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THE FLIGHT FROM DEFENCE TO CIVILIAN SPACE: EVOLUTION OF THE SECTORAL SYSTEM OF INNOVATION OF INDIA'S AEROSPACE INDUSTRY

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ABSTRACT

India is one among the few developing countries that have sought to establish an aerospace industry. The industry has two components, namely aeronautical and astronautic. I first map out the sectoral system of innovation of this industry which is actually located as a cluster in the south Indian city of Bangalore. The paper identifies the three building blocks of the cluster: lead actors, knowledge or technology domain, and the demand. Changes in each of these blocks over time are discussed. The study concluded with a comparison of the performance of the sector in terms of exports and competitiveness and also delves on the policy instruments that are required for placing the industry on a sure flight path.

Key words: India, sectoral system of innovation, aerospace industry, aeronautical, astronautic, offset policy

JEL Classification: L62; O31; O32; O34

Introduction

India is one among the few developing countries which have attempted to create a domestic sectoral system of innovation in a truly high tech sector such as the aerospace industry. The country is currently having one of the fastest growing aerospace sectors in the world: exports of aerospace products from India have grown at a rate of 82 percent per annum during the period 1988 through 2008. Although the sectoral system of innovation of the industry is almost five decades old, for much of that period both manufacturing and innovative efforts of the sector was geared solely towards the defence sector, but this orientation of almost entire defence and governmental hold of the sector started diminishing with the opening up of the sector to private sector actors in 2001. So the evolution of the SSI neatly falls itself into two phases: phase 1 is period, 1959-2001 when both the research and manufacturing were entirely geared towards the defence sector and phase 2 is period since 2001 when the government opened up the sector to private sector participation. In fact this radical shift in policy appears to have made the sector very dynamic in the sense that it has considerably enhanced the breadth and depth of its activities in both research and manufacturing in both the aeronautical and astronautic components of the aerospace industry. Historically speaking Indian public policy has been disproportionately directed towards the astronautic part than the

aeronautical so much say that in terms of public expenditure intensity on space related activities (defined as expenditure on space as per cent of GDP), India is second only to the USA, but ahead of many other OCED and BRIC countries. See Figure 1.

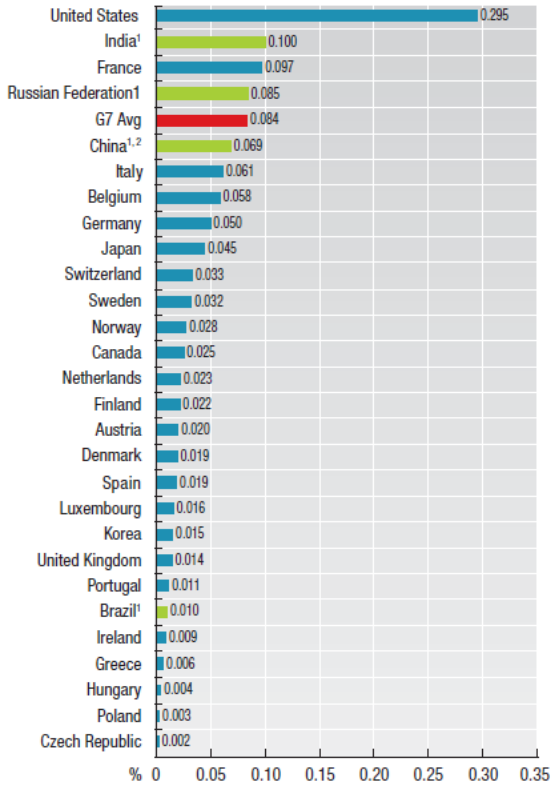


Figure 1: Public space budgets for OECD and BRIC countries as a per cent of their GDP, 2005

Notes 1: BRIC countries are Brazil. Russia, India and China
2: Chinese data based on unofficial estimates.
Source : OECD (2007), p.35

Aerospace industry across the world is structured in the form of clusters. This is because at the centre of the cluster is a large aircraft

manufacturer with a whole host of component manufacturers. In India, the southern city of Bangalore has emerged as one of the leading aerospace clusters in the country. This is essentially due to the existence of four major actors in the SSI of the sector, namely Hindusthan Aeronautics Ltd (leading manufacturer of aerospace products). The National Aerospace Laboratory (leading research facility on aerospace domain under the CSIR network of laboratories across the country), the Indian Space Research Organization (leading researcher and consumer of especially astronautics products from the country), and the Indian Institute of Science (leading centre for training of aerospace engineers). The cluster development policy has received a fillip with the state governments of Andhra Pradesh, Karnataka and Gujarat establishing special economic zones (SEZs) for the aerospace industry. These include:

- The Rs 3,000-crore Aerospace and Precision Engineering Special Economic Zone to be set up at Adibatla, Ranga Reddy district in Andhra Pradesh
- The specialised aerospace park of around 1,000 acres, proposed near the Bangalore International Airport;
- The 2,500-acre SEZ for the aerospace and avionics industry, proposed to be established in south Gujarat, close to the Delhi-Mumbai industrial corridor. This is likely to have a number of MRO (Maintenance, Repair and Overhauling) facilities.

Framework for analysis

In the case of the Indian aerospace industry, its sectoral system of innovation overlaps very well with the Bangalore Aerospace cluster as the major components of SSI are located within the Bangalore cluster. So in our study I use the term, sectoral system of innovation of India's aerospace industry and the Bangalore aerospace cluster interchangeably. Consequent the framework that I employ is an eclectic one by combining

elements of the literature on clusters and the one on sectoral systems of innovation (SSI). The SSI framework is due to Malerba (2004). The eclectic SSI framework identifies *three* crucial elements of the sector, namely:

- Lead actors in the sector
- Knowledge domain and development
- Demand

As far as India/s aerospace industry is concerned significant changes have taken place in all the three building blocks. For instance, during phase 1 the knowledge and technology domain depended to a great extent or almost in its entirety on domestic sources, the actors and institutions were lead by one public laboratory, one public sector research organization which did both research and manufacturing and one leading public sector enterprise in the manufacturing sector and demand was almost entirely and driven by public technology procurement. But during phase 2 there has been a dramatic change in all the three building blocks with the knowledge domain now composed of both domestic and foreign sources, there has been considerable increase in the number and types of actors and institutions and the demand has shifted from domestic public sector to foreign private and public sector enterprises. fast growth in civil aviation, development in manufacturing (especially in the private sector), and emergence of India as an aerospace technology-sourcing center.

Engagement with the literature

Systematic academic literature on India's aerospace industry is scanty and focuses almost exclusively on the astronautic part. Three sets of issues have come up for inquiry and analysis in this literature. The first one deals with overall assessment of past and future public policies on space programmes (Rajan (1988), Kasturirangan (2004), Murthi, Bhaskaranarayana and Madhusudan (2009)). The second one is

a more detailed study on the evolution of the space sector from one being more science oriented to one that is more commercial oriented. The studies in this set also deals with the way India has acquired technological capability in this area (Baskaran (2005) and Sankar (2007). The last one deals with one particular kind of space technology namely remote sensing in which India has managed to have considerable technological capability. The only study in this set (Satheesh (2009) deals with the extent of diffusion of this technology and the factors that have contributed to its diffusion. To the best of our knowledge no studies exist on the aeronautical part of the sector. The present study thus seeks to fill in this gap by focusing on both the sectors and especially on the aeronautical part of the industry.

The basic objective of our study is to understand and map out the sectoral system of innovation of India's aerospace industry and its performance. Since the sector is almost entirely located in one geographic area, namely at the city of Bangalore, I argue that the sectoral system of innovation of India's aerospace industry and the Bangalore Aerospace Cluster (BAC) are one and the same. In very specific terms I are interested in identifying and analyzing the major actors in this sector or cluster, research and manufacturing as well and identifying the linkages that these actors have which each other especially in the generation of new technologies. In keeping with these objectives the study is structured into four sections. The first section traces the historical evolution of the sectoral system of innovation of India's aerospace industry and then maps out in detail the structure of the sector. The second section discusses in detail the three building blocks of the sector in terms of: (i) lead actors; (ii) the knowledge or technology domain; and (iii) the demand. The third section discusses the performance of the sector in terms of certain summary measures. Two dimensions of performance are considered: inter-temporal and inter-spatial. Finally the fourth section summaries the main findings of the paper

I. Lead actors in the Bangalore Aerospace Cluster (BAC)

The city of Bangalore, capital of the southern state of Karnataka, has shot into international fame as the centre for India's information technology industry and also as an innovation hub. Besides it has a very high density of national level research institutes focusing on a range of technology disciplines, same basic and some applied as well. It has also a very density of undergraduate and graduate institutions in science and engineering and some of it like the Indian Institute of Science is of international repute. Further it has a very large number of new technology based firms especially in electronics hardware, computer software and in biotechnology industries. India's aerospace industry has its origin in Bangalore with the establishment of three major institutions in that city, namely the National Aerospace Laboratory, the Hindustan Aeronautics and the Indian Space Research Organization. No other place in India has such a large density of aerospace related institutions as Bangalore has. Although the Bangalore aerospace cluster is now more than 50 years old, over the last ten years or so it has evolved

into a fairly sophisticated and clearly identifiable cluster. Three factors appear to have contributed to this change. First is the increasing market for aircrafts within the country thanks to the phenomenal growth in domestic air travel and the increasing success of India's space programme which has also increased with India emerging to have capability in designing and launching satellites using her own indigenously designed satellite launch vehicles. Second, is the launching of research and development of India's first civilian aircraft, the HANSA and SARAS in 1991 and the establishment of the Antrix Corporation in 1992 for the promotion and commercial exploration of products and services from the Indian space programme. Third is the growth of R&D outsourcing by foreign aerospace companies and one does hear, with increasing frequency, of an increasing number of such outsourcing outfits being located in the country and most of them again happen to be in Bangalore. An indication of the growing importance of Bangalore's aerospace potential can be gauged from the fact that during a recently concluded Aero India 2009 air show – billed as the largest in South Asia – deals worth more than $1.2 billion were signed between Indian and foreign aerospace firms. For all these reasons, I restrict our study to the Bangalore Aerospace cluster. However given the importance of Bangalore in India's aerospace industry, this is tantamount to analyzing India's aerospace industry itself.

Regarding the Bangalore cluster, I first sketch its historical evolution followed by a mapping of the contours of the cluster in terms of the institutions constituting the cluster. This is followed by a detailed analysis of some of the leading actors in the cluster. Finally I end with a discussion of the performance of the cluster in terms of some standard indicators such as exports and R&D.

(i) Brief historical evolution of the cluster: The sector the cluster has a history of very nearly seven decades (Table 1).

Table 1: Historical evolution of the BAC

Year	Major institution/policy instrument
1940	Hindustan Aircraft Company (first aircraft company)
1942	Formation of India Institute of Science and Council of Scientific and Industrial Research
1948	Aeronautical Society of India established
1958	Establishment of Defence Research and Development Organization (DRDO)
1959	National Aerospace Laboratory (NAL) formed
1964	Hindustan Aeronautics Limited (HAL) formed
1969	Indian Space Research Organization (ISRO) formed
1972	Space Commission and Department of Space formed
1991	Society of Indian Aerospace Industries and Technologies (SIATI) formed
1992	Antrix Corporation formed
2001	Defence production opens to private players
2005	Offset clause added to India's Defence Procurement Procedures (DPP). The clause was elaborated further in 2006 and 2008.
2006	Defence Offset Facilitation Agency (DOFA) formed
2009	Entry of Foreign aerospace manufacturers such as Boeing and Airbus.

Source: Based on PricewaterhouseCoopers (PWC) and Confederation of Indian Industry (CII) (2009)

An interesting aspect of the history is that India focused initially on the aeronautical part of the aerospace sector. In fact the astronautic part came almost thirty years later. But it can be seen that later government policy was focused much more on the astronautic than the aeronautical and it is in the former that India has managed to have some clear success.

It is seen that the very first entrant to India's fledgling aerospace industry was a domestic private sector company. The Company traces its roots to the pioneering efforts of an industrialist with extraordinary vision, the late Seth Walchand Hirachand, who set up Hindustan Aircraft Limited at Bangalore in association with the erstwhile princely state of Mysore in 1940. The Government of India became a shareholder in March 1941 and took over the management in 1942. Later on in 1959, the National Aeronautical Laboratory was established under the CSIR network. Hindustan Aeronautics Limited (HAL) came into existence on 1st October 1964. The Company was formed by the merger of Hindustan Aircraft Limited with Aeronautics India Limited and Aircraft Manufacturing Depot, Kanpur. It was to be become the major aircraft manufacturing company in the country for a very long time to come as the industry was reserved exclusively for state-owned undertakings.

The astronautic part had its beginning in 1969. The major distinguishing aspect of the two sub sectors was that government had a much more articulated strategy for the development of the astronautic industry while it had virtually no policy or strategy for the aeronautical sector excepting to direct its activities almost exclusively to the defence needs. In the initial period and almost up to the new millennium, the country was much more pre occupied with creating institutions for both material production and indeed for knowledge generation as well. However during the period since 2000, there is a radical shift in terms of first privatizing the industry and then putting in place a number of instruments to stimulate domestic production of aerospace products.

One can also see a transformation of a state-owned undertaking dominated industry focusing exclusively on defence production to one that is beginning to get populated with private domestic and even foreign companies.

Finally although India started its aeronautical activities (both research and manufacturing) almost three decades prior to another developing country, Brazil, she has been much less successful in this area as the country had no clearly articulated policy for the sector while in the astronautic part, where the policy and instruments were more clearly articulated one sees a fair amount of success. I will elaborate on this in the subsequent sections.

(ii) Mapping the BAC

Based on my field visits and on the basis of secondary source material, I have been able to map out the Bangalore aerospace cluster. See Figure 2. At the core of the cluster are two different sets of aerospace organizations: one set representing the research system and the other representing leading aerospace manufacturers. Around the core are ten different types of parts and machinery manufacturers and two different types of business support, marketing and technology transfer firms.

At the core of the cluster are three major aerospace research organizations. These are the National Aerospace Laboratory (NAL) of the Council for Scientific and Industrial Research

Lead Actors in the BAC: Based Aerospace Players

In this section, I discuss some of the leading actors within the aerospace cluster in Bangalore. Before I do so, I sketch briefly a chronological evolution of the sector or the BAC. This is then followed by a discussion of the lead actors in terms of knowledge and material production actors in both the aeronautical and astronautic sectors. The focus is on the activities of these actors and the S&T linkages that these

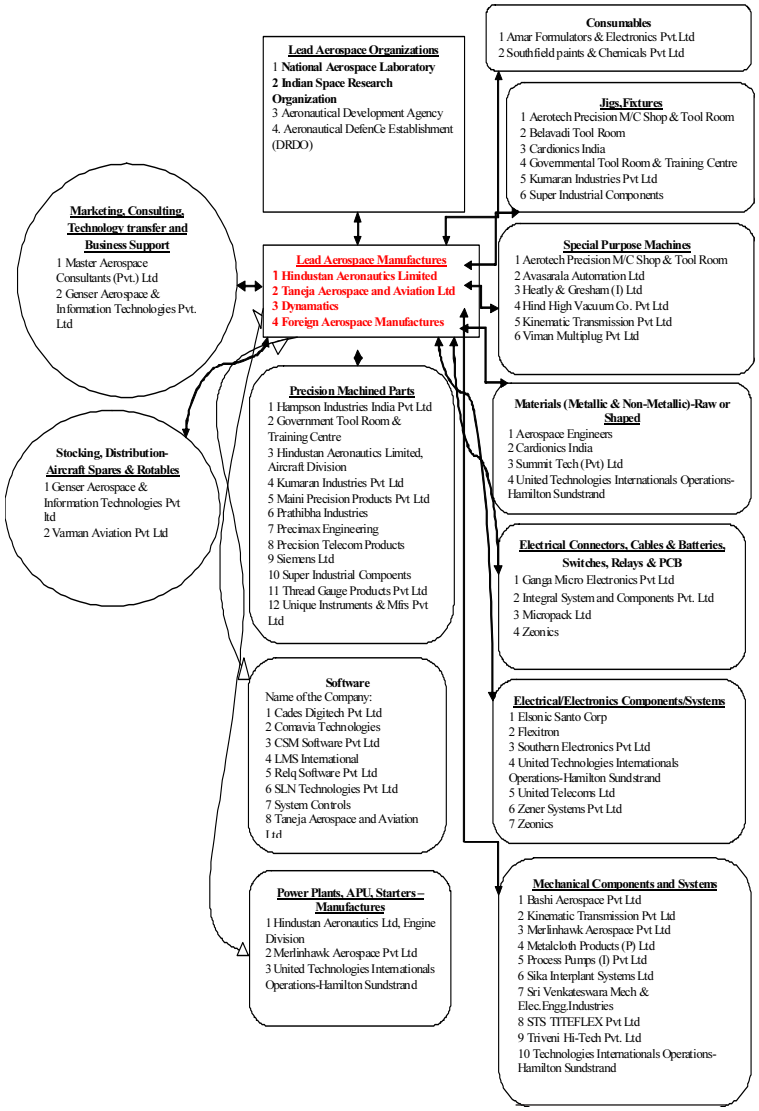


Figure 2: The Bangalore Aerospace Cluster (c2010)
Source: Own compilation

actors have with other actors both in the cluster, elsewhere in India and even abroad. I first start with the research or knowledge base of the cluster followed by the manufacturing base although this division is by no means fool proof as some of the manufacturers themselves have their own in house knowledge production centres (for instance in the case of the astronautic sector, ISRO does both knowledge and material production). The research base in aeronautics is led by the NAL (although the Indian Institute of Science, Bangalore has also a strong contribution to the research base with a stead supply of high quality human resource) and the Indian Space Research Organization in the case of astronautics.. This is followed by a discussion of four of the leading manufacturing enterprises. Through this discussion I hope to track the knowledge flows that are taking place within this cluster.

Actors dealing with knowledge production:

(i) National Aerospce Laboratory

The National Aerospace Laboratory (NAL), Bangalore is a constituent laboratory under the Council of Scientific and Industrial Research of India. NAL is a high technology oriented institution concentrating on advanced topics in the aerospace and related disciplines. Originally started as National Aeronautical Laboratory, it was renamed the National Aerospace Laboratory to reflect its major involvement in the Indian space programme, its multidisciplinary activities and global positioning. It is India's only civilian aerospace laboratory and has made significant contributions to a large number of aerospace programmes like aircraft (civil and military), space, engine development, defense and strategic programmes. NAL is an acknowledged centre of excellence in fields like composite structures, high speed wind tunnel testing, aircraft fatigue and aerospace acoustics, failure analysis and accident investigation. It has also successfully executed some innovative research projects in advanced topics like smart materials, parallel processing, advanced flow diagnostics, airport

instrumentation etc. NAL has been instrumental in the development of HANSA and SARAS aircrafts.

However the lab does not have a good patent record during the five year period 2002-03 through 2006-07 for which data are available. For instance during this five year period it has applied for 230 patents (21 in India and 9 abroad). Of these 30 patents filed, 22 were filed from 8 out of 456 completed research projects during the period and the remaining 8 were based on projects completed before April 2002. Therefore, during 2002-07, only two per cent of the completed projects yielded any patents. It has, of course, a good publication record.

What is most worrying is its success in transferring and commercialising technologies developed by it. In a random sample of 146 projects that were analysed in depth, NAL could develop transferable technologies only in the case of 75 projects and out of this, only 25 (one third) was actually transferred to the end users. Of these 25, only 1 could actually be commercialised. In other words, its knowledge level interactions within the cluster or elsewhere was very low and this is further substantiated by a more quantitative assessment of this issue.

Two of the major R&D projects in the civilian aircraft space that the NAL has worked on in recent times are the development of two different types of aircraft; first a two-seater trainer aircraft called HANSA and the second a multi role light transport aircraft called SARAS. The development of these two aircraft has the potential of infusing some technological dynamism to the constantly evolving aerospace cluster in Bangalore. Of the two, HANSA trainer aircraft has been developed and is currently in use in India[1], although on a very limited scale. The

1 The main competition for the HANSA comes from the Cessna 152 and the Cessna 172. The HANSA 3 is priced around Rs. 6 million (approximately 0.13 million dollars)

HANSA programme got under way in the early 1990s, with the first prototypes flying in 1993 and 1996. In February 2000, HANSA received its type-certification from the Directorate General of Civil Aviation (DGCA) and was cleared for day and night operations. Though NAL had initially manufactured the HANSA on its own and are again doing so, in the interregnum they had had one produced by the only private sector aerospace company, Taneja Aerospace and Aviation Limited (TAAL)[2].

The second and more complex one, SARAS is essentially a twin turboprop[3] multi-role aircraft with air taxi and commuter services as its primary roles. It has a maximum take-off weight of about 6100 kg and a seating capacity of up to 18 passengers in the high density version. With a pressurised cabin, the aircraft will have a level of comfort comparable to regional aircraft such as the Embraer or ATR aircarft. The aircraft is well-suited to fulfill a variety of other roles such as executive transport, light package carrier, remote sensing and aerial research services, coast guard, border patrol, air ambulance and other community services. The project started in 1991, had some interruptions in 1998

2 NAL had entered into an equal cost and work sharing collaboration with Mahindra Plexion to develop a four-five-seater general-purpose aircraft. The aircraft is being designed and developed to perform a variety of missions, including 4 to 5 passenger transport, cargo operations, air taxi, etc. A combination of state-of-the-art composite technology as well as advanced sheet metal fabrication techniques are proposed to be used. It will be contemporary in design with advanced cockpit and comprehensive safety features which include energy absorbing seats and lightening protection. Yet another unique feature is the integration of a number of indigenous components and proven systems and technologies. During the design and development phase, a combined technical team from both the organizations would be jointly involved followed by design validation and testing using the extensive facilities of NAL.

3 SARAS is one of the few aircraft to make use of a pusher propeller configuration. The basic configuration resembles very closely the platform of the Embraer/FMA CBA 123 Vector which never went into production.

due to the sanctions imposed on India by the international community[4] The first prototype was field tested in 2003-4 and the second one in 2007. But the technology is yet to be commercialized as it still has to solve some technical issues wrt to the weight of the aircraft. The conception and design of the project may largely be attributed to NAL although it has actually collaborated with a limited number of international agencies. For instance, (a) a contract has been signed with Honeywell Technologies, Bangalore for the joint development of digital autopilot for the SARAS aircraft; (b) three engines (PT6A-67A) with a power rating of 1200 SHP at 1700 RPM have been procured from Pratt and Whitney, Canada; (c) pusher propellers developed in collaboration with MT Propeller, Germany; and (d) NAL has worked out flow computational programme for a transport aircraft in flight in collaboration with the University of Cambridge.

A more detailed analysis of the HANSA and SARAS cases are attempted in the second section analyzing the performance of the cluster.

NAL is at the moment initiated a new project to design a 70-90 seat Regional Transport Aircarft (RTA) in a public-private partnership mode. Our inquiries reveal that currently it is the drawing board stage. It will be an aircraft which could land in an all weather condition even in airfields which do not have adequate ground infrastructure facilities like Instrument Landing System (ILS). The first test flight is to be done in 2015 and expects to commercialise the new technology by 2016.

I now propose to analyse NAL's interaction with other units in the cluster. There are two ways in which this interaction can be measured and presented. The first method depends entirely on qualitative data on the various types of interactions that the laboratory had with firms in the

4 According to NAL sources, technological and procurement problems - arising out of US sanctions - have adversely affected the development of Saras and raised the cost of its development although this view was contested by the CAG (2008) in its auditing of NAL 's R&D projects.

cluster in terms of transfer of technologies, provision of consultancy services, conduct of collaborative research projects, testing and analytical studies undertaken. The second method is to find out the ratio of the value of these transactions to the total budget of the lab and if this ratio is increasing over time, I assume that the lab's interaction with the cluster is increasing. Ideally speaking I require both the methods to form an informed opinion on this important issue. However since I do not have a comprehensive collection of qualitative data on external interactions, I conduct our analysis of this issue entirely in terms of the second method. For this I rely on the numbers provided in CAG (2008). Based on this understanding I define two variants of a ratio called the Interaction Ratio (IR). The numerator of the both the ratios are same: it is composed of fee received by NAL for: (i) collaborative projects; (ii) consultancy projects; (iii) testing and analytical assignments; and (iv) transfer of technology. This is aggregated and presented as total funds received through external interaction (Table 2). The denominator for IR 1 is the total external cash flow (defined as the sum of funds received through external interaction and funds received through grants-in-aid and sponsored projects), while the denominator for IR 2 is the total budget (grants from CSIR and total external cash flow).

Table 2: NAL's inter action within the Bangalore Aerospace Cluster
(Rs in Millions)

	Funds received through external interaction	Total external cash flow	Total budget	IR1	IR2
2002-03	1.9	288	945.2	0.0066	0.0020
2003-04	1.1	334.5	1042.8	0.0033	0.0011
2004-05	1.8	277.4	1088.1	0.0065	0.0017
2005-06	3.1	305.80	1377.7	0.0101	0.0023
2006-07	3.4	336.90	1573.2	0.0101	0.0022

Source: Derived from Table 1 of CAG (2008), p. 7.

Although the funds received by NAL through external interaction has increased, as ratio of its total external cash flow and budget (IR1 and IR2) it is almost zero for all the years under consideration. This is entirely plausible as its R&D projects in civilian aircraft technologies are yet to fructify.

(ii) Indian Space Research Organisation (ISRO): ISRO was established in 1969 to give a fillip to astronautic research and manufacture. Its administrative parent body, the Department of Space came three years later in 1972. In the history of the Indian space programme, the1970s were the phase of experimentation during which experimental satellite programmes like Aryabhatta, Bhaskara, Rohini and Apple were conducted. The success of those programmes, led to the phase of operationalisation in the 1980s during which operational satellite programmes like INSAT and IRS came into being. India has plans to augment the capacity with the launching of INSAT satellites and increase it to about 500 in 4-5 years to meet its growing needs. Bangalore occupies an important place in India's space programme. See Figure 3.

The government has placed much emphasis on space research by devoting significant budgets to it over time (Table 3). In fact space research alone accounts for about 12 per cent of India's Gross Expenditure on R&D (GERD). The ISRO has, over time, clearly demonstrated its innovation capability in *four* different areas: (a) earth observations (CARTO series); (b) satellite communications and navigation (INSAT series); (c) space science and environment (Chandarayan 1 and 2); and (d) launch vehicles (PSLV, GSLV). More on this issue in the section on knowledge development below.

Over time ISRO has improved its interaction with domestic industry in terms of procuring components and materials for its launch programmes and also in terms of transferring technologies to local firms. A systematic documentation of this is found in Sankar (2007). One of

indicator for measuring this interaction is the flow of funds to industries as a share of its total budget (Figure 4). This has now progressively increased to almost one half of its total budget which is rather a high figure.

In terms of qualitative evidence of instances of technology transfer, its most recent annual report (2008-09) states that the organization has established linkages with more than 500 firms in small, medium and large scale sectors, either through procurement contracts, know how transfers or provision of technical consultancy. The association with the space programme has enabled these firms to adopt advanced technologies and handle complex manufacturing jobs. With Antrix Corporation, the commercial front of Department of Space, having established itself in the global market, Indian firms have begun participating in the fabrication of space hardware to meet the requirement of international customers also.

Table 3: Trends in public budget devoted to space research in India
(Rs in Millions at current prices)

	Public budget on space research	Growth Rate	GDP	Share (%)
1998-99	15110		16160820	0.09
1999-00	17260	14.22	17865260	0.10
2000-01	19090	10.58	19250170	0.10
2001-02	19090	0.04	20977260	0.09
2002-03	21640	13.33	22614150	0.10
2003-04	22740	5.10	25381700	0.09
2004-05	25400	11.69	28777010	0.09
2005-06	26750	5.31	32823860	0.08
2006-07	29970	12.04	37793840	0.08
2007-08	32900	9.78	43208920	0.08
2008-09	40740	23.83	49331830	0.08
2009-10	41670	2.28		
2010-11	57780	38.66		

Note: * These are budget estimates
Source: Government of India (various issues)

Hitherto, 289 technologies have been transferred to industries for commercialisation and 270 technical consultancies have been provided in different disciplines of space technology. Technology transfer activities have made further progress during the year (namely 2008-09). Four new technology transfer agreements were concluded during 2008-09. The technologies licensed to industries for commercialisation include PF 108 Resin, Umbilical Pads, Ammonium Dinitrimide (AND) and ASIC Based Demodulator. A number of technologies licensed during the last few years have entered into regular production. The technology

for manufacture of ISRO patented OLFEX has been in great demand and now has been additionally licensed to two more firms considering the expanding market. Further a number of technologies and application software packages are in various stages of development and will soon be available for commercialisation. Domestic GIS software (IGIS) jointly developed by ISRO was taken up for know how transfer. Through a Memorandum of Understanding (MoU) with industry, the development and supply of Cryo Adhesives (CAS resin) and Crystobalite, a filler material used in silica tiles, has been entered into.

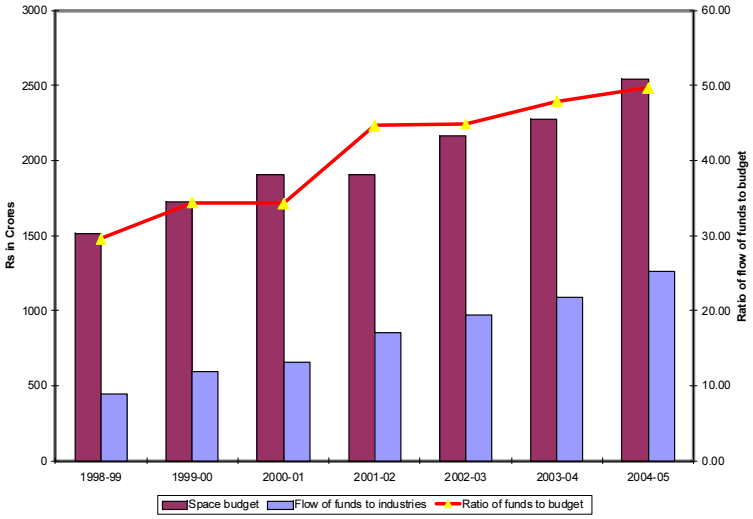


Figure 4: Flow of funds from ISRO to domestic industry
Source: Based on Table 10.1 in Sankar (2007). p. 273

Actors dealing with material production

These are divided into domestic and foreign manufacturers.

Domestic manufacturers

(i) Hindustan Aeronautics Limited (HAL), is a major player in the global aviation arena. It is a defence state owned company and has

built up comprehensive skills in design, manufacture and overhaul of fighters, trainers, helicopters, transport aircraft, engines, avionics and system equipment. Its product track record consists of 12 types of aircraft from in-house R&D and 14 types by licence production inclusive of 8 types of aero engines and over 1000 items of aircraft system equipment (avionics, mechanical, electrical).

HAL has produced over 3550 aircraft, 3650 aero-engines and overhauled around 8750 aircraft & 28400 engines besides manufacture/ overhaul of related accessories and avionics. The Company has the requisite core competence base with a demonstrated potential to become a global player.

HAL has 19 production divisions for manufacture and overhaul of aircraft, helicopters, engine and accessories. It has also 9 R&D Centres to give a thrust to research & development.

HAL's major supplies/services are to Indian Air Force, Indian Navy, Indian Army, Coast Guard and Border Security Force. Transport aircraft and Helicopters have been supplied to airlines as well as State Governments. The Company has also achieved a foothold in export in more than 20 countries, having demonstrated its quality and price competitiveness. HAL is a major partner for the Space Vehicle programmes of the Indian Space Research Organisation (ISRO). It has also diversified into the fields of industrial and marine gas turbine business and real-time software business. HAL is now ranked 34th in the list of world's top 100 defence companies.

The company has made supplies to almost all the major aerospace companies in the world like Airbus, Boeing, IAI, IRKUT, Honeywell and Ruag etc. In 1988 Airbus entered into an agreement with HALto make doors for its A320. Primary interviews with HAL reveal that 50

percent of the doors for Airbus are manufactured by HAL. The company has also entered into an agreement with for the production of flaperons[6] for use on Boeing's 777 series commercial jetliner.

All the production Divisions of HAL have ISO 9001-2000 accreditation and sixteen divisions have ISO-14001-2004 environment management system (EMS) certification. Six divisions have also implemented the aerospace sector quality management system requirements stated in AS 9100 standard and obtained certification. Four of these divisions have also obtained NADCAP certification (National Aerospace Defence Contractors Accreditation programme – USA) for special processes such as NDT, heat treatment, welding etc.

In order to meet with the challenges in the 21st Century, the Company has redefined its mission as follows: "To become a globally competitive aerospace industry while working as an instrument for achieving self-reliance in design, manufacture and maintenance of aerospace equipment, Civil Transport Aircraft, helicopter & missiles and diversifying to related areas, managing the business on commercial lines in a climate of growing professional competence."

HAL has successfully designed and developed the Advanced Light Helicopter, which is currently being operated by the defence services of India and private companies. The Advanced Light Helicopter also has great export potential. Apart from licence production of front line fighters like Su-30 MKI, HAL is also developing the following products through design and development:

(i) Intermediate Jet Trainer (IJT);
(ii) Light combat helicopter (LCH);
(iii) Weaponization of Advanced Light Helicopter (ALH); and
(iv) Tejas-Light Combat Aircraft

6 The 777 flaperons are a highly complex composite assembly that is instrumental in controlling the airplane's maneuverability in flight.

As a result of these expansions of its activities, HAL's total sales have increased on an average at a rate of 16 per cent per annum. See Table 4. Its export intensity has doubled during the period under consideration while it has maintained its research intensity around 7.4 per cent of its sales turn over. This is in fact one of the highest research intensities in the country.

Table 4: Trends in HAL's domestic sales, exports, export intensity and research intensity

	Domestic sales (Rs Millions)	Export Sales (Rs in Millions)	Total Sales (Rs in Millions)	Export Intensity (%)	R&D Expen-diture (Rs in Millions)	Research Intensity (%)
1994-95	13529.5	358.9	13888.4	2.65	961.2	6.92
1995-96	15387.8	281.3	15669.1	1.83	1258.7	8.03
1996-97	17305.7	396.4	17702.1	2.29	819.5	4.63
1997-98	18288.8	410.5	18699.3	2.24	1298.3	6.94
1998-99	20037	440.3	20477.3	2.20	1463.5	7.15
1999-00	23539.2	469.6	24008.8	1.99	1716.6	7.15
2000-01	23879.4	586.1	24465.5	2.45	2040.9	8.34
2001-02	27079.6	668.5	27748.1	2.47	2037.2	7.34
2002-03	30165.3	1038.9	31204.2	3.44	2650.6	8.49
2003-04	35844.3	2153.5	37997.8	6.01	3138.1	8.26
2004-05	43837.5	1500.5	45338	3.42	3066.3	6.76
2005-06	51553.1	1861.9	53415	3.61	4335.8	8.12
2006-07	75131	2705.1	77836.1	3.60	6377.9	8.19
2007-08	82842.5	3410.9	86253.4	4.12	6621.4	7.68
2008-09	99368	4365.8	103733.8	4.39	6747.8	6.50

Source: Hindustan Aeronautics Limited (2009).

(ii) **Taneja Aerospace and Aviation Limited (TAAL):**

TAAL is the only listed company in aerospace manufacturing in India. It manufactures small civilian aircraft, aero-structures and aircraft parts, provides aircraft maintenance services and represents Cessna Aircraft Company, USA, for the sale of its aircraft in India. It is the only private sector company manufacturing entire aircraft in India.

Part of the Pune based Indian Seamless group, TAAL was established in 1994 as the first private sector company in the country to manufacture general aviation i.e. non-military aircraft. The company's vision at the time was to create a nucleus facility for the development of an aeronautical industry in India and in particular to promote affordable general aviation in the country. To kick-off this process, TAAL entered into collaboration with Partenavia of Italy to manufacture the six-seat twin piston-engine P68C aircraft and the eleven-seat twin turbo-prop Viator aircraft.

While TAAL continues to manufacture Light Transport and Trainer Aircraft, the company has since diversified its activities and has established a significant presence in many segments of the aviation and aeronautical industries in India.

TAAL has three distinct business divisions, namely, aerostructures, airfield and MRO and aircraft sales and support.

Aerostructure business division has evolved from the initial business of the company, which was to manufacture the Partenavia P68C, six seat, twin-engine aircraft in India

TAAL currently manufacture aero structures for HAL, NAL, ISRO and Aeronautical Development Establishment (ADE). Of these, the largest structures that the firm manufactures are for ISRO where the company builds most of the structural assemblies for the Booster rockets of the GSLV programme. The company has also built major structures of SARAS.

TAAL's core competence in this area is in the manufacture of sheet metal details, machining, composites and assemblies. Facilities are augmented and upgraded to address the domestic and Global Technological requirements on a continuous basis.

- Manufacture of the P68C, a six seat twin piston-engine aircraft. All detailed parts and assemblies including seats, electrical looming, cable assemblies etc. were manufactured at TAAL's facilities;
- was involved in building up the first three prototypes of the 14 seat, SARAS aircraft for the NAL. . TAAL has manufactured the entire airframe of the aircraft (excluding the wings which are manufactured by HAL) including tooling, parts and assembly.
- was associated with the NAL for the production of the two-seat all composite (glass fiber) for HANSA.
- is manufacturing the airframes for the full composite (carbon and glass -wet lay up and room temperature cured) NISHANT, Remote Pilotless Vehicle developed by the Aeronautical Defense Establishment (ADE);
- is manufacturing all the composite components (Tail cone, Nose cone and air-intake) for the LAKSHYA, Pilotless Target Aircraft (PTA). This aircraft is now in series production;
- is manufacturing the Elevator and Stabilizer for the Intermediate Jet Trainer (IJT) manufactured by HAL;
- is manufacturing a variety of aircraft tooling (bakelite), Sheet Metal Parts etc., for the Advanced Light Helicopters (ALH); Light Combat Aircraft (LCA) Light Combat Helicopter (LCH);Sukhoi (SU-30) andG Series projects of Hindustan Aeronautics Limited (HAL;.
- is manufacturing auxiliary fuel tank, stretcher, Armour Panel and interiors for Advanced Light Helicopters of HAL and also interiors for Defence Service Helicopter;

- parts for Jaguar Drop tanks and Incendiary Containers;
- is doing space structures for PSLV and GSLV of ISRO;
- manufacture of THORP T211 two seater aircraft for domestic and export markets; and
- In the past TAAL has undertaken certain sub-contract work for the Israel Aircraft Industries (ISI) in Indi

In other words TAAL is very much linked to HAL and NAL deriving both contracts and knowledge from these two actors in the cluster. In addition it has also formal contacts for knowledge transfer from western aerospace firms.

(iii) Dynamatic Aerospace

Dynamatic Aerospace is known for the development of complex aero structures like wing, rear fuselage, ailerons flaps, fins, slats, stabilizers, canards and air brakes. Dynamatic Aerospace closely partners with agencies like Ministry of Defence, Hindustan Aeronautics Limited and other defence establishments on several key projects. It has the largest infrastructure in the Indian private sector for manufacture of exacting air frame structures and precision aerospace components.

(iv) Bharat Electronics Limited (BEL)

BEL was established in 1954 to meet the specialised electronic needs of the country's defence services, is a multi-product, multi-technology, multi-unit company. It serves the needs of domestic and foreign customers with the products/services manufactured in its nine state-of-the-art ISO 9001/2 and ISO 14000 certified manufacturing plants in India.

BEL manufactures a wide repertoire of products in the field of Radars, Naval systems, Defence Communication, Telecommunication and Broadcasting, Electronic Warfare, Opto Electronics, Tank Electronics

and Electronic Components. With the expertise developed over the years, the company also provides turnkey systems solutions and Electronic Manufacturing Services (EMS) on "Build to Print" and "Build to Spec" basis. BEL has become a US $ 1 billion company in the financial year 2007-08.

BEL has entered into MoUs with aerospace majors like:

- Lockheed Martin, Boeing, EADS & Northrop Grumman for opportunities arising out of offsets;
- Elisra, Israel, for working on various airborne electronic warfare programmes for the Indian defence
- IAI-Malat for working in the field of Unmanned Aerial Vehicles (UAV); AND
- Signed a term sheet with Rafael, Israel, which is expected to lead to the formation of a joint venture, for missile electronics and guidance technologies

Foreign Companies in the aerospace cluster

(i) The Airbus Engineering Centre India (AECI) – a 100 per cent Airbus-owned subsidiary is one of the most important foreign aircraft manufacturing enterprises in the Bangaore aerospace cluster. Specialising in high-tech aeronautical engineering, the India engineering centre works hand-in-hand with other Airbus Engineering offices around the world, as well as with the Indian aviation industry. As of early 2009, 100 people were working at the facility – including home-grown engineers and other employees – and this number is expected to grow to 400 over the next four years.

The Bangalore-based centre focuses on the development of advanced capabilities in the areas of modelling and simulation, covering such areas as flight management systems, computational fluid dynamics (CFD), as well as digital simulation and visualisation – which are critical

factors in the design and production of high-performance aircraft such as the A380 and the A350 XWB.

As part of the Airbus Engineering Centre India's activity, a simulated A380 flight management system is being developed in cooperation with Airbus engineers in Toulouse, France. This effort will help Airbus systems engineers provide mature specifications for the suppliers of flight management systems (FMS) – which are key elements of modern jetliners, and also can be used in research and development work on evolved FMS functions for new programmes such as the A350 XWB.

As part of AECI Research & Technology activity, Airbus is in negotiations with the Indian Institute of Science, Bangalore, the Indian Institute of Technology and the National Aerospace Laboratory to commence several projects during 2009.

In addition, Airbus Training India (ATI) initiated its operations in Bangalore and has since provided maintenance training to Indian-based airline operators.

Airbus is working in partnership with CAE of Canada to establish ATI as a full-fledged flight training centre, with the capability to train up to 1,000 pilots annually utilising 10 simulators. It also will offer maintenance courses in fully equipped, state-of-the-art classroom facilities.

This centre currently is under construction near the new Bengaluru International Airport, and the facility's initial two simulators have been operational since 2008 for recurrent training.

Airbus also works directly with Indian companies in the design and manufacture of aerostructures and strongly encourages its major Tier 1 partners to do so as appropriate. Dynamatic Technologies Limited from Bangalore has partnered with Spirit AeroSystems to manufacture a complex machining component and assembly (Flap-Track Beams) for

the A320, the world's most popular single-aisle aircraft programme.

Through its Tier 1 suppliers, Airbus also is engaging local companies such as TATA, HAL and Quest for the manufacture of sub-assemblies and detail parts. Additionally, the Airbus Aero-structures Supplier Council has identified India as one of the top "Cost Competitive Country" destination for aerostructure manufacturing.

Furthermore, Airbus has initiated several engineering projects with Indian companies. Infosys, HCL, CADES, Satyam and Quest have been selected to provide engineering services to various aircraft programmes, including the A380 and A350. In addition, Sonovision-Aetos in Bangalore (and Infotech in Hyderabad) have been set up as dedicated centres for work on Airbus Technical Publications.

(ii) Boeing in the Bangalore cluster: In 2005, Boeing entered a research partnership with the Indian Institute of Science (IISc). The Boeing-IISc partnership focuses on research in nanotechnologies, structural alloys, composites, smart materials and structures, process modeling and simulation, manufacturing technologies, prototyping through substructure fabrication and testing. The strategic alliance with the IISc—the first of its kind at Boeing in the area of materials science—is expected to spur aerospace innovation and contribute to the advancement of Boeing's aircraft design capabilities. Approximately a year ago (in March 2009) Boeing opened its Boeing Research and Technology-India centre, which marks a major milestone for Boeing's aerospace research and technology activities in India. The centre will be the focal point for all Boeing technology activities in India, collaborating with Indian R&D organizations, including government agencies and private sector R&D providers, universities, and other companies. It will work with strategic research and technology partners to develop high-end technology, particularly in the areas of aero structures and avionics. This is Boeing's third advanced research centre outside of the U.S.

Software firms in the cluster:

Apart from this hardware related entities in the cluster, the Bangalore cluster is also very well known for a number of software firms which have become important players in the software requirements of some of the international aerospace industry. Mention may be made of two of them, namely WIPRO and Quest. See Box

Box: Software firms active in the Bangalore aerospace Cluster

WIPRO

- Agreement to work jointly on commercial aerospace projects with Britain's BAE Systems
- Entered into an agreement with Boeing to develop wireless and other network technologies for aerospace-related applications (PPP)
- Partnered with Lockheed Martin to create demonstration centers showing new capabilities for linking multiple control centers, aircraft and vehicles
- Wipro became the largest hydraulics company in India and the second-largest globally after an acquisition in Sweden. It is assessing the possibility of creating new designs for smart landing gears and brakes.

Quest

QuEST supports its aerospace customers on global programmes related to aero structures, engines, accessories, actuation systems, aircraft interiors and ground support equipment.It also specializes in complete end-to-end solutions for the aerospace industry right from design and analysis to manufacturing

- QuEST has been selected as EADS E2S preferred supplier for engineering services, manufacturing capabilities, ability to offer offset fulfillment and Risk Sharing Partnerships. The firm recently entered into a JV to launch India's first independent processing facility for aerospace manufacturing and has setup a Special Economic Zone (SEZ) in Belgaum

Source: PricewaterhouseCoopers (PWC) and Confederation of Indian Industry (CII) (2009)

Based on the qualitative and quantitative data on the major entities in the Bangalore cluster, the main difference between the aeronautical and astronautic components of the cluster is the important fact that the cluster is now increasingly getting organized around civilian projects especially in the case of the aeronautical sector. Further the aeronautical cluster is increasingly getting integrated with the international aerospace industry. The astronautic sector, on the contrary, focuses much more on forging linkages within the country even though here too I could detect change in the form of a number of emerging international linkages.

In the aeronautical sector some of the important linkages observed are:

(a) Airbus has been assessing ways to use India for component manufacturing and R&D. It had announced that India will be one of the key centers for design and development of their new A350 aircraft. Airbus Engineering Centre India is the company's high-tech aircraft component manufacturing facility in Bangalore. The facility works on the development of tools to design the aircraft, software for analyzing the stress and strain on airplanes and structural analysis of the aircraft, among other things.

(b) Snecma, a leading global aerospace company, established its R&D center in India in 2002. This center is engaged in carrying out studies and developing engine components, aircraft equipment and onboard software.

(c) Several foreign and private players that have entered the Indian R&D sphere followed the Public Private Partnership (PPP) model for sharing technology/knowledge and commercializing aerospace manufacturing. Prominent partnerships include:

(d) In 2008, Boeing had entered into agreements with Indian Institute of Science, Wipro and HCL to develop wireless and other network technologies for aerospace related applications.

(e) In 2007, Mahindra and Mahindra had signed an agreement for the design and development of a new general aviation aircraft with The National Aerospsce Laboratory (NAL), CSIR and the Government of India. This is the first public private JV in the aircraft design sector in India

Autoparts firms diversifying to aerospace industry

Finally important finding of the study is that a number of autoparts manufacturers have actually entered the aerospace industry: Indian automotive companies are also well-positioned to leverage their strengths towards aerospace. The auto component sector is growing at approximately 20 percent per year and many global OEMs and Tier 1 companies have started sourcing components from India, due to the high quality standards followed by Indian manufacturers. For instance, India has the largest number Deming Award winning companies outside Japan (11) in the auto component sphere and proven practices such as 5S, TPM, TQM and JIT are used by companies. The companies are also conversant with the multiple automotive standards followed in different parts of the globe. Several players are planning to enter the aircraft components production. Most are primarily becoming involved with precision engineering, machining, aircraft lighting, manufacture of tyres and transmission components. For example, Tata Automobile Ltd (TAL) entered into an agreement with Boeing to manufacture structural components for their 787 Dreamliner airplane programme.

The auto component majors have indicated several reasons (PWC and CII) for the entry of these

- Suppliers into the aerospace sector:
- Diversification of product portfolio and de-risking of business;
- Skills and manufacturing processes are similar to those required for aircrafts allowing them to effectively utilize existing capacities and capabilities;

- Higher margins in the sector; and
- Leveraging the benefits of the large quantum of work to come through the offset clause.

This is thus an extremely dynamic cluster evolving continuously.

II. Knowledge and technology domain

According to Malerba (2004) any sector is characterised by a specific knowledge base, technologies and inputs. Knowledge plays a central role in innovation and affects the types of learning and capabilities of firms. In a dynamic way, the focus on knowledge and the technological domain places at the centre of the analysis the issue of sectoral boundaries, which usually are not fixed, but change over time. Knowledge is highly idiosyncratic at the firm level, does not diffuse automatically and freely among firms, and has to be absorbed by firms through their differential abilities accumulated over time.

Regarding the aerospace sector in India, in the knowledge domain the case of astronautics has been fairly well established and researched. As seen earlier, the country has through the ISRO, built up considerable innovation capabilities in four important areas of space research such as: (a) earth observations and remote sensing (CARTO series); (b) satellite communications and navigation (INSAT series); (c) space science and environment (Chandarayan 1 and 2) ; and (d) launch vehicles (PSLV, GSLV). Among these four areas, the one were India has built considerable technological competence are in the areas of remote sensing and in the design and manufacture of satellite launch vehicles and in satellites itself. I discuss these two areas, albeit briefly.

With reference to remote sensing, Satish (2009) has shown that although considerable competencies have been built in this area of technology its actual diffusion for especially urban land planning has been limited due to a variety of factors including certain regulatory

policies of the government itself like for instance the map policy that existed in the country prior to 2005 which discouraged the use of maps with high resolutions. This has since changed. An important innovation in this area has been the development ISRO launched the beta version of its web-based 3-D satellite imagery tool, Bhuvan, on August 12, 2009. Bhuvan will offer superior imagery of Indian locations compared to other Virtual Globe software[6] (like Google Earth and Wiki Mapia) with spatial resolutions ranging from 10 m to 100 m. For the present Bhuvan is available only for India specific locations although it is capable of offering images of the entire earth. It is supposed to be having a number of positive characteristics compared to its immediate competitor, *Google Earth*[7] . But given the large number of technical glitches that the software suffer from its actual diffusion rate has been limited. However Bhuvan represents a new kind of capability in the case of ISRO in terms of combining both astronautic and software capabilities.

Two other areas in which ISRO has built capabilities are in the design of satellite launch vehicles and in the satellites itself. In India, the launch vehicles development programme began in the early 1970s. The first experimental Satellite Launch Vehicle (SLV-3) was developed

6 A virtual globe is a 3D software model or representation of the Earth. A virtual globe provides the user with the ability to freely move around in the virtual environment by changing the viewing angle and position.

7 Google Earth's Zoom levels up to 200 metres – **ISRO's Bhuvan Zoom levels up to 10 metres** Google Earth: Single layer information **– ISRO's Bhuvan: Multi-layer information**

Google Earth: Images upgraded every 4 years - **ISRO's Bhuvan: Images upgraded every year**

Google Earth: No alternate viewing options – **ISRO's Bhuvan: Options of viewing on different dates**

Google Earth: Uses international satellites – **ISRO's Bhuvan: Uses Indian satellites**

in 1980. An augmented version of this, ASLV, was launched successfully in 1992. ISRO has made tremendous strides in launch vehicle technology to achieve self-reliance in satellite launch vehicle programme with the operationalisation of Polar Satellite Launch Vehicle (PSLV) and Geosynchronous Satellite Launch Vehicle (GSLV)[8]. In terms of satellites, ISRO has developed two major space craft systems, the Indian National Satellite System (INSAT) series for communication, television broadcasting and meteorological services which is a geostationary satellite, and Indian Remote Sensing Satellites (IRS) system for resources monitoring and management which is earth observation satellites. Since 1975, it has launched a total of 55 satellites (Figure 5) accounting for about a per cent of the world satellite launches. Although in terms of launches China has a better record.

Of the two types of launch vehicles India has a better success rate wrt PSLVs (almost 80 per cent during 1993-2009) compared to its GSLV programme (of three operational flights one was a failure and the other one was a partial failure). An indicator for measuring PSLVs reliability is the fact that it has launched eight satellites for various customers from abroad. An interesting aspect of ISRO's knowledge development has been the instutionalised processes for learning from past launch failures. In fact as I shall see later on that this in sharp contrast with what I observe in the cause of India's aeronautical technology development where no such procedures existed.

8 PSLV weighing about 300 tons at lift off has the capability to put 1500 kg satellite in polar sun-synchronous orbit.. GSLV 2200 kg satellites into geo-stationary orbit.

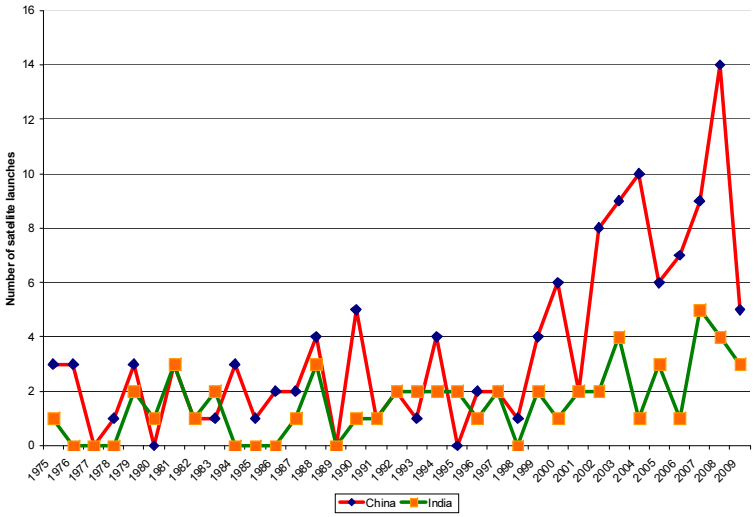


Figure 5: Number of satellites launches per year, 1975-2009

Source: http://www.sciencepresse.qc.ca/clafleur/Spacecrafts-index.html#Megatable (accessed March 24 2010)

I now turn our attention to the issue of knowledge development in the case India's aeronautical industry. Although considerable expertise had been developed in defence aircrafts of various vintages, the sector turned its attention to civilian aircraft technologies only towards the end of the 1980s. These initiatives are discussed in detail below in terms of two different technology development excercises.

It was seen earlier that NAL had developed two civilian aircrafts, one a two-seater trainer and the second one a 14-seater multipurpose turbo prop one. In this section I discuss whether through these R&D projects NAL had actually fostered a cluster of aerospace units manufacturing a range of components and other parts required for these two projects. In discussing these two cases I supplement our primary

data source with the data obtained from one of the recent Comptroller and Auditor General Reports (CAG, 2008) on scientific establishments in the country. Both the cases are first discussed separately and then some common threads are deduced from these two related cases.

The HANSA Case: The project was initiated in 1988 at a total estimated cost of Rs 5 million and was expected to be completed in about two to three years. Market research by NAL showed that considerable demand existed for this type of small aircraft to be used primarily for training and for remote sensing purposes. The project suffered serious time and cost overruns- the project could be completed only in 1998 at a final cost of Rs 55 million implying a time overrun of around 7 years a whopping cost overrun of 1000 per cent. While time and cost overruns are standard for especially high tech R&D projects, what was disquieting was that the aircraft was designed with 100 per cent foreign components and no effort was made by NAL to source even a small proportion of the total components required from domestic sources. Consequently the project had very little linkage effects within the Bangalore cluster or elsewhere in the country. NAL was also unable to transfer the HANSA technology to the only other private sector aeronautical manufacturing company namely TAAL. However TAAL refused to participate as a risk sharing partner but chose to work as a contractor. As result NAL decided to undertake the certification, production and marketing of the aircraft by itself. The initial demand for HANSA was restricted to 10 aircraft demanded by the Directorate General of Civil Aviation (DGCA) for eventual supply to the flying clubs around the country. NAL incurred a total expenditure of Rs 4.34 million per aircraft as against the initial target of Rs 0.05 million per craft. Of the 10, NAL was able to supply the DGCA with only 8 up to the end of June 2007. Nothing much is known about the remaining two as to whether it has been supplied or not. Of the eight, two met with accidents, but according to the CAG Report (p.25, para 1.8.1.3) NAL did not have any documents on investigations on these accidents done by either they

themselves or the DGCA and so could not even create an institutionalized mechanism for learning from these mistakes. Also it was very clear that not much demand existed for these crafts beyond the original eight.

From the case, the following general points emerge. NAL does not appear to have done a systematic project preparation in terms of first assessing the market for this technology, second keeping a tab on both the time and cost of the project and in developing an indigenous vendor network and finally in instituting a framework within the lab to learn from its failures as these kind of failures are usually a fact of life in complex technologies such aerospace. Success lies in learning from these failures and then taking appropriate actions for further improvements.

The SARAS Case: This was one of the most ambitious projects that the NAL had undertaken. The idea, as noted before, was to develop a multi purpose Light Transport Aircraft (9 to 14 seats). Under the project, two prototypes were to be fabricated to obtain DGCA certification. The competent financial authority (CFA) approved a budget of Rs1314 million for the project. Of this, Rs.653.1 (50 per cent) million was to be contributed by Technology Development Board, Rs.90 million (7 per cent) by HAL and balance Rs.571 million (43 per cent) by CSIR. While Prototype-I was targeted to fly in January 2001, the Prototype-II was expected to fly in December 2001. As against the target of January 2001, the Prototype-I flew in May 2004, i.e. after a delay of more than three years. Prototype-II undertook its first flight in April 2007, after a delay of more than five years. Due to the above time overrun, the cost of the project increased by Rs.225.30 million i.e., a cost over run of about 17 per cent. Right through the beginning the two prototypes developed had a problem wrt its weight (in specific terms it was over weight). This meant that its certification by DGCA has been delayed and from press reports it is leant that the certification may be available only towards the end of 2011 as a third and lighter prototype has to be

made for that purpose. In the mean time, it is also understood that the Indian Airforce has expressed an interest to order 15 SARAS aircraft. The actual manufacturing of these aircraft will be by HAL. It is not immediately clear whether NAL has sourced the components and sub systems used in the aircraft were sourced from within the Bangalore cluster or from vendors elsewhere in the country. The only system that was purchased from indigenous sources was the auto pilot unit. However I had seen earlier that TAAL has manufactured the entire airframe of the aircraft (excluding the wings which are manufactured by HAL) including tooling, parts and assembly. In this way, the SARAS project did have linkages, albeit of a limited nature, with other units in the Bangalore cluster. Once the commercial manufacturing starts, these linkages are bound to increase manifold.

An important prerequisite for the generation of knowledge development in this sector is the availability of highly trained human resource. In fact two of the lead actors in the aeronautical sector have had severe difficulties with respect to both securing and retaining highly skilled engineers. For instance according to the CAG (2008), although the sanctioned strength of the lab was 460 scientists and engineers, it had at any point of time vacancies to the tune of 26 to 17 per cent. In fact despite its best efforts in recruiting, the lab failed to find suitable candidates for the various posts indicating thereby lack of availability of good quality aerospace engineers. A similar story exists in the case of both HAL and ISRO. This is despite the fact four of the original Indian Institutes of Technology (namrly at Chennai, Mumbai, Kanpur and Kharagpur) have a four year undergraduate programme in Aerospace engineering and the Indian Institute of Science at Bangalore has even a Master's and doctoral programmes in aerospace engineering. Notwithstanding these factors the number of aeronautical engineers graduating from the country has not shown any increase since 1996. See Table 5.

Table 5: Outturn of aerospace engineers from various technical universities in India (in numbers)

	Aeronautical	Total	Share (%)
1991	58	44724	0.13
1992	75	44141	0.17
1996	102	75650	0.13
1997	113	73936	0.15
1998	117	75210	0.16
1999	90	72247	0.12
2000	90	74323	0.12
2001	132	94639	0.14
2002	127	101914	0.12

Source: Institute of Applied Manpower Research (2008)

In response to this perceived shortage, the ISRO has started the Indian Institute of Space Science and Technology at Trivandrum, Kerala during the academic year 2007-08 and the institute has the present capacity to outturn 40 undergraduates in three disciplines of aerospace engineering, avionics and physical sciences although for the present all the graduating students are expected to be absorbed within the ISRO itself. In fact the supply of sufficient quantity of human resource of the right quality is an important requirement for successful knowledge generation. A recent Parliamentary Committee (Lok Sabha Secretariat, 2007) had noted that there is a severe shortage of design engineers in the field of aerospace engineering within the country and that is likely to affect many of the R&D projects in the area. .

(III) Demand: It is fairly well known in the literature that demand plays an important and crucial role in stimulating innovations in high technology industries. This is where the two components, aeronautical and astronautics differ.

In the astronautic arena, it is generally opined that the successive chairmen of ISRO and indded the space commission worked assiduously to create a domestic demand for their various types of products in each of the four areas[9]. In fact this demand creation was crucial to the the successful development of technologies in this area.

In the case of aeronautical industry, on the contrary, the demand, especially for civilian aircraft of an indigenous design and manufacture is extremely limited although NAL, based on some market research, assumed that a fairly large market existed. However this was not to be the case. As seen in the case of HANSA, such a market never existed. However there is demand for components not only from the domestic defence area but also from foreign aerospace firms. A fillip to this demand has been the offset policy in especially defence purchases. In 2005, an offset clause was attached to India's Defence Procurement Procedures (DPP). The clause was elaborated further in 2006 and 2008.

The new offset clause introduced for the first time in 2005 and elaborated in 2006 and 2008 stipulates a minimum 30 percent plough back of foreign outflows from defence procurement into the Indian defence industry for all contracts above Rs 3 billion. The policy allows foreign vendors to choose their Indian offset partner, private or public. PWC- CII (2009) estimates that the combined offsets could translate into an opportunity of between USD 40 to 50 billion for the Indian market over the next 20 years[10]. For example, the purchase of 126

9 I am grateful to Professor Y S Rajan for alerting me to this important point. Further, Chandrasekhar (2007) while reviewing Sankar (2007) too refer to the elaborate exercise done within ISRO to assess the future potential of various technologies uch as remote sensing that it was planning to develop. Consequent to this internal exercise ISRO was successful in putting forward a strong case for the justification of space programme on the basis of its future potential rather than the basis of its actual capabilities at that time.

10 The detailed exercises underlying these estimates are not easily available. Governmental estimates, on the contrary, place the figure at around USD 30 billion.

medium multi-role combat aircrafts by the Indian Air Force will result in a potential offset opportunity in excess of USD5 billion. Though a formal civil offset policy is still being developed, players like Air India have already taken a lead in this direction by entering into an agreement with Boeing with a 50 percent offset obligation (allowing indirect offsets also). In short these policies may create an opportunity for Indian manufacturers to enter the high tech arena of aerospace manufacturing with its stringent requirements for safety, quality control and precision. I will be examining this proposition, quantitatively, in the next section on performance.

IV. Performance of the Aerospace SSI

In the previous section, I have mapped out the contours of the Bangalore cluster and then focused our attention on some of the lead players in the cluster. I found that there was fair amount of knowledge flows within the various actors and increasingly between these actors and foreign firms, customers and suppliers. Both the aeronautical and astronautic sectors have built up a fair amount of domestic technological capability in designing, manufacturing and selling aerospace products not only in India but even abroad. I therefore focus on the performance of this cluster. I do this separately for both the aeronautical and astronautic sectors of the industry in terms of two broad sets of indicators. First I discuss some macro performance indicators in terms of exports and competitiveness. Second, I discuss in detail a micro performance indicator, namely India's attempt at developing civilian aircraft. However, before I actually presenting these indicators for measuring the performance of the two sectors, a caveat is in order. It is virtually impossible to get data on performance just for the Bangalore cluster alone. Therefore the data on exports that I have used refer to the country as a whole. However given the important place of Bangalore in the Indian aerospace industry, this may not to be a problem at all as most of the exports may have actually emanated from Bangalore-based entities.

(a) Inter-temporal comparison: An important finding of the study is that the firms have, hitherto, been serving the export markets and the linkages that they have been having are more with other larger aircraft manufacturers outside the country. The main direct indicator of this link is the tremendous growth in exports, especially since the late 1990s. Exports have been growing at an average annual rate of 82 per cent (in nominal terms) during the period, 1988 through 2008. See Table 5.

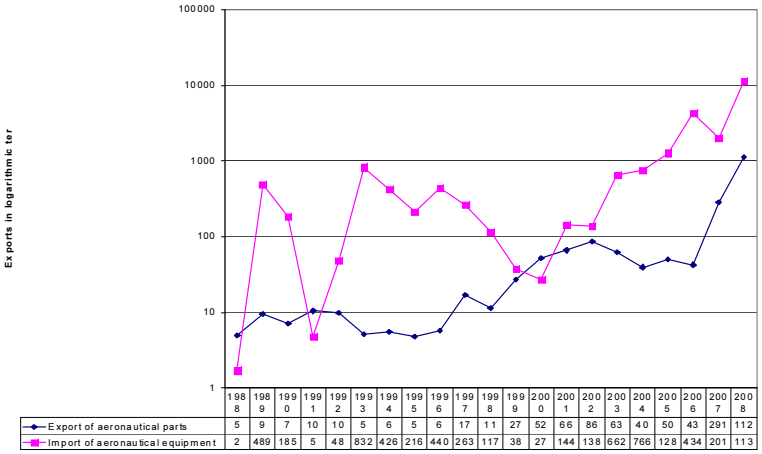
Table 5: Exports of aerospace products from India, 1988- 2008 (in Millions of US $)

	Aeronautical	Astronautic	Aerospace	Growth rate
1988	5	3	8	
1989	9	2	11	38
1990	7	1	8	-31
1991	10	9	20	148
1992	10	0	10	-48
1993	5	0	5	-49
1994	6	1	7	31
1995	5	2	7	4
1996	6	1	7	-1
1997	43	1	44	516
1998	12	1	12	-72
1999	30	0	30	143
2000	52	1	53	77
2001	66	3	70	32
2002	86	3	89	28
2003	70	5	75	-17
2004	40	14	54	-28
2005	50	12	62	16
2006	43	14	57	-8
2007	292	80	372	552
2008	1210	275	1485	299
Average Growth Rate (%)				82

Source: Compiled from UN Comtrade

Our analysis shows that almost the entire quantity that is exported is composed of parts of aircrafts[11].

It is seen that the country is largely an exporter of aeronautical rather than astronautic products. This is because between the two, there is relatively speaking a larger domestic market for the latter in view of the ongoing and increasing space programmes of the ISRO. So it is not incorrect to conclude that in the case of aeronautic component of the aerospace industry the most dominant linkage that you find in the cluster is between domestic component and smaller aircraft manufacturers with large aircraft manufacturers abroad. In the case of the astronautic component the linkages are between domestic manufacturers and their main consumer which is the ISRO. The link between ISRO and their



	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Export of aeronautical parts	5	9	7	10	10	5	6	5	6	17	11	27	52	66	86	63	40	50	43	291	112
Import of aeronautical equipment	2	489	185	5	48	832	426	216	440	263	117	38	27	144	138	662	766	128	434	201	113

Figure 4: Relationship between imports of aeronautical equipments and exports of aeronautical parts, 1988-2008

Source: Computed from UN Comtrade

11 I have used the HS 1996 classification system for extracting the data on exports from the database UN Comtrade. The following three types of parts (a) aircraft propellers, rotors and parts thereof (880310); (b) aircraft under-carriages and parts thereof (880320); and aircraft parts nes (880330) accounts for the largest share of exports from India.

suppliers is actually forged through a commercial subsidiary of ISRO namely the Antrix Corporation.

The government recently announced the new policy for capital acquisitions in which the minimum requirement is of 30 percent offsets in all acquisitions where the purchase cost exceeds Rs.3 billion. Nearly 80 percent of all offsets are in the area of aerospace. As result of this offset policy increasingly equipment suppliers to India are sourcing some portion of their components from India. So the increased exports of essential aeronautical parts from India are actually a result of this offset policy. In order to check this, I have plotted the export of aeronautical parts against import of aeronautical equipments. Given that the level of exports and imports vary considerably, I have transformed the two series into logarithmic values and this plotted against each other over time (Figure4). The figure shows that the two series are correlated with each other with the zero- order correlation coefficient between the two working out to +0.92.

For measuring the performance of the astronautic sector, I rely on the space competitiveness index (SCI) computed by Futron Corporation (2008). The SCI evaluates the space faring nations across 40 individual metrics that represent the underlying economic determinants of space competitiveness. These metrics assess national space competitiveness in three major dimensions: government, human capital, and industry. The ranks obtained by the ten major space faring nations are presented in Table 6.

India was ranked 5 in 2008. Her rank has since slipped to 7 out of 10, although her score is better than Brazil- a country that is very strong in the aeronautical sector. Finally India's aerospace industry compares less favourably with that of China's (Table 4).

(b) Inter-spatial comparison: In the realm of aerospace development there are essentially two success stories from among the

Table 6: India's rank in the Space Competitiveness Index in 2008 and 2009

Rank	Country	Government	Human Capital	Industry	2009 Score	2008 Score(Rank)
1	U.S	38.42	13.96	37.94	90.33	91.43(1)
2	Europe	19.32	9.03	18.46	46.80	48.07(2)
3	Russia	18.57	3.04	10.83	32.44	34.06(3)
4	Japan	15.80	1.72	3.65	21.16	14.46(7)
5	China	12.42	2.98	4.06	19.46	17.88(4)
6	Canada	12.89	3.42	1.82	18.13	16.94(6)
7	India	12.24	1.71	1.39	15.34	17.51(5)
8	South Korea	8.39	1.34	2.31	12.03	8.88(8)
9	Israel	6.72	0.56	1.42	8.70	8.37(9)
10	Brazil	6.10	0.49	0.50	7.08	4.96(10)

Source: Futron (2009)

developing countries. The earliest one is from Brazil and the more recent one from China. The Brazilian aeronautical industry could be traced as far back to 1969 and the only Brazilian aircraft company, Embraer is an important player in the world market for regional transport aircraft. The case of Embraer is very widely discussed in the literature (Ramamurthy, 1987; Frischtak, 1994; Marques, 2004).

The Embraer success could be traced to a number of favourable factors such as the timing of its entry, the active patronage of state in terms of public technology procurement, tax incentives and outright subsidies. Further the technology development was actually done in a company setting and not in a laboratory where the R&D team could constantly interact with the marketing and production departments so that the designs could be adapted to the requirements of the market and the availability of key components etc. The state-owned firm, Embraer that was created in 1969 could inherit key R&D personnel from the Brazilian Aerospace Technical Centre (CTA, the Brazilian equivalent of India's NAL). Embraer also had foreign collaboration with an Italian aeronautical firm, Alenia Aermacchi, and this helped the firm to secure state-of-the art technologies and also get its technical personnel well trained at the latter's facilities. After a series of financial crises, the firm was privatized in 1994. In subsequent years, by launching new products for the defense market, and entering the executive aviation market, Embraer significantly increased its market share, resulting in growing revenues in diversified marketplaces. It has at the end of 2009, 17.000 employees, sales across the globe (but 43 per cent of its sales are in the competitive North American market), sales revenue of about US $ 6 billion, R&D expenditure of US $ 200 million, 244 aircraft deliveries and a firm order for 1762 aircraft (Embraer 2009). The Embraer story is one of a developing country state having a clear focus and strategy and very pro active in times of difficulties in taking bold decisions etc. Compare this with NAL's experience of the state not being having any clearly articulated policy or instruments of support.

The Chinese is still another case of strategy and support by the state to nurture a high technology industry. The Chinese also have managed to have close collaborations with large foreign aerospace companies such as Airbus industries. She has now become an assembler of a certain type of Airbus commercial jets in the country. A comparison of the aerospace industry in China and India is presented in Table 7.

Table 7: The Aerospace Industry in China and India

	China	India
Aircraft manufacturing	• China is ahead of India in production of commercial aircraft and also exports to the US. China merged its two largest aircraft makers (Avtc-I and Avtc-II) to form the Aviation Industry Corp. of China. This body has emerged as a world class aircraft manufacturer with aviation products including a 150-seat jumbo jet. • China flew its first passenger ARJ21 regional jet in September 2008 and also plans to develop 150 seater mainline jets in the medium term. • China started developing turbo propelled regional aircraft Modern Ark 700 (MA 700) for the high-end international market.	• India maintains capabilities in designing and manufacturing military aircrafts (by HAL) but has been unable to establish its presence in passenger aircrafts. • Recently, CSIR approved a plan for its Bangalore aerospace lab to design an airplane that can carry 90 passengers on short flights. • NAL is also building the regional transport aircraft. India is expected to launch the first series of regional jets only in 2012 partnership with Bombardier and Embraer.
Assembly	• Airbus assembly plant in China (Airbus Tlanjin Final Assembly Company) began operations in September 2008. The new plant is expected to assemble 44 aircraft a year by 2011. • China also jointly assembles the Embraer ERJ-145 regional jet.	• India still does not have a complete assembly line set up by any global OEM though the Government is looking to set up an assembly unit for 25-60 seater turboprop aircraft in collaboration with EADS. • India plans to assemble 108 Medium Multi Role Combat Aircrafts (MMROA) out of IAF's purchase of 126 planes. • BAE Systems partnered with HAL to produce Hawk which involves assembling 11,000 components sourced by BAE Systems from UK.

Source: PWC and CII (2009), p. 59

In fact with a significant increase in India's exports in 2008 (300 per cent over 2007), her level of aerospace exports to both Brazil and China has improved considerably (Figure 5). It is expected that this ratio will continue to improve over time in view of the new manufacturing projects that are underway.

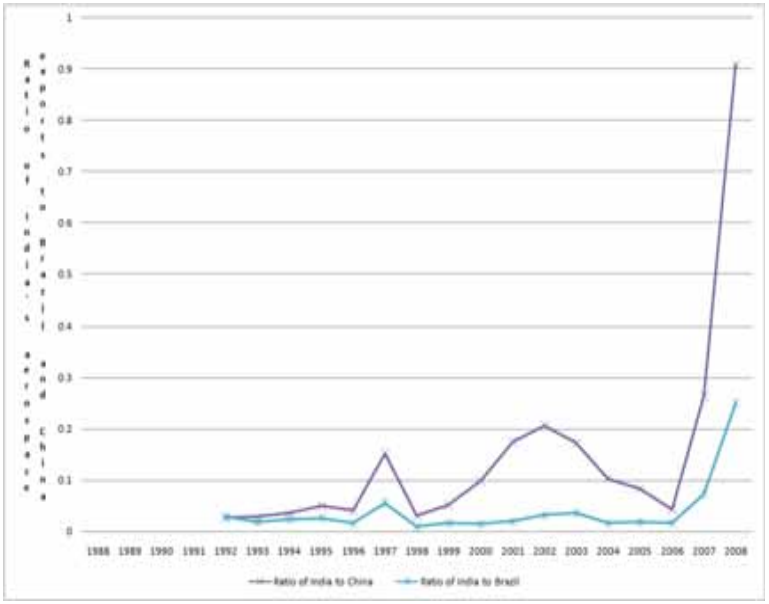


Figure 5: Ratio of India's aerospace exports to that of Brazil and China, 1992-2008

Source: Computed from UN Comtrade

V. Conclusions

India's aerospace industry is slowly but steadily evolving from its defence focus to civilian ones. This can be seen in both its aeronautical and astronautic sectors. In the aeronautical sector, India is in the process of developing civilian aircraft which is capable of serving the regional routes- something which Brazil has accomplished several decades ago and that too with great success. Further the country has become a source of parts, components and software solutions to the International aerospace industry. The Bangalore cluster has been particularly dynamic from this point of view having been very successful in attracting two of the leading aerospace companies in the world, namely Airbus and Boeing to establish both research and manufacturing facilities in the cluster. The new policy on Special Economic Zones too have been very helpful in furthering

the geographic spread of the Bangalore cluster to the periphery of the city of Bangalore thus relieving itself of the infrastructural bottlenecks that the city has now become rather notorious for.

Although India has a very clearly articulated policy and targets for the astronautic sector (see the government component of the SCI in Table 3), she does not have a clear policy for developing the aeronautical sector. The government hopes to turn this constraint into an advantage through the offset clause, mentioned in the Defence Procurement Procedure (DPP). The effective implementation of such an offset policy can facilitate the absorption and indigenisation of foreign aeronautic technologies that accrue to the country by way of offset deals. In doing this, the government wishes to emulate the success of Brazil. Discussions with industry and an engagement with the relevant literature (Behera, 2009) shows that the government by fine tuning the offset policy can use public technology procurement as a policy instrument through which it can place the industry to a sure flight path to success. But the government seems to be too much preoccupied by the domestic aviation industry rather than the aerospace industry as such. Another area where concerted action is required is both in the quantity and quality of aerospace engineers although some efforts in this direction are already visible.

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