componentsystems work together efficiently. Systems Integration refers to theability to understand and model the interaction and integration of themany complex and diverse sub-systems in a platform or system inpursuit of the overall system requirement, and is thus an important keyto performance and commercial success. UK has particular strengths inthis area, which must be maintained and extended if it is to remaincompetitive in the global market.

8.6.2 The panel recommends that systems integration is givenmuch higher profile as a key technological requirement ofadvanced civil aerospace and defence systems. The panel wouldencourage HEIs to place greater emphasis on multi- and interdisciplinary research in conjunction with industry and government, andconsider introducing this topic as part of first degreeengineering courses.

8.7 Process Technologies

8.7.1 It is clear that cost and timeliness are factors which will dominate thecustomer's procurement decisions in both defence and civil aerospace.Product performance will be an important factor, but it is cost(acquisition and whole life) and timescale that will often win thecontract.

8.7.2 The panel recommends that much greater emphasis isplaced on business-process-based developments includingdesign, lean manufacturing, and concurrent engineering toprovide the dramatic reductions in time to market and costwhich customers are demanding and which the UK'scompetitors are already driving hard to achieve. Initiativessuch as the EPSRC's Innovative Manufacturing Initiative (IMI) and SBAC's Competitiveness Challenge should bestrongly supported.

8.7.3 The panel recommends also that an industry-led structure is establishedto ensure that there is good co-ordination of the various initiatives in thisarea, and that results are disseminated widely. In this area particularly,the emphasis needs to be not only on developing new ideas but also onensuring that these ideas are put into productive use.

8.8 Materials and Structures

8.8.1 The competitiveness of Defence and Civil Aerospace products iscritically dependent on the exploitation of advanced materials inefficient, low cost, high performance structures and components. Thismust include development of 'smart' materials and structures and theirassociated technologies. This will require developments in, andintegration of, materials, structural design and integrity, embeddedsensors, manufacturing and inspection. It is essential that the UK has thecapability to specify the materials and their associated manufacturingprocesses needed to meet future product requirements, and to developthese materials and processes at least as far as the full-scale demonstratorstage. This will help to counter the problem of commercial and exportrelated restrictions on vital materials from overseas.

8.8.2 The panel recommends that action is taken to both retainand develop the UK's indigenous research and manufacturingbase for materials and related technologies which are critical tomaintaining our world class standing, particularly whereaccess to key materials from abroad is denied.

8.9 Simulation, Modelling and Synthetic Environments

8.9.1 The need for shorter development programmes and reduced life cyclecosts, along with environmental concerns regarding training activitiesemphasise modelling and simulation and especially the ability tointegrate these interacting system models into a 'synthetic environment'.

8.9.2 The panel recommends that research emphasis is placed onall aspects of modelling, simulation and syntheticenvironments and on the supporting technologies required.

8.10 Aerodynamics (including emissions and noise)

8.10.1 Aerodynamics is an essential underpinning technology for aircraft, rotorsand propulsion systems. Significant reductions in product design timesand costs as well as enhanced product performance can result fromimproved modelling techniques based on computational fluid dynamics. Better understanding of flow phenomena will reduce development riskand allow performance optimisation to be carried out with enhancedconfidence. Ever-growing environmental awareness will place greateremphasis on reduced emissions, increased fuel efficiency and lowernoise.

8.10.2 The panel recommends that continued emphasis is placedon research and development in aerodynamics to enhancethe UK's capability to design world-leading fixed androtary wing aircraft and engines.

8.11 Sensor Systems, Data Fusion and Data Processing

8.11.1 Sensors, data fusion and the processing of multi-sensor information iscritical to many defence and aerospace systems. It is an important factorto be considered in the systems integration activity referred to in Para8.6.

8.11.2 The panel recommends that more support is given toresearch within the HEIs in the key area of sensor, datafusion and data processing technology, to maintain theedge in militarily vital areas such as monitoring,surveillance, command and control.

8.12 High-integrity Real-time Software

8.12.1 High-integrity real-time software is a key component in almost allDefence and Civil Aerospace systems. The capability to specify, design,produce and certificate such software at a cost not higher than that ofnon-critical/non-real time software will be a key differentiator for futuresystems.

8.12.2 The panel recommends that more support is given toresearch within industry and HEIs to the development anddemonstration of the tools, methods and processes neededto achieve the above.

8.13 To summarise, the panel recommends that seven key technology areas are given high priority by industry and the science base when deciding research fundingallocations.

THE SEVEN KEY TECHNOLOGY AREAS

- Systems Integration
- Process Technologies
- Materials and Structures
- Simulation, Modelling and Synthetic Environment
- Aerodynamics (including emissions and noise)
- Sensor Systems, Data Fusion and Data Processing
- High-integrity Real-time Software

8.14 The panel has identified a broad range of technologies which are important for success in this sector, and has the highlighted the seven key technology areas listedabove which should be given high priority by industry and academia. Appropriatemechanisms for implementing these priorities are crucial if the marketopportunities identified by the panel are to be fully exploited.

8.15 In the consultations conducted by the panel, funding has been highlighted as a principal constraint on the UK maximising the wealth creation potential from itstechnology base, and strengthening the relationship between industry andacademia has been highlighted as a key means of making best use of whatresources are available. Developing this relationship, and the focus on exploitationof technology, will lead to an improvement in the flow of technology into worldbeating products.

8.16 The panel believes that a much greater focus on the requirements of industry is needed at the applied research stage, and that the balance of funding expended on Basic and Applied Research, and Technology Demonstration, must be kept underconstant review to ensure that high quality research effort on wealth creationactivities is being developed in line with the SET White Paper objectives. AppliedResearch programmes must have strong industry participation to ensure adequatemarket signals. The resulting direction from the market will result in appropriateprioritisation of research activity.

8.17 The panel believes that the objective could be achieved through a mechanism which:

- promotes closer industry/academia links and so improves technologytransfer;
- facilitates multi-disciplinary research programmes which the panelpriorities demand;
- develops and retains long term capability through stable research teams inwell funded 'Centres of Excellence'.

8.18 The background to the funding concerns and the technology developmentprocess were discussed at Section 7, which also detailed the proposed approach forimproving the targeting and exploitation of academic research. The panelrecommends that two new university-linked applied research schemes areestablished, addressing Dual-Use and Civil Aerospace technology requirements. The proposed schemes would involve participation and funding from MOD,DTI, Research Councils and Industry, and levels of funding to enable this schemeto make an impact have been proposed. The panel recommends that the schemesbe monitored by a Steering Group comprising members from these groups, aspart of the ongoing Foresight activity.

8.19 The schemes would be open to industrial and academic partners from outside Defence and Aerospace to pursue technologies which were truly dual-use. Theemerging Dual-Use Technology Centres may be appropriate locations for someof the programmes that will bid for funding.

8.20 The Panel further recommends an increase in funding for industrial appliedresearch in Civil Aerospace through the CARAD scheme, and a significantincrease in Technology Demonstrator programmes for both Defence andAerospace.

Other Key Priorities

8.21 The Panel recognises that success in exploiting technology depends on a number of factors other than technology itself This section summarises the panel'srecommendations on other key priorities arising from both the Civil Aerospaceand Defence sub-sections of this report.

8.22 The Challenge to Companies

8.22.1 Issues

- Although there is a significant number of issues which need toaddressed by Government in technology and policy areas, thecentral challenge is to UK companies.
- The Foresight exercise highlights issues which need to beaddressed by companies and by Industry as a whole, including:

  how to adapt the ways in which companies plan for newtechnologies so as to support and exploit world-classacademic research, and to make the fullest use of theForesight Framework;

  how to develop effective networks and partnerships withother companies, with Government and Academia;

  how to benchmark their capabilities against industryleaders;

  and, above all, how to reverse the decline in Industryinvestment in Defence and Aerospace R&D.

- In addressing these issues, companies need to give to technologythe same emphasis as is given to other elements ofcompetitiveness such as costs.

8.22.2 Recommendation

-
- Companies should review their technology plans, and their processes for developing such plans, in relation to this report.
- Through Trade Associations and with Academia, Industry should foster technology benchmarking, the sharing of best practice in technology planning and exploitation, and promote increased levels of networking and collaboration

8.22.3 Practical Steps

- The Panel, in co-operation with OST, DTI, MOD and TradeAssociations to organise a senior-level conference on the issuesemerging from this report.
- Trade Associations, in liaison with the Panel, to establish theprocesses recommended.

8.23 National Strategy for Defence and Aerospace Technologies

8.23.1 Issues

- UK expenditures on Defence and Aerospace R&D are declining,both in absolute terms and relative to our major competitors; thisapplies to investment by both Industry and Government and it isnot clear that the R&D reductions being made are consistent withfuture defence requirements or business needs.

- Unless we act vigorously as a nation, we risk being overwhelmedby the enormous ongoing investments in technology made by theUnited States, and also being seriously disadvantagedcompetitively by the investments made by France and Germany.
- The UK faces a particular challenge in maintaining sufficientcontrol of, or participation in, platform leadership in the highvolume sectors of the Defence and Aerospace markets; this iscritical for maintaining system integration skills, but it isincreasingly difficult in an era of collaboration and in the absenceof a clear national strategy.
- The work done by DTI and SBAC for the Civil Aerospace sectorduring the past two years shows that Government and Industrycan agree, to their mutual benefit, on a common strategicframework to guide policy and actions; also, in Civil Aerospace,some progress has been made towards the identification andprioritisation of technologies, through the NSTAP process.
- The SET White Paper ('Realising our potential') provides aframework for developing strategic objectives, improving coordination and making the best use of the resources available.
- There is a clear need across the UK Defence and Aerospacesector for a national strategy for, and a much clearer method ofprioritising and acquiring, those technologies required to satisfyUK defence requirements and to promote business growth andwealth creation.

8.23.2 Recommendation

Industry and Government (OST, MOD and DTI) should work together, with Academia, to develop national strategy/policy frameworks for Defence and Aerospace technologies; these frameworks must incorporate agreed high-level objectives towards which all concerned should work, and be supported by processes which monitor progress.

8.23.3 Practical Steps

- SBAC and DTI to continue the work which has been started on astrategy for UK Aerospace; progress on NSTAP should beaccelerated, with increased resourced Action Teams; progress onNSTAP should be monitored regularly by the DTI AviationCommittee.
- Through the National Defence Industries Council (NDIC),Industry, MOD and DTI should agree objectives and a process fordeveloping a similar strategic framework and technology acquisition plan for Defence; the views of academia and the work done within Foresight would be essential inputs to this technology plan.
- Industry, possibly through Trade Associations, should develop mechanisms through which its inputs can be co-ordinated and should make available resources required for the above tasks.
- The Defence and Aerospace panel, in conjunction with industry associations, should work with OST to help in the implementation phase of Foresight, in the manner specified inthe SET White Paper and as detailed in Section 9 of this report.

8.24 MOD Procurement

8.24.1 Issues

- The fact that MoD has no formal responsibility to foster thestrength of the defence industrial base or wealth creation;
- The openness of the UK defence market to foreign bidders is notreciprocated;
- The UK's leadership of the trend towards more off-the-shelfpurchases poses real threats to the

medium to long termcapability of the UK defence technology base, and to the UK'sability to participate in international collaborative projects, andto our ability to compete in world markets;

- The need to conserve the defence S&T base and exploit it to thefullest possible extent its wealth creation potential, maintainingthe right balance between off-the-shelf procurement and UKdevelopments;
- The UK's difference in emphasis on 'offset' as compared to othercountries has disadvantaged UK companies vis-a-vis their foreigncompetitors;
- The mismatch between industry's need for continuing activity (topreserve skills and capability) and the increasing gaps and budget
- The need for procurement strategies and processes to align withthe rapid evolution in technologies, such as IT;
- Unlike its major foreign counterparts, UK MoD has no remit tosupport development of improved business processes, especiallyin manufacturing.

8.24.2 Recommendation

Government and Industry to review MOD Procurement policies and related Defence Science issues so that, whilst continuing to emphasise value-for-money for the Defence budget, there is also an emphasis on UK industry competitiveness and wealth creation; other policy issues arising from Foresight should also be addressed in this review.

8.24.3 Practical Steps

As a basis for this policy revision, Government and Industry should carry out a detailed review of issues identified in this report, and other related issues, through mechanisms to be established by the NDIC.

8.25 Market Distortions

8.25.1 Issues

In relation to Market Distortions between the UK and its competitorcountries, issues include:

relative levels and terms of Launch Aid and other support (civil sector);
relative levels of R & D support;
export credit availability and terms;
defence export clearances;
rules governing trans-national mergers and acquisitions.

8.25.2 Recommendation

Government, with industry support, should monitor continuously Market Distortions between UK and its main competitors, and take action either to eliminate them or to avoid UK industry being disadvantaged; a formal review should be prepared annually.

8.26 International Collaboration

8.26.1 Issues

- International collaboration is essential because of the need forsufficient market base, and because of the increasing cost of newprogrammes;
- US companies seldom collaborate internationally at primecontractor level, unless there are significant technology or marketadvantages for them;
- UK industry must continue to work in partnership with overseascompanies, both in Europe, and on a more limited basis, in the
- US and elsewhere. Opportunities for equipment companies aremuch enhanced by UK participation as a platform programmeleader or partner;
- Defence budget pressures, together with the need for Europeancompanies to compete with a massively restructured US defenceindustry, make it inevitable that there will be much greatercooperation in Europe - in R & T, development and production;these pressures are now beginning to affect some of theequipment sector as well as prime contractors;
- Prerequisites for successful collaboration are: early agreement ofuser requirements and the alignment of timescales and funding;
- This acceleration of European collaboration is seen by Franceas an opportunity to establish defence leadership in Europe;
- Some collaborative defence projects in Europe, being based onthe 'juste retour' principle, have suffered from inefficientmanagement structures and sourcing policies;
- Although industry has begun to establish cross-border alliances inEurope, progress will be limited in the absence of early agreementon user requirements and acquisition processes; it is also in theinterests of the UK that European defence markets becomegenuinely open to fair competition on a reciprocal basis; thecomplexity of the defence and foreign policy issues related to thisare clear but, unless these issues are grasped and resolved, the UKand European defence industries will face an increasingly difficultfuture.
- UK companies must maintain a full complement of keytechnology skills in order to win leading positions insuch collaborative programmes.

8.26.2 Recommendations

- Government, in consultation with Industry, must accelerate where appropriate the establishment of common defence requirements and acquisition in Europe, on bases which are efficient and which provide reciprocal market access.
- Government and Industry must work closely together at a strategic level to ensure that UK companies have equitable opportunity in new European collaborative programmes whilst, at the same time, recognising that opportunities will continue to exist to collaborate and trade on a two-way basis with the United States.

8.26.3 Practical Steps

MoD, DTI and Industry to establish processes of dialogue whereby themoves towards increased collaboration can be progressed in ways whichmaintain the UK's competitive position.

8.27 Financing

8.27.1 Issues

- Financing issues are threatening the technology base and futureviability of the Defence and Aerospace industries which are keysectors of the economy; this view was confirmed by

Delphirespondents and in the regional workshops; the issues need to beaddressed within national strategies for the industries;

- There is evidence that the problem is exacerbated in the UK bythe financial pressures on companies during recent years, notleast the costs of re-structuring and market pressures on prices,and by the financial markets systematically undervaluingprospective income streams from long-term projects.
- Significant success in Civil Aerospace during the 1980s resultedfrom the successful Government/Industry partnership throughthe coupling of CARAD supported research and demonstrationwith well-targeted Launch Aid support for projects: the issue ishow to develop this for the future.
- The scale of the investment required, long payback periods, andstrategic importance have resulted in Governments world-wideheavily supporting their Defence and Aerospace industries.
- In the Defence and Aerospace sector, R&D investment by UKGovernment and Industry is reducing much faster than that ofcompetitor countries; this reduction threatens the UK'stechnology base and market position.
- Technology Demonstration provides a vital and cost-effectivebridge between applied research and heavy developmentspending but today is critically underfunded.
- Within Technology Demonstrator programmes there is a need to address thearea of business processes, given the increased emphasis on reducing costand time to market.
- There is a need for a much stronger partnership betweenIndustry, Universities, Research Councils and MOD if the bestuse is to be made of the available resources in Applied Research.

8.27.2 Recommendations

- Industry and Government, in partnership, must respond to the threat of loss of market opportunity in the Defence and Aerospace sectors arising from strategic investment by competitor nations, by reversing the current declining UK spend on research and demonstration;
- Two new university-linked Applied Research scheme should be established, focused on Dual-Use Technologies (£24M per annum) and Civil Aerospace (£40M per annum) with a significant industrial contribution to ensure market relevance and commitment to exploit the results.
- The level of DTI funding for industrial Applied Research in Civil Aerospace, through the CARAD scheme, should be increased to £25M per annum, with a matching contribution from Industry.
- Technology Demonstrator Programmes (TDP) should be increasedsignificantly.
- DTI funding for Civil Aerospace TDPs should be increased to £30M per annum immediately, rising progressively to f65M per annum over the next three years. Industry must provide a similar level of funding.
- The level of activity in MOD-funded Technology Demonstrator programmes also needs to be increased, with consideration also being given to expanding their scope to include process as well as product technologies.
- For Civil Aerospace programmes, Launch Aid terms should not disadvantage the UK industry with respect to its competitors and 'partners'.
- Consideration should be given to establishing a Launch Aid scheme for Defence export products.

8.27.3 Practical Steps

- The Panel believes its proposals for new funding mechanisms forApplied Research and Technology Demonstrators in Defenceand Aerospace are crucial for the future of this sector.

Theproposals have been detailed at length in Section 7, and have beensummarised at Para 8.14 et seq. Industry should propose projectswhich will, ideally, facilitate participation by a range of industrialand academic interests, and have specific programmes of workfocused on outputs which will enhance competitiveness;Industry, with the support of the Panel, and in dialogue withGovernment Departments and the Research Councils shouldseek to integrate these projects into a coherent programme in linewith Foresight.
- MOD should review project planning process and fundingprioritisation so that there is adequate focus on, and funding for,technology demonstrators wherever these are justifiable.

8.28 Air Traffic Control

8.28. 1 Issues

- Predicted air traffic growth could be constrained by limitations of theexisting air traffic management system: the quality of air travel woulddecrease markedly, leading to delays to passengers, increased operatingcosts for airlines, increased air pollution due to uneconomic flightpaths, and pressure on safety performance;

8.28.2 Recommendations

- The UK should work through European institutions to develop a fully integrated world-wide system, and focus R&D attention on ATC demonstrators to convince decision-makers of the most cost-beneficial technologies
- The UK should support collaboration between CAA, industry and academia so as to maximise market opportunities arising from European programmes.

8.28.3 Practical Steps

- For UK Air Traffic authorities to work with and withinEurocontrol to ensure that UK industry benefits from theharmonisation and integration developments being pursued.
- Following the above, for Eurocontrol to engage particularlythe US in dialogue on worldwide standards.

8.29 Space

8.29. 1 Issues Of the issues raised in Section 5 relating to Space, two are unique tothat sector.

- The balance between national programme funding andthe UK funding contribution to ESA has changed significantly over thelast few years. There is concern that as it stands, the UK will beunable to get the best value out of its share in Europeanprogrammes.
- There is concern that ESA should adopt new mechanismswhich focus more on competitiveness and market requirements, andstrive to become more efficient. The UK needs a stronger focusfor national space activities and our role within Europe.

8.29.2 Recommendations

- Consideration should be given to adjusting the balancebetween UK national and European funding of Space activities.

- The UK should work towards making ESA more efficient, and to develop new mechanisms which focus more on competitiveness and market requirements. Consideration should be given to creating a UK Space agency with a dedicated Space budget.

8.29.3 Practical Steps

- The Panel will work with industrial, academic and governmentrepresentatives from the Space community as part of its futureprogramme to determine how these recommendations can bestbe implemented.

8.30 Skills

8.30.1 Issues

- The Defence and Aerospace sector needs graduates with abroad view of design, manufacturing and management to be able tocontribute in the key areas of Design & Systems Integration andBusiness Process re-engineering.
- The accelerating advances in Defence and Aerospacetechnologies make maintaining up-to-date the specialist knowledge oftechnical staff crucial, but increasingly difficult.

8.30.2 Recommendations

- Undergraduate training in multi-and inter-disciplinary subjects supporting the Panel's key technical priorities, particularly Design and Systems Integration, should be developed.
- More attention should be paid to providing short courses in specialist technology areas to enable staff in industry to keep abreast of developments.

8.30.3 Practical Steps

- Develop first degree courses introducing more multi- andinterdisciplinary elements.
- Implement the proposals for the new funding mechanism, toencourage post-doctoral staff from universities to work withindustry, so transferring key skills and up-to-date knowledge.
- Develop short courses in specialist technologies designed to allowindustry technical staff to update their knowledge at minimumdisruption to their normal activities.

9. THE FUTURE OF FORESIGHT

9.1 The Foresight exercise for Defence and Aerospace has proved very valuable indeveloping a common view of priorities and in building networks. It isimportant to build on this, as a means of providing a common focus for allinvolved in this sector and as a means of stimulating the cultural and otherchanges which are needed for success.

9.2 In the Defence and Aerospace arena, a great deal of work had already been doneon requirements and technology, both in the UK and abroad. It is perhaps notsurprising, therefore, that the Foresight exercise has added no radically new ideason technologies.

9.3 Foresight has been particularly useful on the Defence side in improving the networking between industry, MOD and DRA, and this is something important to build on. The panel already contains key officials in MOD, the DRA and Academia concerned with the defence research programme as well as senior industrialists and is therefore well placed to work with MOD in taking inward recommendations. The relevant experts networks of 'peer colleges' established by Research Councils should be incorporated within the Defence and Aerospace Foresight network to produce a co-ordinated UK network of UK expertise.

9.4 It is important that the Foresight process should be 'owned' by UK industry and the scientific community. As a first step, the panel recommends that its report should be disseminated to Chief Executives/Managing Directors, Technical and Research Directors and Senior Managers of companies within the Defence and Aerospace sector, to the Government departments concerned, and to the relevantacademic institutions, professional institutions and trade associations.

9.5 The key, however, is the process which uses the results of Foresight in setting the future direction, balance and content of science and technology programmes, both in Government and Industry. The White Paper 'Realising our potential' sets out a process, in the section headed 'A Strategy for Government-funded Science and Technology'. That strategy is based on the annual Forward Look which would draw on the findings of the Technology Foresight programme. More specifically, the purpose would be to set strategic objectives over a 5-10 year perspective, andto consider:

- gaps or imbalances in the education, training and research effort;
- how our efforts compare with those of our principal competitors;the balance between civil and defence research, and between civil researchcommissioned by Departments and that undertaken by the science andengineering base;
- the balance between domestic and international research, and the scope for co-operation with other countries, whether in Europe or elsewhere;
- opportunities for achieving synergy across programmes;
- the scope for greater concerted action and collaboration, both within the public sector, and between the public and private sectors.

9.6 In view of the importance of Government's role in the Defence and Aerospace sector, and in view of our recommendation that national strategies are developed for Defence and Aerospace technologies, the Panel considers it essential that the mechanisms described in Paragraph 9.5 above should function effectively.However, if this is to happen, OST and the other Departments concerned must have the resources to do the tasks. Involvement of Industry in the process is also important. The approach being developed by DTI and SBAC for co-ordination of activities within NSTAP is one way in which this involvement can be achieved.

9.7 The Panel recommends that, in its continuing activities, it should work with OST, MOD, DTI and EPSRC to ensure that the Defence and Aerospace elements of the strategy process are progressed, and that Industry involvement is developed as necessary. This process will be strengthened as the Panel's other future work develops (eg benchmarking) and as action is taken on the panel's recommendations .

9.8 Future activities should aim to build on the specific recommendations and to develop further the network which has been established. These future actions include the following:

9.8.1 Register of Experts. A register should be drawn up of those who are willing to contribute to future activities. Invitations to join the register should be made to those who were invited to the Foresight Defence and Aerospace workshops, attendees of the DIC benchmarking workshops and the existing DSAC register of independent experts. It should also draw from the EPSRC Peer Colleges. All those joining the register should be asked to define the technologies in which they are expert.

9.8.2 Workshops. A series of small workshops should be initiated by MOD and DTI, to address particular problems felt to be important and where an orthogonal view would be valuable to them. The attendance should be drawn from the register. The workshops should include studiesrelated to innovating technology, exploiting technology and policy issues.They may take place in London, at RMCS Shrivenham or at relevantDRA sites. Industry can also be invited to suggest topics for workshopsand to host them.

9.8.3 Town Meeting of Academics. EPSRC should be invited toorganise a Town Meeting covering defence science and technology. This can both address the recommendations of the report and include presentations by DRA and Industry on problem areas where it is felt that academics can contribute. This will also have the effect of broadening the Defence and Aerospace network.

9.8.4 Extensions to Pathfinder. The existing DRA Pathfinder scheme is aimed at Industry. It should be broadened to include an academic Pathfinder scheme with joint presentations by industry and DRA of opportunities for projects with academia, as part of the new fundingscheme recommended in this report.

9.8.5 Industrial Symposium. This will enable industry to communicate their strategic technology needs to academia. This mechanism could well be 'owned' by the SBAC, one of the sector's main trade associations, liaison closely with the panel.

9.8.6 Newsletter. A newsletter should be introduced which highlights developments and interesting news in Defence and Aerospace, and progress in the Foresight recommendations. This would be circulated to all those on the register and to those receiving the panel report.

9.8.7 Benchmarking. MOD/DRA, DTI and Industry should be encouraged to collaborate in the next

HEFC research assessment exercise in relevant university departments. They should then produce a more accurate input to decisions on university funding by the RCs, DRA and industry. Industry and DRA should attempt to focus their activities, in order to build on the potential of the better departments in key areas. SBAC/DTI should be encouraged to collaborate on benchmarking the Aerospace industrial sector, and DIC to lead a further exercise in the Defence sector.

9.8.8 Taxonomy. Experience of this first round of UK Foresight highlightsthe need for a nationally accepted taxonomy of defence systems, militarycapabilities and technologies. The taxonomy produced for the DICbenchmarking study has proved to be a good basis for this and should befurther refined through the Defence and Aerospace panel. In associationwith this, the products and technologies database established at RMCSShrivenham should be expanded and updated. A similar exercise for Civil Aerospace would also prove valuable.

9.8.9 Further study. The ongoing work of the Defence and Aerospace panel should include progressing work in areas which could not be dealt with adequately within the time available in this initial Foresight exercise; for example the marine sector, skills and education, benchmarking (see above), communication of science and technology achievements and issues to the media and wider public. The Defence and Aerospace panel has only been able to do a limited amount of Foresight work on Space issues. The panel should co-opt key individuals in industry, academia and government involved in space-related issues and produce a more detailed review of Foresight issues in the Space sector.

9.8.10 Supply Chain Study. As part of its ongoing work, the Panel wishes to conduct a study, probably in association with key trade associations, into the detailed workings of the supply chains operating in Defence and Aerospace. The objective of such a study would be to improveunderstanding of the mechanisms influencing information disseminationand technology transfer, particularly to SMEs, with the aim of effectingimprovements in the overall competitiveness of the sector.

9.9 Recognising that Foresight is an ongoing interactive process, subject to refinement, revision, updating and assessment, the panel should continue to meet at regular intervals of about 4 months to monitor the progress, implementation and impact of Foresight on Industry, Academia, Government and the Funding Councils. In addition to regular consultation with the Defence and Aerospacecommunity, the panel should produce an Annual Report informing members of the network of the progress being made.

9.10 These activities are important in providing a common focus for all involved in this sector and a means of stimulating the cultural and other changes needed for success. A key element in these changes is the fostering of much more openness in Industry, and between Industry and Government, on research and development thinking.

9.11 In addition, these activities will ease the task of any future Foresight panel on Defence and Aerospace. To assist further in the next round of UK Foresight, the Defence and Aerospace panel should produce, in liaison with the existing network, a report on 'lessons learned' from the 1994/95 round. In establishing the Defence and Aerospace panel for its ongoing role, it is important that these lessons are heeded and that adequate resources (eg secretariat) are provided to support itsactivities, and facilitate liaison with Trade Associations and the Government Departments concerned.

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2

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3

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6

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GLOSSARY OF ACRONYMS

ADF
Air Defence Fighter
AEW
Airborne Early Warning
ASTOVL
Advanced Short Take-Off and Vertical Landing
ATC
Air Traffic Control
ATM
Air Traffic Management
BAe
British Aerospace

BERP
British Experimental Rotor Programme
BNSC
British National Space Centre
CCCI
Command, Control, Communications and Intelligence
CAA
Civil Aviation Authority
CAD
Computer Aided Design
CAE
Computer Aided Engineering
CALS
Computer Aided Logistics Systems
CAM
Computer Aided Manufacture
CARAD
Civil Aircraft Research and Demonstration
CFC
Computational Fluid Dynamics
CIRPLS
Computer Integration of Requirements, Procurement, Logistics and Support
CSCE
Conference on Security and Co-ordination in Europe
DESO
Defence Export Services Organisation
DRA
Defence Research Agency
DSAC
Defence Scientific Advisory Council
DTI
Department of Trade and Industry
EAP
Experimental Aircraft Programme
ECCM
Electronic Counter-Counter Measures
ECM
Electronic Counter Measures
EFA
European Fighter Aircraft - New Eurofighter 2000
EPSRC
Engineering and Physical Sciences Research Council
ESA
European Space Agency
ESM
Electronic Surveillance Measures
EW
Electronic Warfare
FLA
Future Large Aircraft
FMS

Foreign Military Sales

FSU
Former Soviet Union

GEC
General Electric Company

GPS
Global Positioning System

HEI
Higher Education Institution

HMI
Human Machine Interface

IR
Infra-red

IT/E
IT & Electronics

ISW
Information Systems Warfare

JGS
Joint Grants Scheme

MOD
Ministry of Defence

NATO
North Atlantic Treaty Organisation

NATS
National Air Traffic Services

NDIC
National Defence Industries Council

NSTAP
National Strategic Technology Acquisition Programme

OST
Office of Science and Technology

RCS
Radar Cross Section

RF
Radio Frequency

RMCS
Royal Military College of Science

SBAC
Society of British Aerospace Companies

SST
Supersonic Transport

SSTO
Single Stage to Orbit

STOL
Short Take-off and Landing

TDP
Technology Demonstrator Programme

UKISC
UK Industrial Space Committee

UN
United Nations

USN
: United States Navy

VLCT
: Very large Commercial Transport

VSTOL
: Vertical/Short Take Off and Landing

VTOL
: Vertical Take-off and Landing

WEU
: Western European Union

WHL
: Westland Helicopters Limited

Acknowledgements

The Panel has received help and advice from manypeople over the last 12 months, but particular thanks are due to Sarah Slade(Rolls-Royce), Lt Col Ian Abbot (RMCS) Shrivenham) and Sam Cherry(Short brothers), who have provided sterling support throughout.

The Panel also wishes to thank Roger Quince (Segal (:Quince Wicksteed), who acted as the our facilitator during the initial analysis phase, and has providedmany useful inputs since. Thanks are also due to Col Mike Charlton-Weedy of RMCS Shrivenham and David McOwat of the MOD scientific staff for their valuable contributions.

The Panel wishes especially to place on record its appreciation of the work of Bill Chrispin, Technical Secretary to the Panel, whose efforts and knowledge have been invaluable.

ANNEX A. DEFENCE AND AEROSPACE SECTOR

The Panel and its work

A1 The Defence and Aerospace sector panel is chaired by Roy McNulty, President of Short Brothers, and comprises 22 members from industry, academia and government. John Chisholm, Chief Executive of the DRA and a member of the Technology Foresight Steering Group, acted as the panel's assessor. The panel also received the valuable assistance of co-opted personnel from RMCS Shrivenham, Rolls-Royce and Shorts.

A2 The panel members' names, affiliations and roles within the panel are shown at Appendix 1. Short biographies are presented at Appendix 2. The close involvement of government in this sector led to a high representation from Government departments - 6 out of the 22 members (including 2 from the Defence Research Agency). The input from these government representatives has been of great benefit to the panel; however, the constraints of their positions made them unable to comment on issues of Government policy.

A3 The Panel's Terms of Reference are presented at Appendix 3. The Panel operated mainly in two sub-groups covering the Civil Aerospace and Defence sub-sectors. Membership of the sub-groups is also shown at Appendix 1. This report covers the work of the 2 sub-groups individually before bringing together their priorities into a combined set of recommendations.

A4 The panel consulted widely during its working programme, beginning with an initial scoping survey of a small group of experts to establish key trends and issues, continuing with a Delphi survey of over 200 experts on specific market and product opportunities, and finishing with 4 regional workshops engaging around 100 senior people from the Defence and Aerospace sector. A separate workshop on Space issues was held with 30 experts from industry, academia and government. Inaddition, the panel has sought views from the principal Professional Institutions and Trade Associations on the key issues within the sector, to augment its own analyses. The Civil Aerospace sub-group has commissioned work from the DTI Aviation Market Panel and conducted a competitiveness survey of the UK Civil Aerospace Industry. The Defence sub-group commissioned a market survey fromRMCS Shrivenham and has been able to draw on the results of acompetitiveness survey of the UK Defence Industry commissioned by theDefence Industries Council.

A5 The panel has also maintained links with the other sector panels which have a particularly close relationship to Defence and Aerospace. These are Manufacturing, Production and Business Processes, Materials, Communications, IT & Electronics and Transport. Summaries of the findings from these various exercises are presented in Annexes B-F.

A6 The face-to-face consultations conducted during the panel's programme have been particularly productive: panel meetings themselves and the regional workshops have demonstrated the benefits of building new, and extending existing, networks to assist Academia, Industry and Government to become more aware of each other's problems and requirements.

A7 The flow chart at Figure A1 illustrates the principal elements in the panel's work, and how the external sources and consultation processes have been used by the panel to contribute to the overall Foresight priorities analysis.

Notes on Panel Member appointment changes during Foresight

David Balmford retired from Westlands in May 1994, but continues to act as a consultant for the company.

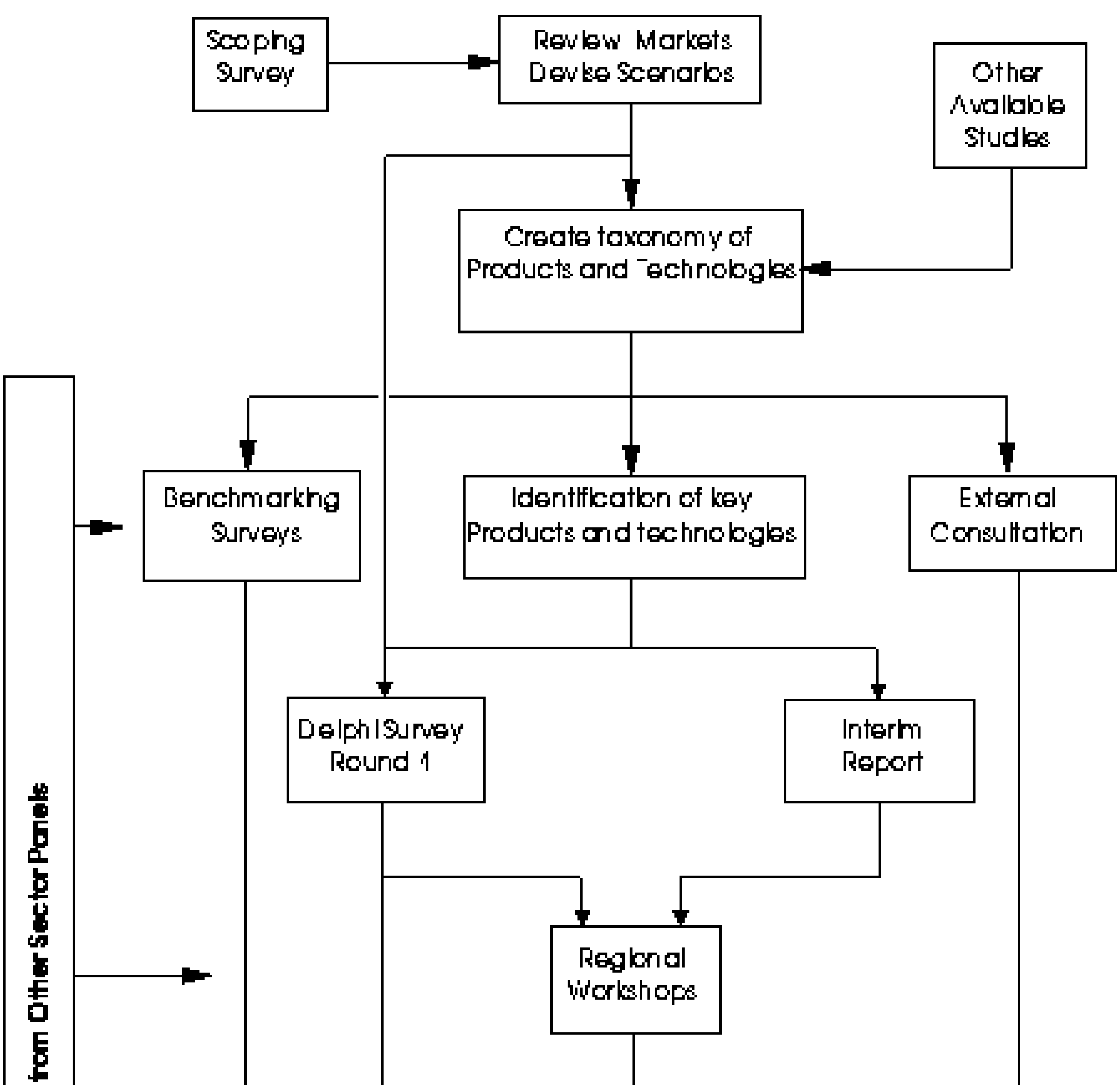
Maj Gen Edmund Burton was appointed ACDS OR(Land) in September 1994 from his previous post as Commandant of the Royal Military College, Shrivenham.

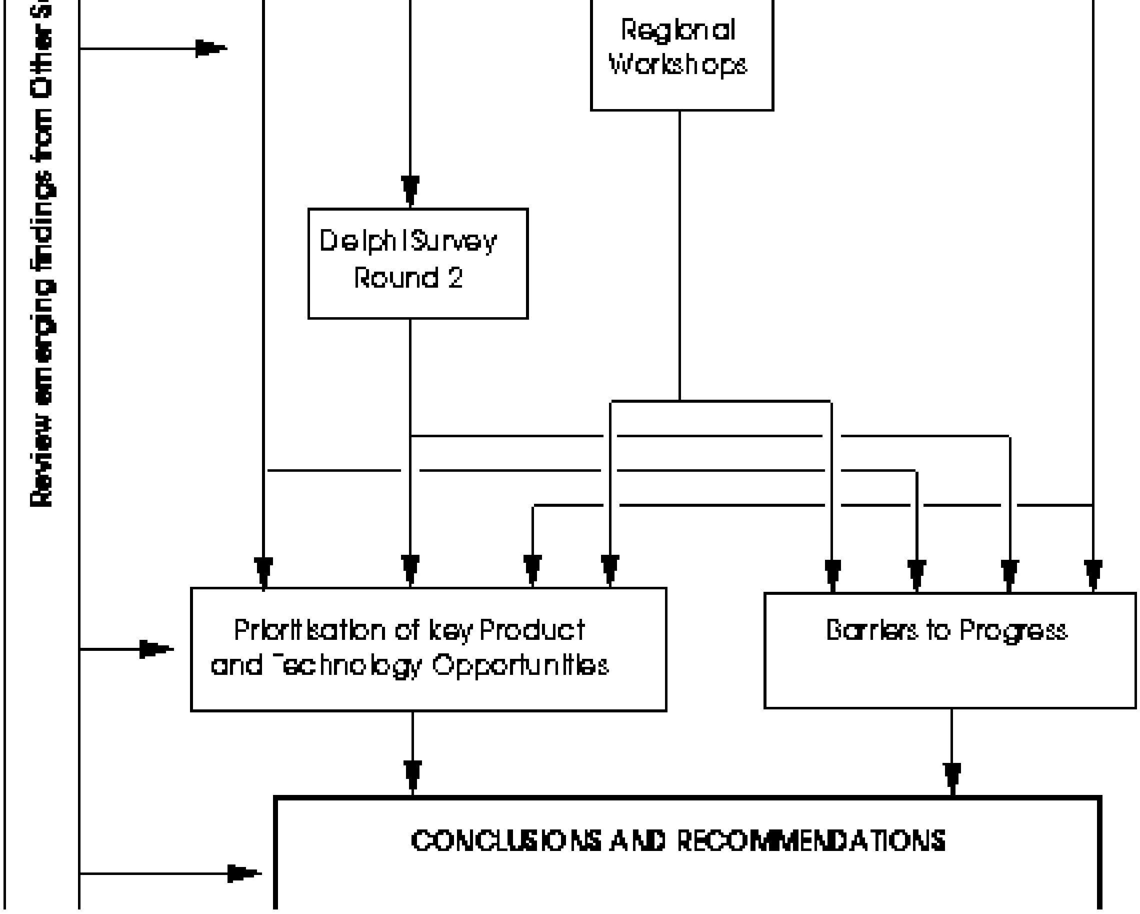
Dr Julia King was appointed Head of Materials at Rolls-Royce in November 1994 from her position as Senior Lecturer in Materials at Cambridge University.

Dr Les Salmon moved from his post as Director, Fighting Vehicles & Systems at DRA Chertsey in October 1994 to become Director of Strategy and Implementation in the new Defence Test and Evaluation Organisation.

DEFENCE AND AEROSPACE PANEL

Figure A1 - General Model of Panel Process





APPENDEX 1 TO ANNEX A

DEFENCE AND AEROSPACE PANEL - ORGANISATION

The following table details the membership of Defence and Aerospace panel, their allocation to the Defence and Civil Aerospace sub-groups, and responsibilities for liaison with other sector panels.

Panel Member	Affiliation	Defence	Civil	Cross-panel Liaison
Roy McNulty	Short Brothers	*		Manufacturing
Phil Ruffles	Rolls-Royce		***	
David Balmford	WHL Consultant	*		
Bill Bardo	GEC-Marconi	**		
Peter Blair	Racal Research	*		
Martin Boyce	BAe Airbus		**	
Edmund Burton	ACDS OR(Land)	***		
Ann Dowling	Cambridge Univ		*	
Geoff Haines	Dowty Aerospace		*	
Chris Harris	Southampton Univ	*		
Cyril Hilsum	GEC	*		
Julia King	Rolls-Royce		*	Materials
Terry Knibb	BAe	*		
Tony Mathers	GKN Defence	*		
Adriain Mears	DRA	*		

Malcolm Ralph	DTI		*	Transport
Malcolm Rutherford	DCDS(S)	*		
Les Salmon	DTE	*		
Paul Sutcliffe	ACSA(R)	*		
Phil Tittler	BAe		*	
Paul Wrobel	VSEL	*		
Geoff Young	BAe	*		IT/Electronics

***Team Leader **Deputy Team Leader *Team Member

APPENDIX 2 TO ANNEX A

DEFENCE AND AEROSPACE SECTOR
Panel Member Biographies

Roy McNulty

Roy McNulty joined Short Brothers as Director of Finance and Administration in 1978, became Deputy Managing Director in 1986, and then Managing Director and chief Executive in 1988. He is a Chartered Accountant with a background in financial management, industrial relations, management of human resources, information systems, and commercial functions.

Roy McNulty was appointed to his present post as President of the Shorts Group following the acquisition of Shorts by the Canadian company Bombardier Inc. in 1989. The Shorts Group is the European counterpart of Bombardier's North America Aerospace Group.

He is a past President (1993/94) of the Society of British Aerospace Companies(SBAC) and has recently been appointed Chairman of the DTI's AviationCommittee. He is also a member of the Confederation of British Industry'sNational Manufacturing Council, a member of the Industrial Development Boardfor Northern Ireland and Chairman of the Northern Ireland Growth ChallengeInitiative. He is a fellow of the Royal Aeronautical Society, and IndustrialProfessor of the Warwick Manufacturing Group, Warwick University, and wasawarded the CBE in 1993 for services to the aerospace industry.

Philip Ruffles

Phil Ruffles was appointed to his present post as Director - Engineering atRolls-Royce in 1991, having held posts as Director of Technology, Director of Design Engineering and Technical Director.

Phil Ruffles has spent his whole career at Rolls-Royce since joining theCompany in 1961 as a graduate apprentice. During this time he has worked in allthe major Engineering disciplines and on Civil, Military and Helicopter engineprojects.

He is a Fellow of the Royal Academy of Engineering, the Royal AeronauticalSociety and the Institution of Mechanical Engineers. He is an HonoraryProfessor - Warwick University, Department of Mechanical Engineering and is the Mechanical Engineering Secretary on the Council of the Royal

Academy of Engineering.

In 1987 he was awarded the Ackroyd Stuart Prize by the RoyalAeronautical Society for his paper on "Reducing the Cost of Aero EngineResearch and Development".

Professor David Balmford

After 41 years in the aircraft design and manufacturing industry, David Balmfordretired from the position of Chief Scientist at Westland Helicopters in theSummer of 1994, and now acts as a self-employed consultant.

He graduated in mathematics from the University of Durham in 1953, and wassubsequently employed as a stress and dynamics engineer in both fixed and rotarywing aircraft, before moving into research and advanced project activities. He hasrepresented Westland on many international and national organisations andcommittees, including Chairmanship of the SBAC Research Committee for aperiod of 4 years. He provided the helicopter input to NSTAP, and was a memberof the DSAC ATB Working Group on Long Term Aerospace Technology.

David Balmford was a member of the Westland team which received theMacRobert Award for technical innovation in the Lynx helicopter in 1975. In1991 he was appointed a Visiting Industrial Professor in the Department ofAerospace Engineering in the University of Bristol, received the OBE for servicesto helicopter development in 1993, and was elected a Fellow of the RoyalAcademy of Engineering in 1994. He is also a Fellow of the Royal AeronauticalSociety.

David has held a current private pilot's licence since 1955.

Dr William Bardo

Dr Bill Bardo is Group Technical Director of GEC-Marconi Limited. He joined Marconi as Technical Director of Marconi Space and Defence Systems in 1980, assuming his present post in April 1984.

His professional qualifications include B.Sc., M.Sc., in Quantum Electronics anda PhD awarded for theoretical and experimental research in quantum mechanismsof molecular beam masers. He was a Science Research Council Post DoctoralFellow at the University of St. Andrews between 1969 and 1971, investigatingthe mechanisms of molecular gas lasers. In 1971 he moved to the Royal Signalsand Radar Establishment at Malvern where he worked until 1980.

Peter Blair

Peter Blair joined Racal Electronics in 1985, and is now Managing Director of Racal Research, which supplies research and advanced development services to the whole of the Racal Group.

Following his initial engineering training and Dip.EE award while with the Marconi Wireless Telegraphy Company, Peter Blair worked on broadband microwave links before joining STL in 1962 to research solid state microwave applications for both communications and radar. He moved into the field of defence system research in 1967 and led teams working on microwave landing systems, low level air defence, tracking radars and Navstar GPS. Much of this work was in collaboration with ITT teams in the USA, France, Germany and the UK

Peter Blair has served on a number of FEI and SBAC committees, and is amember of the DSAC Sensors Technology Board. He is a Fellow of theRoyal Academy of Engineering and a fellow of the IEE.

Martin Boyce

Martin Boyce is currently Head of Future Development and Planning in theEngineering Directorate of British Aerospace Airbus Ltd at Filton. During hiscareer with British Aerospace and previously GEC and Plessey, Martin Boyce hasbeen responsible for, variously, research and technology, advanced engineering,and product development for products ranging from airborne and ground-basedequipment, through major integrated systems to complete aircraft, in both thedefence and civil sectors.

Martin Boyce is a graduate of the Faculty of Engineering at the University ofBirmingham and is a Fellow of the Institution of Electrical Engineers.

Major General Edmund Burton

Edmund Burton was appointed to the post of Assistant Chief of the Defence Staff Operational Requirements (Land Systems) in the Ministry of Defence inSeptember 1994. In this appointment he is responsible for the formulation ofoperational requirements for land systems for the Armed Services and forsponsoring those requirements through the procurement cycle until and includingacceptance into service.

He was commissioned from RMA Sandhurst in 1963 and read MechanicalSciences at Cambridge University. His regimental service has been with theRoyal Artillery, principally with field artillery regiments in Germany. He attendedthe Army Staff Course at RMCS Shrivenham and the Royal Navy Staff Course atGreenwich in 1975n6 and the Higher Command and Staff Course at Camberley in1987. His previous appointments and representing the User in the Ministry ofDefence involved artillery guns, rockets, air defence and related target acquisitionand command and information systems. He has also completed two tours at theRoyal Military College of Science, Shrivenham; as a member of the DirectingStaff and recently as Commandant. From 1989-91 he was Military Attache/ Commander British Army Staff in Washington DC. He is Honorary Colonel ofthe Cambridge University OTC.

Professor Ann Dowling

Ann Dowling is currently Professor Mechanical Engineering at CambridgeUniversity and a Fellow of Sidney Sussex College.

Professor Dowling's research interests are in the areas of acoustics and vibration,unsteady fluid mechanics and flow instability. She works on problems ofaeronautical and of underwater interest, including aircraft noise, aero-engineinstabilities and sonar systems. She is a consultant to both aerospace andunderwater industries. Since 1979, Professor Dowling has been a faculty memberof the Engineering Department at Cambridge University, serving as Deputy Headof Department from 1990-93. She has published extensively in scientific journalsand is a co-author of two books. In 1990 Professor Dowling was awarded the A BWood Medal by the Institute of Acoustics for her work in underwater acoustics.

As a keen private pilot, Ann Dowling owns and flies a lightaircraft.

Geoff Haines

Geoff Haines is currently Research Manager at Messier-Dowty Ltd, the UKcompany within the joint venture set up to amalgamate the aircraft landing gearbusiness of T.I-Dowty and Snecma-Messier Bogati.

Following graduation from University of Bristol in 1959, Geoff Haines hasenjoyed a career almost wholly in the aerospace industry, holding varioustechnical appointments within Dowty companies. Current research managementresponsibilities cover landing gear systems but previously have included aircrafthydraulic, actuation and propeller systems.

In recent years Geoff Haines has represented the UK Aerospace industryequipment sector in various research for a. These include the EuropeanEquipment Industry Management Group which interfaces with EuropeanCommission on Aerospace R and T. He was also an industry member of theworking group set up by the Aviation Committee to prepare the NationalStrategic Technology Acquisition Plan (NSTAP).

Professor Chris Harris

Professor Chris Harris is currently Head of the Image, Speech and IntelligentSystems (ISIS) research group within the Department of Electronics andComputer Science at the University of Southampton. He is the holder of theLucas Chair in Aerospace Systems Engineering.

His research interests lie in intelligent autonomous vehicles, multi-sensor datafusion, intelligent command and control systems, systems integration,conditioning monitoring for real time processes, as well as in the basic theoryof neuro-fuzzy systems. Current applications of this research include gas turbinecontrol, missile guidance, underwater vehicle control and guidance, collisionavoidance for helicopters and machine perception for advanced transportation.

Chris Harris is author of 12 research books and over 180 research papers inadvanced control and systems engineering and their application to Aerospace andDefence Systems.

Professor Cyril Hilsum

After spending most of his career as an Individual Merit Scientist in the Ministryof Defence, and subsequently as Director of Research, GEC plc, Cyril Hilsum isnow a Corporate Research Adviser to GEC, and a Visiting Professor in Physicsat University College London, and he consults for MoD on electronic andoptoelectronic materials and devices.

His research included infra-red devices, semiconductors, and electronic displays. Heled the UK team which invented biphenyl liquid crystals, the world-standardmaterials. His general interests now include the organisation of industrialresearch, and Technology Transfer, on which he chairs a new Europe-wide study.He has published over 100 technical papers in these fields, and has over 40patents. For contributions to materials science he has awards from the IEEE, theIoP, and the German Physical Society, plus the highest award of the IEE, theFaraday Medal. He is a Fellow of the Royal Academy of

Engineering, a Fellow ofthe Royal Society, and a Foreign Associate of the US National Academy of Engineering.He was the President of the Institute of Physics from 1988-90. He was awardedthe CBE in 1990 for services to the Electrical and Electronics Industry.

Dr Julia King

After 16 years as an academic researcher and university lecturer, Julia Kingjoined Rolls-Royce Aerospace Group as Head of Materials in November 1994.

Dr King's academic interests lie in the field of micromechanisms of fatigue andfracture. Following post-doctoral research as a Rolls-Royce Research Fellow atGirton College Cambridge, Dr King lectured at Nottingham University for sevenyears before returning to Cambridge in 1987 as the first Royal Academy ofEngineering Senior Research Fellow, supported by British Gas. Dr King's mostrecent appointment in Cambridge was as Assistant Director of the UniversityTechnology Centre for Ni-base superalloys, established in collaboration withRolls-Royce. Dr King has published over 130 papers on fatigue and fracture ofstructural materials and was awarded the Grunfeld Medal in 1992 for her work onNi-base alloys.

Terry Knibb

Terry Knibb is currently Director of the British Aerospace Sowerby ResearchCentre. The primary task of the centre is to carry out strategic research for thebusiness benefit of the BAe companies, entering into collaboration programmeswith the Science Base and other organisations where appropriate. Researchencompasses a range of disciplines, including aerodynamics, lasers andlaser material interactions, materials science, human factors, computationalengineering and advanced information processing.

After graduating in Physics from the Imperial College of Science and Technology,he joined the Allen Clarke Research Centre of the Plessey Co. in 1966. There hewas involved with a number of semiconductor device technologies, including LEDdisplays and infra-red detectors. In 1981, he moved to the Hirst Research Centre ofthe GEC, initially to take responsibility for an infra-red detector programme.Later, he reached the position of Assistant Director with responsibility foroptoelectronic and microwave devices and the central materials science laboratory.In 1988, Mr Knibb joined British Aerospace as Principal of the Sowerby ResearchCentre, being promoted to his current post in 1989.

In addition to his BAe responsibilities, Mr Knibb is active in the Society ofBritish Aerospace Companies, where he is Chairman of the TechnologyCommittee and a member of the Technical Board. Additionally, he is one of thetwo UK representatives on the Technology Committee of the European DefenceIndustries Group. Past committee activities have included membership of theAdvanced Devices and Materials Committee (SERC/DTI), RNEC ResearchAdvisory Committee and the SCIOS (Scottish Combined Initiative inOptoelectronic Science) steering group. He is a non-executive director ofSpectrum Technologies Ltd and a member of the SBAC Technology Board.

Tony Mathers

Tony Mathers is a Director of GKN Defence, one of the companies that comprisethe Aerospace & Special Vehicles Sector of GKN plc.

He joined GKN Defence in 1987, initially as Technical Director responsible for allprototyping, design and development engineering. Since 1991 he has beenresponsible as Project Director for the company's Armoured Vehicle Programmesfor both UK and overseas customers. This has entailed product support activitiesin the Gulf, Bosnia and other training and deployment locations.

He has been involved in military equipment procurement for nearly 30 years, asignificant proportion of that time concerned with logistic and combat vehicles atthe Ministry of Defence R&D Establishment MVEE/RARDE (Chertsey) nowDRA. This involved collaboration with the MoDs of UK/French/ GermanGovernments on Main Battle Tanks and vehicle systems. He is currentlyresponsible for the Company's private venture R&D programme and recentlyrepresented the UK as the National Focal Point for a major NATO vehiclecollaboration programme.

Dr Adrian Mears

Adrian Mears is the Technical and Quality Director of the Defence Evaluation andResearch Agency and the Technical Director of the Defence Research Agency. Heis responsible for DERA's technical strategy, corporate research programme,research with academia, benchmarking and quality assurance, and for increasing thebenefit of DERA's work to UK wealth creation.

He began his career in 1961 in the computer industry, then spent 6 years atOxford University and three years doing post-doctoral research at the University ofMaryland, USA. From 1971-1987 he worked at the Royal Signals and RadarEstablishment (now DRA Malvern) on flat-panel displays, microelectronics,lasers, signal processing and information systems engineering. In 1987 he joinedthe Defence Staff in MOD as the first Director of Science for Command ControlCommunications and Information Systems. He returned to DRA in January 1990and since then he has played a central role in reshaping DRA as a governmentagency and coping with the large cuts and changes in defence research.

Malcolm Ralph

Malcolm Ralph is Head of Branch 3 in Aerospace Division of the Department ofTrade and Industry with responsibility for market assessments of civil aerospaceprojects, these assessments being used as the basis for Departmental orGovernment involvement. He has responsibility in the Department also formarket inputs relating to military aerospace procurements, and for aerospaceenvironmental issues.

His career began in the Ministry of Technology in 1967 as a Scientific Assistantworking on wing design and testing. After studying mechanical engineering andpost-graduate aerodynamics, he moved to Warren Spring Laboratory to work inlow speed aerodynamics and environment. He moved in 1983 to AerospaceDivision to head a section working on market assessments of large civil projects,with his first being the Airbus A320. He became Head of Branch in 1989 andwas awarded special recognition in 1992.

Vice Admiral Malcolm Rutherford

Vice Admiral Malcolm Rutherford took up his current appointment as DeputyChief of the Defence Staff (Systems) in March 1994 and at the same timeassumed the responsibilities of Chief Naval Engineer Officer.

Vice Admiral Malcolm Rutherford joined BRNC Dartmouth in 1959 having beeneducated at New College School, Oxford and Gordonstoun. He has a LondonUniversity Degree in Electrical Engineering. His early Service years were mainlyspent in the submarines HMS Conqueror and Sceptre. On promotion toCommander in 1978 he attended the National Defence College at Latimer and laterwas the Weapon Engineering Officer on HMS Glamorgan on Gulf Armilla patrol.He left the ship on promotion to Captain in 1984.

As a Captain his appointments included Weapon Systems Director for Upholderclass submarines building at VSEL and Cammell Laird, and command of theWeapon Engineering Training Establishment, HMS Collingwood. He becameCommodore and Director Personnel in the Ministry of Defence, Whitehall, inSeptember 1990 and Naval Secretary in October 1992 on promotion to the FlagList.

Malcolm Rutherford is a Fellow of the Institution of Electrical Engineers, and anItalian Interpreter. He was awarded the CBE in the 1991 Gulf Honours List.

Dr Les Salmon

Les Salmon moved from the DRA to the Defence Test and EvaluationOrganisation as Director of Strategy and Implementation in October 1994.

After obtaining a PhD in solid state physics, Dr Salmon joined the Royal AircraftEstablishment, Farnborough where he initially worked on software engineeringfor aircraft applications. This was followed by experience in a variety of aircraftrelated areas, notably: avionic systems research, human factors, cockpit design,EMC/EMP, and system integration, leading to his appointment asSuperintendent, Avionics Division. He then moved to Whitehall to become afounder member of the UK Strategic Defence Initiative office where, after a periodas Assistant Director (Technology) he worked as a project manager for the USArmy. After a short period in MOD(PE) engaged in purchasing securecommunications equipment he joined the DRA, as Manager, Missile Technologyand Countermeasures Department before becoming Director, Fighting Vehiclesand Systems Sector.

During his career, Dr Salmon has sat on a wide range of panels, including theSAE, various SBAC groups and NATO.

Paul M Sutcliffe

Paul Sutcliffe is the Ministry of Defence's Deputy Chief Scientist (Research andTechnology). As such he oversees the whole of the MOD's research programmeand is the immediate customer for the Corporate Research, including innovativeresearch and underpinning technology. In addition, he is sponsor for MOD'scollaborative research, both national and international.

Paul graduated from Worcester College, Oxford in 1965 with a BA in Physics.He spent much of his early career in MOD at the Defence Operational AnalysisEstablishment, but moved into technical research in 1986 when he transferred tothe then Admiralty Research Establishment, Portland. He later became the firstDirector Underwater Systems in the newly formed Defence Research Agency. Hemoved to his present post in 1992.

For much of his career, Paul Sutcliffe has worked in the field of MaritimeOperational Research, covering most aspects of maritime systems and warfarefrom the design of patrol craft to total force mix issues, but he has also workedon such diverse topics as economic warfare, space and missile technologyintelligence and underwater weapons and technology.

Phil Tittler

Phil Tittler was appointed to his current post of Executive at PLC Headquartersresponsible for External Relations in January 1994.

Phil Tittler studied a BSc Engineering degree at Manchester and on completionjoined BAe in 1976 from the National Coal Board. His career started in theElectronic Systems Department where he moved through the Test andManufacturing Development areas to lead the Engineering Design team. Secondments to the then Advanced Avionics Department and Advanced Projectsteam lead to his appointment in 1988 as Research and Development Manager forElectronics at Military Aircraft Limited.

In late 1989 he was transferred to Systems Technology R&D Department asStrategic Studies Manager (MAL), responsible for formulating an overallSystems Technology R&D strategy which would support MAL's developingbusiness whilst matching the changing market environment. This was followedby a move to Advanced Technology in 1991 to develop an overall Strategy forTechnology and to produce the Technical Directorial Business Plan. In February1992 he was appointed Chief of Advanced Technology.

Mr Paul Wrobel

Paul Wrobel is currently VSEL's Project Director for the Batch Two TrafalgarClass Submarine Prime Contract.

After graduating from Cambridge University (Engineering) and LondonUniversity (Naval Architecture), Paul Wrobel worked for ten years with theMOD(PE) in a range of technical and project appointments. His last ten yearshave been with VSEL and his previous appointment was as Director of DesignTechnology, responsible for Future Naval Projects and Professional EngineeringDepartments including R&D Programmes.

Geoff Young

Geoff Young is currently Head of Research & Development in the HQ of BAe atFarnborough where he has worked for the last three years. He has worked atBritish Aerospace for 26 years on a wide variety of defence and civil aerospacetopics.

After six years at RAE Bedford, Geoff Young obtained an MSc in AviationElectronics before joining industry. In his early appointments he wasresponsible for the engineering of a wide variety of projects including controland navigation systems, communications, EQ/ESM and underwater vehicles.

In 1984, Geoff Young was appointed as Executive Director, Engineering in BAeDynamics at Bristol where, amongst other things, he was responsible for theengineering aspects of BAe's Naval Weapons and Army Weapon launchers andsupport vehicles. In 1987, he became Director of Technology of BAe CommercialAircraft Limited HQ at Haffield. From 1989 until his current appointment, he wasTechnical

Director of BAe Space and Communication Systems (based atStevenage).

APPENDIX 3 TO ANNEX A

Terms of Reference for Foresight Sector Panels
Background

1. On 28 February 1994 the Chancellor of the Duchy of Lancaster announced the 15 sector panels which were to carry forward the main work of the Technology Foresight Programme. The Programme was divided into three phases. These were:

(a) initial foresight work (April - August 1994);

(b) wider consultation about the results of this initial work (SeptemberDecember 1994); and

(c) in the light of (a) and (b) an assessment of priorities within and between sectors, taking account of relative strengths and weaknesses in the UKindustrial and science and engineering base (benchmarking) January March 1995).

2.The purpose of this note is:

(a) to make clear what work sector panels were asked to undertake andon what timescale; and

(b) to clarify how the work of panels fitted into the Programme as a whole, including in particular their relations with the Chief Scientific Adviser, Office of Science and Technology (OST), and the Technology Foresight Steering Group.

The following is an extract from the remit given to sector panels in April1994 describing the work of the three phases of Foresight.

Phase 1: Initial Foresight Work (April - August1994)

3. Each panel will wish to start considering at the outset of its work:

(a) how best to access and make use of work already undertaken in its sector (eg databases on markets and technologies, other relevant foresight work);including work of the research councils and professional bodies in its area;

(b) key economic and social trends likely to affect market developments in its sector over the next 10 to 20 years;

(c) what new products, processes and services might emerge over the next 10 20 years;

(d) what developments in science and technology will be needed to enable the UK to remain at the forefront of technological innovation in its area; and

(e)

technological possibilities within the sector.

4. Each panel should prepare a brief progress report to the OST and the Steering Group on the work above by the end of May 1994. The Steering Group and the OST will liaise with the panels on how best to take forward work during the remainder of phase one.

5. The aim of this first phase is for each sector panel to produce by the end of August 1994 a preliminary report about possible market and technological developmentsin its sector over the next 10 to 20 years. This report will be submitted to the Steering Group and the OST. Once the Steering Group and the OST havecommented, these reports will then serve as the basis for the formal consultationwhich each panel will undertake in Phase 2 of the Programme (September December 1994).

Working Methods of the Panel during Phase 1

6. It will be for each panel to decide how it carries out the tasks above and it will be given flexibility, under the chairman, on how it takes the process forward. In some cases, much work will have been done already. In others, the panels will be startingmore or less from scratch. Each panel might wish to consult a sample (say 30-50 representation) of the wider pool of experts (ie experts in that sector not selected for panel membership), relevant trade associations, professional institutions, Government Departments and Research Councils, Research and Technology Organisations OST and networks identified during the conomination process.

7. Panels may wish to establish working groups on specific tasks or commission studies on particular issues. Each panel will wish to establish arrangements toexchange views with panels in related or overlapping sectors.

8. To aid discussion across panels, panels may wish to follow similar formats when drawing up questions and issues to be addressed during the consultative phase of the Programme. A template survey form will have been introduced to chairmen and panel members during March/April. Panels can then adapt this template to the individual circumstances of their sectors.

Phase 2: Wider Consultation Phase (September toDecember 1994)

9. In the light of comments by the Steering Group and the OST, each panel should submit its preliminary report to wider consultation through the Delphi processand regional workshops. The preliminary report will be put to experts from all thesector panels to make sure that all cross-sectoral aspects are properly considered.Sector panels will undertake consultation through regional workshops.

10. This wider consultation should be undertaken on the following timetable:

(a)
each panel receives initial responses from consultees in the Delphi process by end of September;

(b)
each panel should complete their series of regional workshops by end of October;

(c)

each panel should have received the second round of responses from consultees in the Delphi process by the end of October; and

(d)

each panel should summarise the results of this wider consultation phase andsubmit a report to the Chairman of the Steering Group by the end of1994.

Phase 3: Assessment of Priorities January to March1995)

11. In the light of comments from the Steering Group and the OST on the report submitted by the panel during December, each panel should deliver to thechairman of the Steering Group by end-January 1995 a final report covering:

(a)

the factors it considers important in future markets, including some assessment of their relative importance;

(b)

an assessment of the most promising opportunities for matching new technological advances to future markets; and

(c)

the panel's perceptions of the strengths and weaknesses of the UK industrial, scientific and technological base as identified during Phase 2 and as identified in the benchmarking work of the OST's foresight team.

How the Work of the Panels fits into the Foresight Programme as a Whole

12. Chairmen and members of sector panels are appointed by the Chief Scientific Adviser and Head of the OST, taking account of advice from the Technology Foresight Steering Group, the results of the co-nomination process, and other representations.

13. The main point of contact between each panel and the OST on day-to-Day matters will be the Technical Secretary (see paragraph 16 (i) below). In addition, the OST central foresight team will keep in touch with the chairman of each panel.

14. Each panel has assigned to it one or more members of the Foresight Steering Group who will serve as assessors and who will act as a point of contact betweenthe sector panel and the Steering Group. Relevant Government departments willalso have an observer on each panel.

15. When panel reports are at the draft stage, the OST central foresight team will arrange for them to be circulated to other panels, to Steering Group members, and to relevant Government Departments. Final reports should be delivered to Professor Sir W D P Stewart as Head of the OST and Chairman of the Steering Group.

16. Panels will have a Chairman and Elce-Chairman, and:

(i)

A Technical secretary who will provide executive support to the work of the panel (for example, arranging the panels' meetings, drafting andcirculating papers, taking forward action outside meetings in consultationwith the Chairman);

(ii)

A facilitator, hired by the OST on a consultancy basis, with some knowledge of the particular sector. The facilitator will be available to panels to provide advice on Foresight methods appropriate to work in their sector during Phase 1 of the programme;

(iii)

One or more Assessors from the Steering Group.

17. Additionally, the OST will provide each panel with information about Foresight work which has been carried out previously in its sectoral area, if any. The OST will also make available to each panel a small budget to enable the panel to commission consultancy assistance.

ANNEX B SECTOR SCOPING SURVEY

Introduction

In May 1994, the panel conducted a questionnaire-based survey amongst a small group of 44 individuals from its expert pool. The experts were asked to identify the key issues/trends for the sector, and the markets, products and technologies that these key issues would give rise to.

Analysis of the Responses

Analysis of the responses showed there were 10 major issues/trends, six being purely defence, two civil and two related to both sub-sectors. The tables attached at Appendix 1 summarise the markets and products identified by respondents, together with the key underpinning technologies.

These responses provided useful guidance to the panel's initial work on key products and technologies.

APPENDIX 1 ANNEX B

Summary of the Scoping Survey Outcome

Issues/Trends	Market/Product	Technology
(a) Cost reduction		
	Improved software design	Design for production
	Advanced manufacturing technologies	Process modelling Sensor technology
	Improved reliability BITE	
	Expansion in skill market and computer design data	New analytical techniques
	Modular integration platforms	
	Performance prediction tools	Better affordable computer codes and verification
	Add-on seeker	£1,000 multimode seeker
	Separation of compressor and combustor	Non-mechanical torque transfer
	Synthetic environments	
	Low cost rugged components	

	Variable cycle gas turbine for supersonic cruise	Metal matrix composites, CFD
	Reduced cost, large composite structures	Design technologies for manufacture of composite structures
	Collaboration	
	Automated ship and bridge designs	
(b) Increased regional conflict	Autonomously controlled platforms	Expert systems for remote sensing data analysis, Multi-spectral, multi waveband sensor system
	Simulation for design and training	
	Non-Lethal Warfare	
	Personal Protection	
	Coded identification source receiver	IR + millimetric wave sources, Minimally cooled detectors
	Uncooled, small low cost laser radar	
	Light, long life battery powered portable computer	Ultra highspeed, low power, low noise transistors
	Toxic gas sensor	
	Ultra sensitive magnetometer	Magnetic field transducers in InSb or high temperature
	Smart mortars	Low cost, rugged IR and microwave seekers
	NLW energy directing weapons (RF, laser, acoustic)	
	Lightweight weapons and ammo + support systems	Low cost Ti alloys
	Personal IFF	Low cost composites
	Counter IFF	
	STOVL capability	
	Intelligent mines	
	Lighter armour	
	Safer munitions	
(c) Environment and safety	Design for environment	Design methodologies
	Portable EMC test set	
	Improved HUMS	Pattern recognition, Stress wave sensors, Acoustic monitoring
	Generic helicopter simulators	
	Energy efficient aircraft	Advanced CFD technologies, Laminar flow techniques
	Supersonic civil aircraft	Advanced high temperature materials

	Low cost launch vehicles	
	Low emission gas turbine combustion	
	High efficiency engines	High temperature ceramics and ceramic composites
	Prop fan engines	Noise reduction technologies, Blade design for high integrity
	Highly automated ATC system	Very large computing systems
	Accurate modelling of emission impact	
	Collision avoidance systems	
	VLCT aircraft	High lift systems (blown flaps, variable counter)
	Quiet, safer helicopters	Active control of noise and vibration
(d) Military	Low cost, high performance thermal imaging	Minimally cooled IR detectors
	Stealthy platforms	
	Passive systems	
	GPS integration	(Counter measures)
	Decoy-based defence systems	
	Quiet power sources	
(e) Defence Industry Restructuring	More and deeper out-sourcing by primes	
(f) Prohibition of weapons of mass destruction	Verification techniques Satellite remote sensing	
(g) Minimisation of collateral damage	High precision, high effect weapons High manoeuvrability weapons	Sensors/real time data fusion, Air breath prop for high speed weapons
(h) Terrorism	Directional fibre indicator	
(i) Increase air travel	VTOL feeder network/aircraft	

ANNEX C. THE DELPHI SURVEY

Introduction

C1. One of the few mandatory activities conducted by each panel was a Delphi survey of a large pool of sector experts. The Delphi technique consists of defining a number of statements or topics on markets, products or technologies and posing a series of questions concerning the degree of impact on wealth creation and qualityof life, timing, necessity for collaboration, UK strengths and weaknesses and constraints. The results of this survey are then presented to the respondents, and they are asked to indicate whether they wish to revise their original views.

C2. The panel devised 86 topics, based on the output from the initial scoping survey and, for defence, a separate questionnaire on systems and technologies administered amongst panel members and associates during July 1994.

C3. The questions posed were defined centrally, following inputs from Panel members. The final list was as follows:

Degree of Expertise (1-5)a
Degree of Impact on Wealth Creation (1-4)a
Degree of Impact on Quality of Life (1-4)a
Period within which the event will have first occurred (6 time periods)
Necessity of Collaboration (national, European, global or none)
UK's current position in 4 areas
Constraints on occurrence

C4. It should be noted that this Annex presents key findings only from what is a large amount of data.

Constructing the Expert Pool

C5. The Panel used a number of sources to construct a pool which fairly reflected the many interests covered by this sector. The co-nomination list formed the initial pool, and this was augmented by the panel's own suggestions and names submitted by Professional Institutions and Trade Associations. Each name was classified in two ways; firstly as Research, Manufacturer or User, and then byto identify areas where new names were required. The balancing was donesubjectively through panel members - no quotas or targets were set. The Delphiquestionnaire was eventually sent to 607 people.

C6. It was recognised from the outset that the panel would have little control over the balance of the respondent pool. Details of the respondents are presented later in this Annex.

The Panel's Topics

C7. The panel experienced some difficulty in reducing the number of topics it wished to include in the survey to the target figure of 80. Eventually, 86 topics were included, arranged in 15 sub-sectors. Appendix 3 lists the topics in full. 45 relate to Defence, 29 to Civil Aerospace with 12 relevant to both, including three on Space.

C8. It was whilst devising these topics that the Panel recognised there will be products or technologies which are likely to appear unattractive by Delphi criteria, but which the UK must pursue to maintain critical aspects of its defence capability, eg stealth. These technologies will not be immediately exploitable since they contribute to the 'technology edge' so crucial in maintaining a war-winning capability.

Basic Response Statistics

C9. Appendix 4 presents details of the respondents sample, which totalled 222, ie a response rate of 36%. This was, in fact, the highest of all 15 sectors. The sample was predominantly male (97% of those who stated gender), with a small proportion (10%) under 40 years of age. The job categories used on the Delphi form do not map onto the panel's more detailed matrix but looking at the balance of the former, the production/operations area only attracted 6 respondents (4%). The other categories were well represented.

C10. The average number of respondents was 158, with the average number of experts (3-5 rating) at 50. Topic 71 received the fewest respondents and experts (140 and 21 respectively). Topics 1 and 38 received the most respondents (174), with Topic 82 having the highest number of experts (107).

C11. Distribution of Expertise The following shows the distribution of expertise for the whole respondent sample:

Degree of Expertise	1	2	3	4	5
All Respondents (%)	45	23	18	11	3
Experts (%)		/ td>	58	33	9

The following topics had no respondents rating 5: 33, 42, 71, 75,76

The following topics attracted the highest number of respondents rating 5: 49, 50

Key Findings

C12. The large amount of data contained within the Delphi survey can be cut and presented in many ways. For the purposes of this headline presentation, the following areas have been selected for analysis and presentation from the vast range of possibilities:

- Overall figures on Wealth Creation and Quality of Life;
- Top topics for Wealth Creation and Quality of Life;
- Forecasts;
- UK's Current Position;

- Constraints.

C 13. Overall Wealth Creation and Quality of Life. The proportion of responses against the four ratings were as follows:

	Negative	neutral	Positive	Highly Positive	Positive & High Pos
Wealth Creation (WC)					
All	2	33	51	14	65
Experts	1	27	54	18	72
Quality of Life (QOL)					
All	3	62	29	6	35
Experts	2	60	30	8	38

Here, we see that the experts (3-5) are more optimistic than all respondents onboth WC and QOL. Moreover, there is a much higher proportion of respondentssaying the topics will have a positive or highly positive impact on WC thanQOL. But it is instructive to divide the topics into Defence and Civil Aerospace:

	Negative	Neutral	Positive	Highly Positive	Positive & High Pos
CIVIL AEROSPACE					
Wealth Creation (WC)					
All	1	22	57	19	76
Experts	1	17	58	24	82
DEFENCE					
Wealth Creation (WC)					
All	2	39	48	11	60
Experts	1	32	53	14	67
Quality of Life (QOL)					
All	2	72	22	4	26
Experts	2	69	24	5	29

Clearly, and perhaps unsurprisingly, the Defence topics are seen as relativelylow on Quality of Life whereas more than half the respondents rank CivilAerospace topics as positive or highly positive for QOL.

C14. Top Topics for Wealth Creation and Quality of Life. The following criteria have been used to highlight individual topics:

Top 20	Top 20 Topics for Wealth Creation	(Figure C1)
Top 20	Top 20 Topics for Quality of Life	(Figure C2)
Top 20	Civil Aerospace for Wealth Creation	(Figure C3)
Top 20	Defence for Wealth Creation	(Figure C4)

The ranking is based on the scores by Expert (3-5) Group.

Figure C1 shows that, in terms of wealth creation, Civil Aerospace dominates,with only 2 of the top 20 topics being exclusively Defence, although a further 6are relevant to both. It is noticeable that the top 5 topics for wealth creationfeature in the top 20 for Quality of Life (Figure C2).

These charts all display data from Experts (rated 3, 4 or 5) and all respondents. Innearly all cases, the experts group scores topics higher than the group of allrespondents. The Top 20 would not alter dramatically if the scores from allrespondents had been used to rank them, although the order would change. Sincefew respondents who ranked themselves 1 (unfamiliar) then went on to completethe scoring for a particular topics, these differences are a measure of the effect ofthose who ranked themselves 2 (casually acquainted).

C15. Forecasts. The average proportion of respondents estimating the period when topics would occur is as follows (there is virtually no difference between experts and all respondents):

	1995-99	2000-04	2005-09	2010-15	2015+	Never
All	6.5	27.0	34.0	20.5	9.0	3.0
Experts	7.0	27.5	33.5	20.5	8.5	3.0

Out of the panels, Defence and Aerospace had the highest proportion of topicsexpected to be realised after 2010, reflecting the long timescales in this sector.The topic that attracted the highest score for 'Never' was Topic 42 (personalisedair transport), indeed it has one of the highest 'Never' ratings in the whole Delphi.Interestingly, this was the Defence and Aerospace topic that received the mostnegative ratings for QOL impact.

C16. Collaboration. Not surprisingly, Defence and Aerospace topics received very high ratings on the need for collaboration:

Type of Collaboration

	UK	European	Global	
All Respondents	5	37	57	32
Experts	5	38	55	33

The topics that received high ratings for Global collaboration (>75%) were:

3 Integrated airport check-in
4 Security screening
9 Ozone layer control
10 Wide area ATC system
26 Space-based sensors
27 Low cost space launch system
31 Supersonic STOVL aircraft demo
39 Very large (>1000 seats) subsonic transport aircraft
40 Next generation supersonic transport

C17. The UK's Current Position. The main finding to be highlighted inthe benchmarking section of the Delphi is the contrast between the Scientific and Technological Capability and Exploitation and Commercialisation Potential. Of all the Foresight sectors, Defence and Aerospace had the highest percentage oftopics where a majority of experts agreed that in S&T Capability the UK is leading(46%). This compares with the mean score for all sectors of 14%. On the samemeasure on Exploitation potential, however, virtually all topics are rated average.

C18. Constraints. The two constraints which had by far the highest percentage of topics with majority agreement amongst the experts were Technical Feasibility(72%) and Lack of Funding (88%). Interestingly, the other sectors wheretechnical feasibility is a major constraint are Materials, Health & Life Sciences andChemicals, and indicates that these are areas which require significant inputs ofS&T to achieve success. Materials and Health & Life Sciences also feature lack offunding strongly as a constraint. The concern that funding problems may preventthe necessary technology development occurring was a constant theme at theregional workshops.

C19. A full set of results from the Defence and Aerospace Delphi Survey is available on request from the OST.

ANNEX 2 TO ANNEX C

EXPERT POOL CATEGORISATION MATRIX

	RESEARCHER IN (R)	MANUFACTURER OF (M)	USER OF (U)
1	Aerodynamics/Hydrodynamics	Aircraft (a) Civil (B) Military	Civil Aircraft
2	Structural Materials	Vehicles	Military Aircraft
3	Electronic Materials	Ships	Land systems
4	Mechanical Systems	Weapons	Sea systems
5	Electronic systems	Command, Control, Comms & Intelligence systems	Space systems
6	Manufacturing & Processes	Equipment	General
7	Environment & Safety	Sensors	
8	Sensors	Space systems	
9	Energetic materials	Materials/manufacturing	
10	Design		
11	Medical		
12	Marine		
13	Operational Analysis		
14	Space		

APPENDIX 3 TO ANNEX C

Final List of Delphi Topics

Sub-sector	No Delphi Statement	Civil/Defence
Airport Systems		

	1	Widespread use of advanced ground management systems for aircraft and ground-based vehicles which maximise the use of existing airports under all operational conditions and are fully integrated with ATC	Civil
	2	Widespread use of fully integrated automated baggage handling systems which are fast, secure and reliable, capable of growth to 800 seat aircraft, and significantly cheaper than current systems	Civil
	3	Worldwide use of fast, secure airport systems for identifying people and their hand luggage, integrated with check-in, security and customs, to reduce departure and arrival times to 15 minutes maximum	Civil
	4	Worldwide use of secure screening equipment that discerns guns and explosives from other materials contained in innocuous items	Civil
Air Environment & Efficiency			
	5	Halving of subsonic aircraft direct operating costs per passenger mile by increasing aircraft productivity, and reducing aircraft first cost and the cost of fuel, maintenance and crew	Civil
	6	Widespread exploitation of methods for laminar flow control leading to large civil aeroplanes with about 2/3 the drag (approximately 1/3 skin friction drag)	Civil
	7	Practical demonstration of a total aircraft de-icing system which does not require ground support services and is economically viable	Civil
	8	Widespread use of economic, lightweight, reliable anti- and de-icing systems for helicopter rotors, and for helicopter turboprop engine air intakes	Civil
	9	Practical demonstration of technologies which can be used to control ozone layers in the atmosphere and hence negate aircraft effects both above and below the tropopause	Civil
Air Traffic Management	10	Practical use of integrated wide area ATC systems and aircraft sensors which allow greatly increased flow capacity and automatically maintained reduced separation	Civil

	11	Practical use of autonomous take-off/flight/ landing aircraft and helicopter management system with functionalities (intelligent navigation, weather, ATC, flight plan and human computer interaction) to provide increased reliability and safety	Civil
	12	Practical use of all weather category 3 aircraft landing, takeoff and taxiing system using non-visual technology (eg fused radar/ IR imaging conditioned by differential GPS)	Civil
Command, Control, Communication Intelligence			
	13	Widespread use of commercially-based information systems to cope with huge volumes of military sensor and intelligence data, and able to respond to incomplete natural language queries and context cues	Defence
	14	Widespread use of diverse military-commercial networks using rugged and highly secure fibre-optics, satcoms and mobile communications to civil telecommunications standards	Defence
	15	Practical use of 3D direct-view A4 full-colour flat panel displays, with real-time data presentation fast enough for aircraft blind flying	Defence
	16	Practical use of helmet protection systems to fuse sensor and navigation data by voice command, and to control weapon aiming by gaze direction	Defence
	17	Practical use of very high performance all-optical computers for defence processes capable of withstanding electro-magnetic pulse effects	Defence
	18	Demonstration of a reliable IFF, coded to merge with noise and usable with all platforms and weapons, including autonomous precision-guided munitions engaging targets near own forces	Defence
STA Sensors			
	19	Prcatical use of optimal, real-time data fusion and integration of disparate sensors to provide improved, integrated, overall situation assessment which is robust to gradual loss of sensor information	Defence

	20	Practical use of adaptive/self-learning processors and full spectrum distributed/ conformal sensor arrays providing an order of magnitude improvement in counter-stealth and real-time classification of weak/ intermittent signals against complex backgrounds	Defence
	21	Practical use of low cost semi-autonomous robotic ground-based surveillance device, capable of remote insertion with multispectral optical and radio frequency sensors, providing remote intelligence via secure data link	Defence
	22	Practical use of a low cost semi-autonomous robotic ground-based surveillance device, capable of remote insertion with multispectral optical and radio frequency sensors, providing remote intelligence via secure data link	Defence
	23	Practical use of a low sensor, for a 155mm artillery round costing no more than £15K with maximum range of 40km, able to discriminate and attack various vehicle targets	Defence
	24	Practical use of a conformal phased array providing air defence fighters with all-round coverage for tracking multiple targets, and allowing high angle off-axis engagement thereby relaxing requirement for increased manoeuvrability	Defence
	25	Practical use of stealthy, high altitude surveillance platforms for detecting the boost phase of, and characterising, a ballistic missile threat	Defence
Space			
	26	Widespread deployment of space-based sensors, both civil and military, to prevent surprise attack, or permit deception during land forces attack against a wary and well-equipped enemy	Both
	27	Demonstration of a low cost launch system capable of placing up to 10 tonnes in low earth orbit at a recurring cost of 10% of current expendable vehicles with an operating run-round time of 2 days	Both

	28	Practical use of pocket-sized satellite/ cellular terminal allowing users to access radio and TV, receive and transmit data and voice, and provide position and route information by display on a screen map anywhere in the world	Both
Advanced Military Aircraft			
	29	Demonstration of a next generation combat aircraft with increased survivability and life cycle costs reduced by 50%	Defence
	30	Practical use of a Maritime Patrol Aircraft with time-on-station double that of today's aircraft, and significant improvements in target localisation system performance	Defence
	31	Practical demonstration of a supersonic STOVL capability providing an overall system performance no worse than that achievable on a navalised CTOL platform at the same unit cost	Defence
	32	Practical use for a Mach 1.2 trainer aircraft having space for radar and extensive weapons suite, capable of deployment as a combat aircraft, with life cycle costs 25% less than today's subsonic trainers	Defence
	33	Demonstration of a system trainer aircraft, with embedded systems (and targets) simulating those of a combat aircraft, able to train aircrew at no cost increase compared to today's training process	Defence
	34	Practical use of an unmanned, convert surveillance platform capable of zero ground speed at altitudes between 30,000 and 50,000 feet and remaining on station for a day	Defence
	35	Practical use of a small, expendable, remotely-controlled and manoeuvrable airborne platform for surveillance and peacemaking, having a recoverable sensor pack and coupled to a C3 system able to react instantly to identified threats	Defence
	36	Demonstration of an autonomous unmanned aircraft for surveillance purposes, with the flight, soaring, take-off and landing ability of a large bird of prey such as a condor	Defence
Advanced Passenger Aircraft			

	37	Practical use of a large transport aircraft of 600-800 passengers with around half the manufacturing cost relative to current practice	Civil
	38	Widespread use of large (>300 seats) subsonic aircraft which are quiet enough to take off and land at night from airports in populated areas	Civil
	39	Practical use of a very large (>1000) subsonic aircraft compatible with existing airport taxiways and stands	Civil
	40	Practical use of supersonic transport aircraft that is economically viable and environmentally acceptable, with a range of 6000 nautical miles at Mach 2-2.5	Civil
	41	Widespread use of cost-effective communications systems allowing full electronic office facilities for business travellers and access to the full range of personal communication and entertainment sources by all passengers	Civil
	42	Practical use of personalised air transport costing little more to buy or run than a medium range car, operable from home and requiring no more skill than is required to drive the family car	Civil
Rotorcraft			
	43	Practical use of rotocraft with safety increased tenfold and operating costs halved compared to today's helicopters, having improved passenger ride quality and reduced obtrusiveness to the general public	Civil
	44	Practical use of rotocraft with increased cruise speed (>25kts) and high speed agility, but no penalty in hovering and low speed flight, with reduced life cycle costs and improved survivability	Defence
	45	Demonstration of a rotor system exhibiting reduced radar and accoustic signatures, improved ballistic tolerance, 50% reduction in manufacturing costs and producing 30% greater thrust for a given rotor diameter	Defence
	46	Demonstration of a helicopter in which electric power replaces the mechanical and hydraulic power to the main and tail rotors	Defence

	47	Demonstration of lightweight gearbox with minimum parts, gear meshing patterns independent of torque and temperature, able to operate safely for at least 5 hours after total loss of lubrication	Defence
	48	Demonstration of an agile, stealthy aerial platform for engaging surface and aerial targets, with 350Kt dash, 6 hours loiter or 2 hours hover, and life cycle costs 20% less than today's advanced attack helicopters	Defence
Aircraft Materials Structure & Design			
	49	Accurate modelling of the behaviour of composite materials used in aerospace components which gives certifying authorities the confidence to accept materials and process changes without extensive testing	Civil
	50	Volume production of aircraft composite primary structures at the same cost and a 20% lower weight than equivalent metal structures	Civil
	51	Widespread use of polymer resin composite systems for continuous operation above 350 degrees C	Civil
	52	Widespread use of Al-Li based alloys in aerospace structural applications	Civil
	53	Practical demonstration of fully adaptive airframe providing an optimised configuration for the role and phase of fight, with damage alleviation and in-built health and usage monitoring	Civil
	54	CFD methods allow practical elimination of low and high speed wind tunnel testing for the design of turbofan powered subsonic civil aircraft	Civil
	55	Demonstration of novel shaped aircraft, eg flying wings or ground effect large vehicles, which integrate the wing, fuselage and powerplant, to improve revenue earning capability through increased lift to drag ratio	Civil
Aircraft Propulsion			
	56	Demonstration of an affordable military aircraft combat engine with 15:1 thrust/ weight ratio and the same, or improved, specific fuel consumption	Defence

	57	Practical demonstration of advanced military aircraft engine using variable cycle technology to match aircraft thrust and fuel consumption requirement around the flight envelope	Defence
	58	Demonstration of defect tolerant structural materials for gas turbines capable of operating uncooled above 1400 degrees C and in an oxidising environment	Both
	59	Widespread use of low density, heat resistant intermetallic compounds in aircraft engines	Both
	60	Widespread use of low emissions combustion system for civil aero engines of 50:1 pressure ratio which reduces NOx emissions at cruise by 60% compared to today's best production engines	Civil
Control Systems			
	61	Practical use of integrated engine and flight control systems for civil/military aircraft and helicopters for improved manoeuvrability, flight/operating envelope and emergency handling, and reduced fuel usage and crew workload	Both
	62	Demonstration of airborne platforms with all electric actuation, control and signalling giving the same vehicle performance capability as hydraulic systems, but with less weight and lower cost	Both
	63	Practical use of intelligent wings with disturbed sensors and actuators, for civil aircraft, leading to a reduction in weight, and an increase in fuel efficiency and airframe life	Civil
	64	Practical use of active control technologies including management of instabilities (eg surge) to enhance the performance of gas turbine engines	Both
	65	Widespread us of distributed control systems which improve civil aircraft operational performance and reduce weight and cost	Civil
	66	Widespread use of multivariable and intelligent controls on aircraft, helicopters and engines to improve their operational characteristics, including noise and vibration reduction	Both

	67	Widespread use of intelligent health and usage systems, to facilitate fault diagnosis, isolation and process reconfiguration, and provide increased safety and continued functionally, so enabling maintenance on-condition and reduced costs	Both
Sea and Land Systems			
	68	Practical use of a stealthy aircraft carrier fast enough to keep up with the main battle group after periods of steering into wind	Defence
	69	Practical use of a highly manoeuvrable 120 knot, stealthy missile patrol boat	Defence
	70	Practical use of non-nuclear submarine with a sub-surface endurance of at least 14 days and high efficiency propulsion system	Defence
	71	Practical use of a 2-man highly manoeuvrable, very robust and stealthy combat vehicle of less than 15 tonnes, sized to fit 20 tonne class air transport, with anti-tank capability and low life cycle cost	Defence
Weapons and Counter Measures			
	72	Demonstration of an affordable modular missile system with all-weather detection and tracking, target identification, precision guidance and rapid C3, against stealthy aircraft, terrain-masked helicopters and guided/ballistic missiles	Defence
	73	Practical use of a stealthy missile with autonomous imaging precision guided munitions for dispersed land/sea targets capable of return and recovery if no target of reasonable value is located	Defence
	74	Introduction of new energetic materials which have high energy efficiency, low vulnerability, high stability and are safe and easy to handle	Defence
	75	Practical use of a small-arm with a pattern-recognition sight which will automatically fire when the boresight crosses a target preselected by the soldier	Defence
	76	Practical use of non-explosive anti-personnel mines that incapabitate for a substantial period but do not injure permanently, and which have remote control and totally reliable automatic disposal	Defence

77	Practical use of easily crated, non-detectable barriers and incapacitating mines which discriminate against a range of land and sea targets, and are remotely-controllable and guaranteed safe when no longer required	Defence
78	Practical use of countermine equipment capable of incapacitating plastic mines during over-flight	Defence
79	Practical use of a low cost suite of sensors, lasers, jammers, and decoys to protect land platforms against missile attack	Defence
80	Demonstration of low cost, passive electromagnetic measures, including improved platform/propulsion integration, which significantly reduce platform signatures with minimal degradation in performance and no maintenance penalty	Defence
81	Demonstration of technologies which enable platform signature to be actively tailored to counter a perceived threat, eg by generation of alternative decoy/pseudo-covert signatures	Defence

Policy/General

82	Widespread application of commercial business processes (including concurrent engineering) to defence procurement, which reduce life cycle costs by 30% and halve procurement timescales	Defence
83	Widespread use of synthetic environments and multi-sensory techniques for mission rehearsal, planning and decision-making, for defining equipment requirements and for at least 25% of all military training	Defence
84	Practical use of multi-disciplinary whole aircraft/missile optimisation suite of design tools for product definition encompassing aerodynamics, electromagnetics, structural strengths and dynamic techniques able to cope with practical engineering constraints	Both
85	Widespread use of fault tolerant software for safety critical systems with a tenfold improvement in development productivity, thereby equalling the certification costs of non-safety critical systems	Both

86	Demonstration of bulk superconductors for power systems capable, when cooled to 77K, of driving military platforms including submarines	Defence

ANNEX D. THE REGIONAL WORKSHOPS

INTRODUCTION

This paper summarises the modus operandi and overall findings of the series of Regional Workshops held by the Defence and Aerospace panel.

LOCATIONS AND ATTENDEES

The panel held 4 workshops, at the locations and dates, and with numbers of attendees, as shown in the following table:

DATE	LOCATION	ATTENDEES			
		Academic	Industry	Government	TOTAL
25 October	London	6	10	5	21
27 October	Bristol	2	18	2	22
1 November	Manchester	6	18	0	24
10 November	London	11	18	11	40
Total Attendees		25	64	18	107
Percentages		23	60	17	100

230 individuals had originally been invited to participate; around 50% accepted and 90% of those actually attended. The balance of invitees had been 55% industry (manufacturers and users),35% academia and 10% government. Although each person was invited to a specific workshop, all were offered the opportunity to attend any of the 4 being held.

Each workshop was attended by panel members and panel support staff.Facilitation support was also provided.

MODUS OPERANDI

At each workshop, the Chairman for the day (a panel member) gave a brief introductory presentation outlining the aims of the workshop. The Technical Secretary then gave a presentation on the overall Foresight process before the facilitator presented results from the Delphi survey.

The Defence and Aerospace panel had set the dates of its workshops such thatresults from the postal Delphi would be available. The panel had not wanted theirDelphi presentation to include just the results from a small sample of workshopattendees. An analysis of the postal Delphi survey data was available and provideduseful presentation material, including a whole series of interestingcross tabulations.

Prior to the workshop, attendees had been furnished with a copy of the panel'sPreliminary Report and a proforma listing the major issues the panel hadidentified in its early analysis, requesting them to indicate those issues they wouldwish the workshop to address. These issues, posed as questions, were arrangedunder the following headings: Role of Government, Competitiveness, Investmentand Funding, Skills, Markets and Products, Costs, Modelling and TechnologyTransfer. Attendees were also offered the opportunity to nominate issues of theirown choice. Analysis of these returns was used to set the topics for the syndicategroup discussions.

There are common issues affecting Civil Aerospace and Defence, but the marketdrivers are sufficiently different to have led the panel itself to break into 2 distinctsub-groups, and the workshops were organised along the same lines. In returningtheir issues proforma, attendees had also indicated whether they wished toparticipate in a Civil Aerospace or Defence syndicate.

Each workshop held 2 syndicate discussion sessions. At the first Londonworkshop, the first session had focused on the Delphi results. It proved ratherunproductive, concentrating on the perceived shortcomings of the process. Whilstthese views will be heeded, the first session of the remaining workshops wasexpanded to focus on markets, products and technologies, using the results ofDelphi analysis to inform the discussion. The second syndicate session at eachworkshop focused on the major issues highlighted by attendees' responses.

A questionnaire was issued asking attendees to comment on the workshop itselfand what they regard as the major issues not covered. Responses were helpful inmonitoring the success of the approach adopted, and have provided usefuladditional material for the panel to consider.

FINDINGS - GENERAL

Although this panel has had the best response ofall to the Delphi questionnaires, there was some criticism of the Delphi process,mainly complaints that many topics had tried to include too much and that toomany aerospace topics had been included at the expense of land and sea systems.Sea Systems were well represented at the Bristol workshop and have provided thepanel with valuable material on marine markets. Several workshop attendeesregretted that definitions of wealth creation and quality of life had not been givenand that these terms were ambiguous. In general, though, audiences accepted thepanel's view that most people had an intuitive understanding of the terms, sufficient for them to pass judgement on what degree of impact a topic wouldhave on each.

Perhaps unsurprisingly for this sector, there were no regional issues raised at any of the workshops.

The following presentation reports the overall findings, in bullet pointformat, against the 2 themes of Markets, Products and Technologies andMajor Issues, arranged under Civil Aerospace and Defence headings. Itconcludes with a summary of the headline findings.

FINDINGS - MARKETS, PRODUCTS AND TECHNOLOGIES

Civil Aerospace

- Cost reduction is essential, through application of technology to products,but principally by re-engineering business processes, including concurrentengineering. Example: 747 needed 40,000 shims to correct manufacturingerrors - 777 required just 4.

- The Delphi had captured the main global market issues, but had omitted some promising niche markets, eg supersonic bizjet.
- The equipment/component sector makes a large contribution to the added value of aerospace platforms and overall sales. It was important to involve this sector in risk-sharing partnerships.
- Collaboration was reducing the number of UK-specific whole platforms,and this was reducing the opportunity for UK industry to apply its systemintegration skills which is a particular UK strength.
- Regarding emerging competition, notably in the Far East, somesaw parallels with the UK shipbuilding industry. The off loading ofmanufacturing activity to emerging competitors would inevitablybe accompanied by technology leakage.
- Estimates of 5% growth per annum in the Civil Aerospace market wasgenerally agreed. The Pacific Rim and China were seen as particularly highgrowth markets (Chinese market growing at 40% per annum). The FarEastern market could absorb its projected growth, but problems wereforeseen in Europe and the US unless air traffic control issues were notaddressed.
- A number of specific market opportunities were identified: increasedcomfort for smaller aircraft, further noise reduction (up to 20dB could befeasible), VLCT (in collaboration). Key product/ technology areas arewings, aero-engines, composites and laminar flow.

Defence

- Estimates of **15-20% reduction in world defence markets**were probably accurate.
- Basic defence conundrum: **technology edge** is needed to stay ahead onthe battlefield. **Equipment for export** must therefore provide thecustomer with an edge in his arena without compromising the UK'soverall technical advantage.
- The problem of selling into overseas markets without the UK ArmedForces procuring the kit is a real drawback.
- **Dual-use**, and more specifically the adoption of **commercialstandards for defence equipment** was highlighted as a majorpotential contributor to cost reduction, but who will pay for clearing thesecommercial standards.
- UK has strengths in **customisation,** matching what could emerge as a feature of future export equipment buys.
- MOD should be more flexible in allowing equipment specified for its ownrequirements to cater more for **export needs.** Upgrade for MOD, rather than downgrade for export, was the recommendation.
- UK has strengths in **customisation,** matching what could emergeas a feature of future export equipment buys.
- MOD should be more flexible in allowing equipment specified for its ownrequirements to cater more for **export needs.** Upgrade for MOD, ratherthan downgrade for export, was the recommendation.
- The Delphi has not given sufficient cover to **Marine** topics.Valuable material was provided on potential marine defence products.
- **Upgrading existing platforms** which are required to continue inservice longer than originally envisaged was seen as a potentially largemarket in which the UK has strengths. **Modular systems** benefit thisapproach.
- **Affordability** will become an even more important criterion -investment in **lean manufacturing technology** is vital.
- **Human factors** are important in considering marketopportunities. Users' and maintainers' requirements must becarefully assessed.
- Several specific **market opportunities** were highlighted: information,non-lethal weapons, simulation/synthetic environments, autonomousvehicles, logistic systems, anti-terrorism.

FINDINGS - MAJOR ISSUES

Civil Aerospace

- Aerospace needs **Government support** because of timescales and scale offunding required. Need to compete on level playing field.
- **Many aerospace strategy initiatives:** NSTAP (1992), HoC SC(1993), SBAC (1994), Foresight (1995). The UK needs a nationalstrategy for aerospace.
- Danger that current market success is product of technology with roots in1960s research - need to **establish research base for futuremarkets *now***.
- **UK strengths** lie in its knowledge base, access to market, systems/subsystems and a low cost economy.
- **UK weaknesses** lie in productivity, marketing and teamwork(within companies, with suppliers and industry/academia).
- **Technology Demonstrators** are vital in maintainingcompetitiveness and reducing risk.
- **Civil/Military interdependence:** either re-direct funding to DTI for industrial base development, or give MOD a wealth creating role.
- **Reducing whole life** cost is paramount - it is cost competitiveness that winscontracts.

Defence

- Under **competitiveness,** hygiene factors such as quality,conformance, ownership costs, reliability, timeliness and flexibilitywere identified as important. **Benchmarks** were defined: order backlog,market share, productivity, employment. IPR and 'Not Invented Here'(NIH) were identified as barriers to progress. There was a suggestion ofMOD Framework programmes to encourage industry to collaborate onprecompetitive research.
- The **role of Government** attracted much discussion. Many stated that either MOD should have a specific brief for developing wealth creating opportunities, or should act more in partnership with DTI to foster same.The focus on competition had gone too far - the UK needs a strong defenceindustrial base for strategic reasons, and the case can be made on the basisof long term cost effectiveness for MOD itself. But many thoughtGovernment should apply an holistic/systems approach to defenceprocurement, as do the French and US.
- **Technology transfer** was a popular discussion issue. **Partnerships**between industry and university were encouraged, but only where the jointstakeholders had a Joining share - this ensured real commitment.Universities need to be more highly motivated to support wealth creation.Work which is industrially relevant should have similar recognition to thatwhich is academically excellent. **People** were the main agent of technologytransfer. A number of practical suggestions for fostering technology transferwere made: staff development, industrial clubs, Centres of Excellence, benchmarking, cross-sectoral S&T programmes, directed programmes.
- A major problem in the UK was bridging the gap between research anddevelopment, and again the call for more investment in **TechnologyDemonstrators** was made.
- On **Skills,** there was surprise that the Delphi had shown skills to beunimportant as a constraint to realisation of nearly all topics. Loss ofnational facilities was highlighted by the marine sector, with a request thatfacilities should be better utilised and offered at marginal cost. There was acall to identify and build core competencies matched to wealth creatingmarkets.

SUMMARY

Overall, the following comprise the principal pointsemerging from the workshops:

- UK needs a **national aerospace strategy**
- **Cost reduction** is vital for marketsuccess
- **Technology demonstrators** are vital to plug the skills gap andprovide low risk technology
- UK needs a **strong defence industrial base** for strategic reasonsand to ensure future low cost procurement
- The panel should focus on **real markets** and not be tempted to look for 'wild' ideas
- **Foresight** must be seen to make a **difference**

ANNEX E. OUTCOME OF WIDER CONSULTATION

Introduction

In July 1994, the panel wrote to a number of Professional Institutions, TradeAssociations and other bodies (see attached list at Appendix 1) seeking names forthe expert pool, and also requesting advice on those issues these organisations feltwere important to the sector. The scoping survey approach - the 'chain' of drivingforces, trends, markets, products and technologies - was outlined and organisationswere invited to consider framing their responses in these terms. In addition, anumber of organisations and individuals have contacted the panel direct andsubmitted their views (see Appendix 1 list).

Nearly all the groups contacted provided names for the panel's expert pool, andmany made many useful contributions on sectoral issues which the panel has usedin formulating its recommendations. The SBAC, Institute of Physics, IEE andUKISC provided particularly comprehensive inputs.

The results of these consultations have been summarised under two headings.Firstly, the market demand, product/process needs and technology requirements arepresented in tabular form at Appendix 2, and summarised below. The strategicconcerns expressed by respondents have been listed in bullet point form below.

Markets, Product/Processes and Technologies

All respondents laid great emphasis on the need to reduce cost and time to market,and stressed the importance of **business process re-engineering and newmanufacturing processes** to achieve this. Many examples of specifictechnologies were given - these are summarised below and have been incorporatedinto the main body of the report.

The rapid changes in the global security situation - collapse of Warsaw pact,growth in regional powers and conflicts, unstable regimes, declining defencebudgets - have implications for defence markets, and defence equipment and theirunderpinning technologies.

The biggest markets will be in the Pacific Rim and Middle East, withcompetition coming from USA, Russia, South Africa and China. The US threatwould grow as it maintained its expenditure on defence technology. Surprisingly,France was omitted from this list.

Respondents saw the need for the following broad products and productcharacteristics:

Affordable weaponry
Flexible weapons systems
Ballistic missile defence
Stand-off weapons systems

Smart, precision weaponry
Unmanned surveillance and attack aircraft
Non-lethal weaponry for peacekeeping

The important underpinning technologies would be surveillance and trackingsystems, with their associated sensors, command/control and data fusion systems,advanced structural materials, lightweight structures and smart structures,aerodynamics, advanced control & guidance. Improved modelling of physical,manufacturing and business processes will grow in importance, as will the relatedtechnologies associated with simulation and synthetic environments. There wouldbe a need for affordable systems with superior performance to compete with lowcost technology from Russia and China.

Strategic Concerns

There were several issues raised by respondents which, whilst not related tospecific technologies, express strategic concerns for the long-term UK technologybase. These are summarised below, and have been extensively drawn upon by thepanel in identifying barriers to progress and framing its policy recommendations:

- The growing demand for **Systems Integration** expertise is notreflected in any appropriate demonstration programmes designed toenhance skills/ capability;
- **International collaboration in R&T** is essential, but should bebased on a sound national programme;
- The UK Government must recognise the role it has to play in creating alegislative and financial environment which will encourage the **longterm investment** necessary for leading edge technologies;
- **The UK Defence Equipment Procurement programme** is animportant mechanism for supporting the UK's technology base, and theUK should audit future defence procurements to identify those thatimpact on commercially important technology areas;
- **The exploitation potential** of civil communications andcomputing technology in the defence field should be carefully considered;
- Access to **state-of-the-art materials** can be vital in establishingmarket position, and steps must be taken to ensure such access wherethere is no indigenous supply;
- In defence, there will be a growing requirement for **interoperabilityof services** between user groups, both nationally and internationally;
- There will be a greater emphasis on **dual-use technologies,** witha growing requirement to adapt technologies from the civil sector fordefence applications;
- The movement to **'off-the-shelf/ defence procurement** threatens to erode national skills and experience;
- There is an urgent need for a **UK technology development strategy**the programmes which generated our currently successful products are 1020years old;
- There should be greater emphasis on the role of **TechnologyDemonstration** in reducing risk cost and time to market;
- The **Ministry of Defence** should have a formal responsibility for theUK defence industrial base and **national wealthcreation;**
- Despite the low priority given to **skills/education** in theDelphi responses, there are key areas where education weaknesses needaddressing, notably Design & Systems Integration and Simulation,Modelling & Synthetic Environments;

APPENDIX 1 TO ANNEX E

List of Professional Institutions, Trade Associations and other organisations contacted

Defence Scientific Advisory Council
Defence Industries Council
Defence Manufacturers Association
Electronic Components Industry Federation
Electronic Engineering Association
Engineering and Physical Sciences Research Council
European Regional Airlines Association
Federation of Electronic Industries
Institute of Physics
Institute of Marine Engineers
Institute of Materials
Institute of Energy
Institution of Electronics and Electrical Incorporated Engineers
Institution of Mechanical Engineers
Institution of Mechanical Incorporated Engineers
International Institute for Strategic Studies
Marine Technology Directorate Ltd
Nautical Institute
Royal Society
Royal Institution of Naval Architects
Royal Aeronautical Society[b]
Royal Commission on Environmental Pollution'
Society of British Aerospace Companies
Society for Underwater Technology
The Meteorological Office
The Royal Academy of Engineering
The Engineering Council
The Institution of Electrical Engineers
UK Equipment Industries Management Group
UK Industrial Space Committee

The following organisations and individuals provided writtenadvice to the panel

Shell Aircraft Limited
Particle Physics and Astronomy Research Council (PPARC)
MSF (Manufacturing, Science and Finance) Trade Union
Professor M V Lowson (Bristol University)
Mr Tom Kerr
Professor David Andrews (University College, London)

ANNEX 2 TO ANNEX E

Market Demand	Product/Process Need	Technology Requirement
Reduced first cost and time to Market	Design for economic manufacture	Concurrent engineering business process re-engineering
	Reduced assembly manufacture	Increased automation, Jiggless assembly, Computer modelling of manufacturing processes, Computerised factories, Low cost joining methods, manufacture of large components (rapid casting, SPF/DB)
	Low cost manufacturing processes	Further automation, Computer aided engineering, Computerised machine centre
	Reduced cost composites	Low temperature curing, Non-autoclave curing, Low cost fibres and thermoplastics, Low cost pre-forming, Autoclave optimisation
	Reductions in non-recurring cost (design, tooling, testing)	Improved materials databases, Rapid prototyping, Exploitation of commercial electronic components, Knowledge-based design tools, Design optimisation methods, Low cost tooling, manufacture, More sophisticated accurate and reliable computer modelling, Improved requirements capture automated generation of certified code for safety critical systems.
Reduced cost of ownership	Corrosion resistant components	Improved materials and coatings
	Inspection procedures	Improved in situ techniques, Reliable, low labour corrosion detection
	Reduced need for inspection	Damage tolerant materials, Better understanding of damage tolerance, Sensor integration in structures for HUM
	Improved engine reliability	Health monitoring and on board fault diagnostics
Weight reduction	Mass optimisation software	Improved solid modelling, Improved processing power to facilitate use of finer elements
	Higher strength to weight materials	Improved property Al-li; alloys, spatially-reinforced composites
	Extension of composite use	Metal matrix composites, Toughened epoxies, Computer modelling of composite impact damage, Lightweight structural cores

	Engines	High power density/low weight heat exchanges, High temperature super conductors
Increased fuel efficiency	Drag Reduction	CFD codes for aerodynamic shape optimisation, Laminar flow technology, Software for multi-variable optimisation of whole aircraft
	Reduced engine fuel burn	Improved materials for higher cycle temperature and pressure, Improved cooling technology CFD codes
	Reduced engine bleeds	Alternative power sources, High temperature electronics
	Smart controls	Advanced control system technology, e.g. optics, fuzzy logic, neural networks, Integrated engine/airframe control, Active controls to improve engine performance
Superior performance and capability	Advanced data management and communication	Satellite-bases sensors and communications, Pattern recognition/ feature extraction, High data rate theatre communications, Information management software, Sensor technologies, Data fusion, Wide band communications, Improved real-time intelligence gathering, analysis and dissemination, Flexible human machine interface, Remote data-link tele assistance
	Flexibility and mobility	Improved design methods for large, complex, real-time C3 systems
	Reduced engine auxiliary power	All-electric aircraft, High integrity electrical actuation, Electric power management, High density electronic system, Miniaturisation/ruggedisation
Multi-operational capability	Multi-weapon carriage	Functions determined by software, not hardware, Hardware/software reconfiguration, Rapid weapon management system software re-load
	Quick role change; real-time mission re-planning	Very much more intensive software engineering processes
	Counter-threat capability	Mobile threat counters, e.g. ABM, NBC, DEW
Survivability	Stealth	Signature reduction and control, Covert optical data communication, Stealthy materials
	Damage survival	Distributed avionics, Automated first line test & repair

	Crew assistance	Artificial intelligence crew assistance, Comprehensive health diagnosis & prognosis, System health sensing/ profiling
	Autonomous weapons	Precision strike technologies, Sensors & data/image processing
Product customisation	Lean/agile manufacturing	Modelling of whole design to assembly process optimisation of business process
Increased air traffic	Sophisticated air traffic management	All weather ground management systems, High integrity, failure survival satellite navigation and communications 4-D flight path control
Response to congested airspace/airports	Very large commercial transport	Noise-reduction, High stiffness, low weight materials
Response to congestion in ground-based transport	Economical short-haul aircraft	Low cost STOL, quiet fuel efficient engines
Commercial aircraft passenger appeal	In flight entertainment and communication, Quiet cabin	Computer/avionics, Reduced engine noise, Cabin noise suppression (active & passive)
	Increased aircraft speed & supersonic transport	Higher temperature structural composites, Transonic flight drag reduction, Dual-cycle engine
	In flight business centre	IT systems, video & telecommunication world wide, high reliability communications, Commercial data management and cryptographs, Electronic document processing systems
Increased environmental sensitivity/regulation	Reduced fuel use	Reduced airframe weight via materials & design methods, Recyclable materials
	Reduced use of environmentally unfriendly materials, Reduced noise	Noise absorption technology, Understanding of underlying proccess-modelling
Improved vehicle, health and safety	Improved HUMS	Smart materials, structures & system
	Collision avoidance	Intelligent aircraft control technology
	Navigation system, Improved ice protection	Satellite-based navigation, Ice accretion modelling, Low weight and energy protection systems
	Avoidance of human error	Automation of crew function, Monitoring crew decisions

Fault tolerant systems	Smart structures, Continuous monitoring of system condition, Miniaturisation of sensors and components, Safely certified automatic software engineering processes.

ANNEX F. RELEVANT FINDINGS FROM OTHER FORESIGHT PANELS

F1. The Panel identified the following five sectors as having particularly relevance to Defence and Aerospace:

- Communications
- IT & Electronics
- Manufacturing, Production and Business Processes
- Materials
- Transport

F2. Defence and Aerospace panel members were appointed to act as links to the panels covering these five sectors. In the case of Materials, the Defence and Aerospacepanel link member, Dr Julia King, was also a member of the Materials panel.

F3. The first four of the above sectors act primarily as technology providers for the Defence and Aerospace sector. Transport is mainly a technology user, the linkswith Defence and Aerospace stemming from the overlap in air transport and somecommon technology requirements in, for example, the telematics and vehiclematerial/structures area.

F.4 The emerging findings from these 'link' panels have been reviewed for issuesrelevant to the Defence and Aerospace sector. The results of this review arepresented in two tables, with short commentaries, as follows:

- **Table F1**- identifies the Key Technical Priorities highlighted in theDefence and Aerospace report which have similarities, and/or are relevant,to the findings of other panels;
- **Table F2** - identifies the major issues relevant to Defence and Aerospacehighlighted by each of the link panels, and the areas of the Defence andAerospace sector that are affected. Any action required by the Defence andAerospace panel in response to a cross-sectoral issue is also highlighted inthis table.

F.5 Future developments in the Defence and Aerospace sector will be particularly dependent on IT- and materials-based technologies. Appendix 1 and provide a more detailed commentary on the issues arising from the IT &Electronics and Materials panels respectively, with Appendix 2 reportingon the results of the Materials Delphi topics relevant to Defence and Aerospace.

F.6 The Transport Panel also included a number of Delphi topics relating to AirTransport. Comparison of these results with the Defence and Aerospace panelDelphi is reported at Appendix 3.

Ref	Key Technical Priority	Comms	IT&E	Manuf	Mater	Trans

1	Design and Systems Integration		2			1
2	Process Technologies		2	1	1	1
3	Materials and Structures		2		1	1
4	Simulation, Modelling and Synthetic Environments		1	1	1	1
5	Aerodynamics (including emissions and noise reduction)					1
6	Sensor Systems, Data Fusion and Data Processing	2		2	1	1
7	High Integrity, Real-time Software	2	2			1

Key Technical Priority has some similarities to link panelrecommendation

Key: 1 Key Technical Priority is very similar to major recommendation from link panel

2

3 Key Technical Priority is relevant to link sector, but not explicitly identified in link panel report

Short Commentary

The Manufacturing, Materials and Transport sector recommendations showed ahigh level of overlap with the Defence and Aerospace Key Technical Priorities.Perhaps surprisingly, the IT & Electronics and Communications sector panelsmade little reference to Defence and Aerospace, despite the potentially largemarket for IT-based products that this sector represents. These panels did nothighlight specific key technical priorities.

APPENDIX 1 TO ANNEX F

IT & ELECTRONICS PANEL

Summary of Commercial IT & ElectronicsTechnology Trends

Systems Axioms

Some of the axioms which have been observed or assumed in the IT market placeare:

At constant performance, a system reduces in cost by a factor of 10every decade.
At constant cost, a system increases in performance by a factor of 10every decade.
Users have constant purchasing power which buys increasingly powerfuland functionally rich systems.
Many system images remain constant (the use of Fortran as aprogramming language, Windows technology as a user interface, thespreadsheet as a management tool, etc).
Technology discontinuities create new products (the microprocessorleading to the development of the PC, flat screens leading to thedevelopment of the laptop computer, etc).

Systems Theorems

Systems migrate through the market (the corporate mainframe of the 1960s is theconsumers' PC of the 1980s, the aircraft simulator of the 1970s is the arcadegame of the 1990s).

The raw power of a given user's system increases by a factor of 10 every decade.But an increasing proportion of that power (processing and memory) is absorbedby the user interface.

Technology Challenges

a)
Weight. Present packaging technology is too heavy forconvenient consumer products. The first solution is to abandon individual packagingof individual chops in favour of module or product packaging. The secondsolution is to reduce the operating voltage, and thereby reduce the batteryrequirements. This should happen within five years.

b)
Cooling. Cooling is already a problem with present packaging; it couldbe aggravated still further by solutions to the weight problem. The solution isto reduce the operating voltage to one volt or below, eliminating coolingfans, reducing battery weight and improving speed and reliability.

c)
Cabling. Cabling between computing modules is unreliable, inconvenient and costly. Look to radio, audio, or optical links to eliminate thisproblem.

d)
Complexity. Software complexity is a major logjam particularly inthe development time for large systems. The palliatives for this are less likelyto come from improved languages, provability and other software techniques,than from the increased use of multiple processor systems, ensuring muchbetter modularisation and separation of software functions.

e)
Security. The increasing degree of interworking will focus attention on the problems of security in computer systems. It is easy to provide securityon the transmission of information; the problem lies with the ability tocreate protection against subversion of the internal security of a computer.Present levels of computer security are extremely inadequate, but cannotreadily be improved without radical changes to the operating systems andprobably to the hardware itself.

f)
Efficiency. Present software is appallingly inefficient in its use ofmemory and processing.

Technology Discontinuities

Steady progress is being made in most areas of IT. However, therearediscontinuities where leaps in progress are made, or changes in particular methodsof doing things occur very quickly. Examples of this are: the convergence betweenthe TV set, the PC and other office products; the explosion in the use of interorganisation networking via Internet; the use of video disks to store huge amountsof data compactly; the use of hand-held communications devices, etc. New marketsare created by, amongst other things, technological discontinuities.

Product Evolution

i)
The Supercomputer. There is a continuing trend towards massiveparallelism. As a consequence, very rapid performance and price/performance improvements, above the historic trend, ie 100x will occurover the next ten years. However, there is a very slow trend towardslanguages and programming techniques which exploit parallel processingmore

effectively.

ii)

Servers. There will be a continuing replacement of the programmable mainframe by the server, providing the central resources and facilities for acomputer network.

There will be a continuing replacement of bespoke software by standardpackages, and packages customised by consultants.

iii)

Workstations. There will continue to be a market in the 0K to0K bracket for a personal system for the professional user.

There will be an increased emphasis on 3D graphics and improved 3Duser interaction, with immersive virtual reality becoming thegenerally accepted interface for a wide variety of applications.

The workstation market will be distinguished by an increasing range ofprofessional software packages closely targeted at specific industriesand applications.

iv)

The Video terminal. There are a variety of separate developmentswhich will affect the personal computer; many of these are happening at the sametime, leading to a confused period.

The most immediate development is the increased use of local areanetworks, and the consequent growth of group-ware. This will have aradical impact during the rest of this decade on the way in which peopleinterwork in offices and companies. A far greater proportion of companyinformation will be computer based.

Paralleling this, but somewhat later, will be interworkingbetween companies through Internet and its successors.

There is the obvious converge between the television set and various officeproducts; personal computer, telephone, answerphone, videophone, fax andcopier. This is leading to the emergence of the video terminal, the ultimateproduct being an HDTV (High Definition TV) resolution monitor, videocamera, user interface processor, floppy disc and compact disc, and highbandwidth local or remote communications interface. The resulting productwill be used primarily for displaying, storing and editing video and textinformation.

v)

Notebook systems. There are a variety of technology innovations,which will be incorporated into more powerful products, but will have mostimpact on the form of the notebook computer. The present laptop and pencomputers have serious limitations in ergonomics (poor displays, tooheavy, too bulky, etc). These limitations will be resolved over the next 10years, making the notebook computer the hand-held terminal of thefuture, displacing the mobile phone, whose functionality it will incorporate.

The key developments are: a) paper quality lightweight display (before theyear 2000), b) pen or brush touch sensitive display, c) handwriting inputand d) voice input.

vi)

The Head-up computer. Making large displays will always beexpensive.

The future is the head-up computer - a pair of glasses which can optionallydisplay over part or all of the field of view a computer generated 3D image,eliminating the need for conventional displays.

vii)

Embedded systems. The theme is programmability. The basic component is the PC chip, a programmable device incorporating a DOS basedoperating system. Because the designer works entirely at a supportedsoftware level, product development is cheaper, lead times are reduced, andvariants, or improved products can be introduced at low cost.

Summary of Defence & Aerospace IT & Electronics Trends Useof Commercial Electronics by Defence & Aerospace Sector

The UK faces continued pressures in declining defence budgets and will movetowards greater use of Commercial off-the-shelf (COTS) procurement of newmilitary equipment. Military requirements in IT and Electronics will continue, butwith greater emphasis on cost reduction in military systems. Defence andAerospace applications will track and utilise components and technologies whichhave been developed for high volume commercial applications, with enhancementswhere particular characteristics are required for Defence &Aerospace applications(eg. temperature range, ruggedness, radiation tolerance). In the future, it is likelythat specific technologies will only be developed for Defence and Aerospaceapplications where there is no perceived commercial application or wherecommercial development is proceeding too slowly for specific Defence andAerospace projects.

Military Specific Electronics

Areas where military specific technologies are likely to be required include:

- Protective devices for sensors against battlefield laser threats
- BLIP limited IR detectors and the hardening of all IR detector/sensors.
- Tuneable radiation sources for the remote detection of chemical pollutantsand other military applications.
- Signature control of military platforms.
- Synthetic aperture radar imagery and reconnaissance processing.
- High speed, high accuracy, ADCs for the conversion of sensor output intothe digital domain.
- Very high bandwidth, reconfigurable, photonic data highways for the high EMIenvironments.
- High accuracy and robust direct voice input in harsh environments.

Enhancements to Commercial Electronics

Areas where enhancements will be required to commercially driven technologiesinclude:

- Key aspects of information processing, in the digital domain, includingimage understanding and

machine vision, information fusion, humancomputer interfaces and embedded processing from humans through tosophisticated sensor suits.
- Optical signal processing using advanced photonic devices and advanceddigital signal processing algorithms integrated with supporting hardware forsensors, weapons and communication systems.
- Highly parallel computing systems of small size and low powerconsumption for real-time applications requiring very high performanceprocessing.
- High power, efficiency and frequency GaAs device and MMICs forimproved solid state transmitters for radar and communicationapplications.
- Embedded computers and software for high integrity applications, parallelprocessing, neural nets and robust algorithms.
- High absolute resolution and large area LCDs including 3D displays.
- Thermal detectors for low cost lightweight sensors.
- Integrated silicon transducers, ASICs and multi-chip modules forapplications requiring small size and weight and low power consumption.
- High temperature superconductor devices for microwave filters, magneticanomaly detectors and power control.
- Discrete event modelling and simulation.
- Bulk synthetic diamond for high speed missile domes and genericelectronic applications.
- CAD tools for high power microwave radar tubes.

APPENDIX 2 TO ANNEX F

MATERIALS PANEL
Introduction

In the Materials Panel assessment of industrial sectors in which improvedmaterials technology would have a major impact, both Defence and Aerospacescored highly. The Materials Panel report recommends that an increasedproportion of available resources should be focused on several topics highlyrelevant to Defence and Aerospace: sensor materials and devices, weight savingand high temperature materials and improved materials for IT andtelecommunications .

Other common features of the Materials and Defence & Aerospace conclusionsinclude the need for integrated supply chains, partnership programmes andindustry-university links through 'Centres of Excellence'. Materials also noted theneed for multi-disciplinary training and research.

The current standing of the UK science and technology base and the ability ofindustry to exploit new developments in the aerospace materials area was ratedhighly compared to many other sectors.

The Materials Panel attempted to assess the importance of materials in wealthcreation/ competitiveness at higher levels in the supply chain. It asked all theother Panels to attempt to assess the value of materials in their products. Defenceand Aerospace was one of the few Panels to attempt a sensible reply. The valueof "materials" in various aerospace products ranged from about 2% (equipmentand airframes) to around 35% (aeroengines).

Delphi Survey

Comparison of the Materials and Defence and Aerospace Delphi responses yieldsthe following points:

- Both Delphi's showed the same general trend of UK being seen as astronger performer in science and technological capability than inexploitation and commercialisation potential.
- Whilst neither Delphi indicated particularly high levels of concern over theskill base (as a constraint), this was seen, on average, as slightly more ofa problem by materials than defence and aerospace.

A number of defence and aerospace related materials questions were included onthe Material Delphi.

Topic

1 (Material) Practical use of defect tolerant structuralmaterials for gas turbines capable of operating uncooled above1400°C in an oxidising environment. **58 (D&A)** Demonstration ofdefect tolerant structural materials for gas turbines capable ofoperating uncooled above 1400°C in an oxidising environment.

Despite the difference in phrasing, the Materials respondents expected thisadvance at least 5 years earlier than the Defence and Aerospace community.

The D&A respondents were more positive about the UK position from Scienceand Technology (UK at leading edge: 23% M, 45% D&A) through toexploitation and commercialisation (UK at leading edge: 13% M, 21% D&A).

80% of both communities saw lack of funding as the main constraint, with 40%of the Materials respondents anticipating industrial/commercial constraints,compared to 20% for D&A. 27% of Materials respondents were concerned aboutskill base, compared to 7% for D&A.

Topic2 (Materials) and **51 (D&A)** Widespread use of polymer resin composite systems for continuous operation above 350°c

In terms of time, the results for these were more similar, although withthe Materials respondents being a little more optimistic than the D&Areplies.

Responses on capability were very similar from both communities:

UK at leading edge:

	Materials	D&A
S&T:	19%	27%
Innovation:	27%	30%
Exploitation:	14%	15%

Funding was again seen as the main constraint, and the materials respondents were more concerned about the education/skill base (23%) than D&A (8%).

Topic8 (Materials) Elucidation of an understanding of thebrittleness of intermetallic materials leads to the design ofdoped intermetallics for practical use in a range of hightemperature applications. **59 (D&A)** Widepread use of lowdensity, heat resistant intermetallic compounds in aircraftengine".

In terms of time, the materials community was again about 5 years ahead of D&A.

Both communities had a similar view of UK position in S&T (40% atleading edge for D&A, 42% for Materials) but the D&A were moreoptimistic on exploitation (UK at leading edge: 8% M,21% D&A).

Other Materials Delphi questions relevant to D&Awere:

Q3 Semiconductors to operate at 500°C

52% 2000-2004

Q4 Ni base superalloys with 60°C higher T capability than current best

58% 2000-2004

Q5 Advanced thermal barrier coatings

38% 1995-1999

43% 2000-2004

Q10 New joining methods for composites and A1 alloys in transportapplications

59% 2000-2004

Q11 Joining methods for materials with widely differing coefficient of thermalexpansion coefficients

40% 2000-2004

Q13 Sensor fibres in composites

44% 1995-1999

49% 2000-2004

Q15 Materials with in-situ life monitoring capabilities

41% 2000-2004

Q22 Recycling methods for composites in aircraft and automobiles

44% 200-2004

Q33 Corrosion resistant, high temperature Mg alloys

42% 2000-2004

Q34 Lightweight energy absorbing materials for body armour

52% 2000-2004

Q37 Practical use of continuous fibre metallic and intermetallic matrixcomposites in gas turbines.

30% 2000-2004

35% 2005-2009

Q38 Low cost Aluminium MMCs with good mechanical properties

50% 2000-2004

Q78 Development of accurate modelling of behaviour of composite materialsused in aerospace components allows certifying authorities to acceptmaterials and process changes without extensive testing.

27% 2005-2009

30% Never

APPENDIX 3 TO ANNEX F

TRANSPORT PANEL
Results of Air Transport Delphi Topic Responses

The Transport panel Delphi questionnaire included seven topics relating to AirTransport. Three were identical to those posed in the Defence and AerospaceDelphi, and three covered similar ground. The Transport panel topics, and theirDefence and Aerospace equivalents, are shown at Table F3. The followingparagraphs present the Transport panel results and compare them with the resultsobtained through the Defence and Aerospace Delphi survey for the identical

Topic

1 (Trans) & 38 (D&A) Widespread use of large (>300 seats)subsonic aircraft which are quiet enough to take off and land at nightfrom airports in populated areas
D&A rated this topic as having a higher impact on WC than Transport, andlikely to be more beneficial to QoL.
D&A thought the topic would happen in 2005-2009,5 years behind Transport.
Capability ratings were very similar - very strong on S&T and Innovation.
Funding was the largest constraint in both cases.

Topic

6 (Trans) & 5 (D&A) The direct operating cost per passengermile of subsonic passenger aircraft is halved by measures whichincrease aircraft productivity and reduce aircraft first cost andthe cost of fuel, maintenance and crew

D&A rated this topic slightly higher on WC and significantly so onQoL.
There was no consensus from Transport on when this topic would occur. D&Abelieved 2005-2009.
Very similar assessments of capability.
Technical Feasibility and Funding were the top constraints from both Panels.

Topic

7 (Trans) & 12 (D&A) Practical use of all-weather Category 3aircraft landing, takeoff and taxiing system using non-visualtechnology (eg fused radar AR imaging conditioned by differential GPS)

Transport experts rated this more highly than D&A for WC, similar for QoL.
Both communities agreed that 2000-2004 was the most likely timeframe, andgave almost identical capability ratings.
Transport believed Funding would be the major constraint, whereas D&A citedRegulatory.

TRANSPORT	DEFENCE & AEROSPACE
1 Widespread use of large (>300 seats) Subsonic aircraft which are quiet enough to take off and land at night from airports in populated areas	Topics 38
2 International development of new air traffic management methods, technologies and standards to greatly increase safely the throughput capacity of European airspace	Similar to Topic 10
3 Commercial introduction of a supersonic aircraft with over 200 seats, range over 6000 nm and seat mile costs within 20% of subsonic equivalent	Similar to Topic 40
4 Commercial introduction of a subsonic aircraft with seating capacity between 600 and 1000 compatible with existing airport taxiways and stands	Similar to Topics 37 and 39
5 Commercial introduction of a quiet form of air transport for passengers or freight which does not require large scale airports or ground based facilities, eg VSTOL, airships, flying boats	No equivalent topic
6 The direct operating cost per passenger mile of subsonic passenger aircraft is halved by measures which increase aircraft productivity and reduce aircraft first cost, and the cost of fuel, maintenance and crew	Topic 5
7 Practical use of all-weather Category 3 aircraft landing, take-off and taxiing system using non-visual technology (eg fused radar/IR imaging conditioned by differential GPS)	Topic 12

Sector	Issue	Def & Aero Reference
Transport	Transport with improved capacity utilisation is needed.	Large civil aircraft, Improved ATC

	Demand should be spread over time and space (E. g. quieter so can fly at night and area navigation/ ATC?)	Quiet civil aircraft and helicopters
	Improved vehicle characteristics (more fuel efficiency, lower noise, lower cost, more capacity, higher safety, built in monitoring)	Materials and Structures
	Telecommunications, video phones, tele-commuting, virtual reality and remote monitoring could reduce the need for business travel (see also IT/E and Manuf)	Addressed in Civil Aerospace market analysis
	As concern over congestion and pollution increase, people will be encouraged to utilise collective transport systems rather than personal transport	Potential for aircraft to access short-haul routes, but cost and environmental issues must be addressed
Manufacture	Initial purchase cost reduction is vital. Can be partly achieved through: Integrated engineering process (incl. concurrent engineering); Production efficiency; Supply chain management; Team working (incl flexibility and multi-skilling); Integrated standards; Automated production processes	Coincides with a major theme of the Defence and Aerospace panel - potential for joint initiative
	Skill base: Delphi showed concerns, reflected in recommendation on business process awareness and continuing education	Def & Aero report addresses Skills needs despite Delphi
	In general, enabling developments in Manufacturing are estimated to occur 5 years ahead of the Def & Aero applications (Delphi)	Consistent with the relationship between the two sectors
	The perception of the UK positiion in all four capability	
	areas covered by the Delphi was consistently more pessimistic than Def & Aero	A potential area for joint benchmarking studies
	Environmental themes will dominate in 10-20 years, requiring additional manufacturing process costs.	Environmental issues in Manufacturing not explicitly addresses
Materials	Materials Panel Delphi indicates several advanced high temperature materials will be available 5 years before the Defence & Aerospace industry expects (from its Delphi).	
	Materials more concerned about skills base than D&A (Delphi)	Section 6 of Final Report
	D&A more positive about UK ability to exploit materials developments than Materials (Delphi)	
	Materials highlight requirement for industry involvement to achieve technology exploitation through integrated supply chains, partnership programmes and centres of excellence.	Section 7 of Final Report
	Importance of multidisciplinary approach to technical and commercial issues.	Sections 6 and 7 of Final Report

To remain in aeroengine design and manufacture, the UK must retain R&D capability in materials.	
Strong UK position in high temperature materials, weight saving materials and life prediction of structural materials	Reflected in Materials and Structures key priority
The cost of "materials" in aerospace products ranges from 2% (for equipment and airframes) to about 35% (aeroengines)	
Defence R&D has made a major contribution to civil communications in the wireless communication area. E.G. techniques to combat jamming are now used to improve spectrum reuse in the civil field: Frequency hopping techniques; Spread spectrum techniques; Adaptive (nulling) antennas; Phased array antennas; Cryptographic techniques; Component technologies such as TWTs, LNAs, etc.	
The increasing requirements for wireless access to telecom, networks (e.g. for mobiles) is putting pressure on defence frequency allocation. (Once frequencies relinquished almost impossible to get them back even in a period of tension.)	

ANNEX G

Benchmarking the Science Base

G1 The responses to the Defence and Aerospace Delphi questionnaire concerning (i) the ranking of current UK scientific and technological capability and (ii) theextent to which the educational/skill base was regarded as a constraint, paint apositive picture of the present UK science base in the Defence and Aerospacesector. In almost all areas, current capability was judged, on average, to be ahead ofother countries, with certain areas where the UK is world class. The educational/skill base was only seen as a significant constraint in one area, the application ofbusiness processes (although other inputs have led the Panel to highlight certainskills areas as requiring attention - see para G5 below).

G2 The last Universities Funding Council Research Assessment Exercise, covering 43,000 academics in 170 institutions, carried out in 1992, supports this view.Academic Departments with the top ranking of grade 5 (indicating work ofinternational excellence in some areas and national excellence in most others) arefound across the range of science and engineering disciplines which support theDefence and Aerospace industries. Table G1 shows that these grade 5departments represent a resource of around 1800 UK academics who couldpotentially contribute to Defence and Aerospace research and development.

G3 The Institute of Science Information Journal, Science Watch, produces leaguetables based on journal papers citations worldwide. The UK standing in Defenceand Aerospace related fields (see Table G2) for the period 1981-1991 was aboveaverage in almost all areas, but with particular strengths in (i) metallurgy, (ii)control and sensors and (iii) optics/acoustics, (iv) mechanical engineering and (v)electronics. At first sight, the UK's apparent weakness in Aerospace Engineeringmay be a concern, but it should be noted that this assessment is based on anaverage of only 24 papers per year, and publication in this area is sometimesconstrained by security or commercial issues.

G4 In general, UK academic capabilities provide a sound foundation for the future needs of the UK Defence and Aerospace industries. It is essential that thesecurrent capabilities are maintained and developed for the future.

UFC Subfield	No UFC grade 5 staff	No UFC grade 4 staff	Staff at grade 5
Physics	568	519	33%
General Engineering	302	96	31%
Elect & Electronic Engr	247	405	11%
Mech Aero & Manufacturing	219	345	13%
Metallurgy & Materials	105	126	16%
Computer Sci	338	316	19%
TOTAL	1779	1807	

Subfield	UK Papers 1981-1991	UK/World citation impact*
Metallurgy	899	+60%
Control & Sensors	1318	+58%
Optics & Acoustics	2041	+39%
Mech. Engr.	2331	+38%
Elect. Engr.	3294	+29%
Physics	6576	+18%
Materials Sci.	2877	+6%
Computer Sci	2505	-6%
Aerospace Engr.	243	-22%

G5 However, critical multidisciplinary and process-based technology areas are not well represented in universities. Particular effort needs to be focused on improving the science base in the areas of business processes and systems integration.

ANNEX H

Defence Sub-group Prioritisation Process

The following describes the Defence sub-group prioritisation process.

Step	Activity
1	A comprehensive market survey was carried out and scenarioswere generated from several sources (including the initialscoping survey).
2	From this market and scenario work, a set of key defence requirementswas derived (market opportunities).
3	In parallel, a taxonomy of about 450 defence products and technologieswas generated. The products were grouped into 62 broad defence systemdesignations (see Appendix H1).
4	A database of over 500 suggestions for technology improvement wasgenerated using a questionnaire-based survey and these were reviewed bythe panel to remove duplication and select the most significant in thecontext of the key military capabilities.(These were also used as the focus for the Delphi technology questions.)
5	The 62 defence system designations were prioritised by assessing thelikely overall world market and the likely opportunity for UK Industry toaccess the market and generate wealth. The 32 highest scoring systemareas are listed at Appendix H2. (They were the focus of the Delphiproduct questions.)
6	The Delphi survey for Defence and Aerospace was carried out as describedin Annex C.
7	An interim report was produced and distributed to invitees to theregional workshops. Four workshops were held as described in Annex D.
8	Views were sought from professional institutions, trade associationsand other organisations as listed in Annex E, and from other Foresightpanels (Annex F).
9	A comprehensive benchmarking process was undertaken by the DefenceIndustries Council who consulted over 200 UK firms.
10	The outcome from the regional workshops, Delphi survey, externalconsultations and the DIC benchmarking survey were combined togenerate the prioritised list of key technology opportunities detailed in the mainreport. Good correlation was found between the priorities from the DICbenchmarking survey and from the group's own prioritisation at steps 4& 5.

APPENDIX H1 - DEFENCE SYSTEM DESIGNATIONS

Land/Air

Tanks
Light armoured vehicles
Anti-tank guided weapons (ATGW)
Artillery
Ammunition
Precision-guided munitions (PGM)
Air Defence
Surveillance/Target Acquisition (STA)
Engineering (eg bridges)
Nuclear, Biological and Chemical Defence (NBC)
Trucks
Command, Control, Communications & Intelligence (C3I)
Mines
Counter-mines

Air/Land

Air Defence Fighter
Multi-role Combat Aircraft
Fighter Ground Attack Aircraft
Training Aircraft
Helicopters
Air-to-air weapons (AAW)
Stand-off Missiles (SOM)
Heavy lift Aircraft
Airborne Early Warning (AEW)
Airborne Stand-off Radar (ASTOR,
In-flight Refuelling (IFR)

Air/Sea

Maritime Patrol Aircraft (MPA)Airborne Early Warning (AEW)Carrier-borne aircraft
Helicopters
Air-launched anti-ship missiles (AASM)
Air-to-air weapons (AAW)
Airborne anti-submarine (ASW)
In-flight Refuelling (IFR)
Mines
Ship-launched SOM

Sea/Air

Surface Ships
Diesel submarine (SSD)

Nuclear submarine (SSN)
Patrol
Replenishment
Anti-submarine warfare (ASW)
Air Defence Missiles
Anti-ship missiles
Guns
Radar for ships
Command, Control, Communications & Intelligence (C3I)
Minehunter and counter-measures

National Air Defence

Surveillance/Target Acquisition (STA)
Missiles
Air Defence Fighter
Command, Control, Communications & Intelligence (C3I)
In-flight Refuelling (IFR)

Ballistic Missile Defence

Warning
Detection
Tracking
Destruction

Strategic Capability

Surveillance
Communications
Cryptographic
Intelligence
Global positioning system

Internal Security

APPENDIX H2 - KEY PRODUCT OPPORTUNITIES

Land/Air

Precision-guided munitions
Air Defence
Surveillance/Target Acquisition
Mines & Counter-mines

Air/Land

Air Defence Fighter
Multi-role Combat Aircraft
Fighter Ground Attack Aircraft
Training Aircraft
Helicopters
Air-to-air weapons
Stand-off Missiles

Sea/Air

Surface Ships
Air Defence Missiles
Anti-ship Missile
Radar for ships
Command, Control, Communications & Intelligence
Minehunter & Counter-measures

Air/Sea

Maritime Patrol Aircraft
Carrier-borne aircraft
Helicopters (Ship mounted)
Air-launched anti-ship missiles
Air-to-air weapons
Airborne anti-submarine
Mines
Ship Launched Missile

National Air Defence

Air Defence Fighter
Command, Control, Communications & Intelligence

Ballistic Missile Defence

Warning
Detection
Tracking
Destruction

Strategic Capability

Surveillance
Communications
Global Positioning System

Internal Security

APPENDIX 3 TO ANNEX H

Example of Product/Technology AnalysisAdvanced Air Defence Fighter (ADF)Aircraft

Sensor Systems with longer range, autonomous target detection andacquisition, and improved all-weather detection and discrimination. Improved IFFcapability.
Airframe Systems with health and usage monitoring, all-electric control andactuation, autonomous self-healing systems and improved environmental control.
Avionics Systems with highly re-configurable architectures, zeromaintenance, and highly interchangeable modules with multi-servicemodularity.
Propulsion Systems featuring higher thrust-to-weight ratio, variable cycle,improved integration with the aircraft, vectoring nozzles, and improved reliabilityand life cycle costs.
Human Machine Interfaces (HMI) featuring reduced crew workload andimproved situation assessment.
Defensive Aids System with improved protection against multi-spectralseeker systems, better DEW protection and zero false alarm rates.
Stealth achieved by balanced low observables (RCS, IR, acoustic, visible),with better modelling and in-service test and validation.
Guided Weapons with higher offboresight capability and improvedagility.
Communications with higher bandwidth and improved integrity.