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Introduction

The Indian defence Research and Development (R&D) machinery comprises primarily of 46 scientific laboratories and six establishments under the Defence Research and Development Organisation (DRDO)[1].The DRDO in India maintains a strong partnership with about 40 premier academic institutions, 15 national Science and Technology (S&T) agencies, 50 Public Sector Units (PSU's) (which include the nine Defence PSU's (DPSU's), 39 Ordnance Factories (OF's) and 1000 plus private-sector industries[2].The investment in R&D by the Indian Defence Industrial Base (DIB), i.e. by the DRDO, DPSU's, OF's, private sector and the armed forces, in absolute terms, is relatively very small by world standards. The best performing Indian defence industries are the Hindustan Aeronautics Limited (HAL), the OF's put together under the Ordnance Factory Board (OFB) and Bharat Electronics Limited (BEL)[3] of which, BEL invests just around six to eight per cent of its annual turnover in R&D[4].The defence industry in India is largely under the state's control.

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1 *"Government of India MOD Annual Report 2013-14"* p. 83 available at http://mod.nic.in/writereaddata/AnnualReport2013-14-ENG.pdf (Accessed January 07, 2015).

2 Mohanty, Deba R, "*A Dismal Show amid Pockets of Excellence: The State of Defense Innovation in India ",* p.4 IGCC Defence Innovation Brief January 2015 *available* at http://igcc.ucsd.edu/research/technology-and-security/defense-innovation/in India (Accessed January 10, 2015)

3 The Ranking of HAL, OFs and BEL are 42nd, 54th and 82nd, respectively. See *Stockholm International Peace Research Institute, "The SIPRI Top 100 arms producing and military services companies in the world excluding China, 2013",SIPRI Factsheet* December 2014 available at http://www.sipri.org/research/armaments/production/Top100 (Accessed January 15 ,2015).

4 "Government *of India MOD Annual Report 2013-14"* p. 67 available at http://mod.nic.in/writereaddata/AnnualReport2013-14-ENG.pdf (Accessed February 02, 2015).

The DRDO as the main defence research organisation of the country has the mandate of developing products and technologies to modernise the armed forces[5]. Its vision is to empower India with cutting-edge technologies and equip the Services with internationally competitive systems. DRDO since its inception in 1958 has developed many state of the art strategic and tactical military systems and related technologies in the diverse military disciplines of aeronautics, armaments, combat vehicles, combat engineering, electronics, materials, missiles, naval systems and life sciences. The DRDO's technological strength is its long experience in system design, system integration, testing, evaluation and project management. This has been built over the last five decades and has enabled it to develop indigenous capabilities in developing weapon platforms and their delivery systems[6].The DRDO's mandate covers the broad activities of design and development of products, systems and technologies for the Indian armed forces; providing advise to the defence minister on matters of technology with respect to acquisitions and production; creating a strong S&T base in the country in coordination with the academia and building infrastructure as required for its projects and programmes[7].

DRDO's R&D activities are undertaken as projects which are categorised as S&T, Technology Demonstrator (TD), Mission Mode (MM), Infrastructure and Facilities (IF) and Product Support (PS). In addition, DRDO also supports the development of various technologies & products which are handled through its research boards and Extramural Research (ER) which get grants-in-aid schemes. In the process of these developments, DRDO generates Intellectual Properties (IP's), trade secrets and copyrights

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[5] "*About Defence Research & Development Organisation (DRDO)*" p.1 *available* at http://drdo.gov.in/drdo/English/index.jsp?%20pg%20=policies.jsp (Accessed February 03, 2015).

[6] *"Ministry of Defence Demands For Grants (2014-15) for Ordnance Factories and DRDO"* p. 15 presented by the Standing Committee on Defence to Lok Sabha on December 22, 2014 and available at http://164.100.47.134/lsscommittee/Defence/16_Defence_5.pdf (Accessed February 05, 2015).

[7] "*About Defence Research & Development Organisation (DRDO)*" p.1 *available* at http://drdo.gov.in/drdo/English/index.jsp?%20pg%20=policies.jsp (Accessed February 11, 2015).

for which it has put in place an institutional mechanism to initiate adequate action to protect the IP's[8].

Once a system or product to be developed is identified and qualitative requirements are established, suitable industrial entities i.e. DPSU's, OF's and the private industry are identified to participate in the activity as 'developmental partners'. During the development of the product, the DRDO continuously involves the identified industries in the design reviews. After the lab developed prototype system is successfully developed, trial evaluated and accepted by the armed forces, the technology is transferred to the Production Agency (PA) i.e. the Indian industrial entities to manufacture the product for meeting the requirements of the armed forces. While transferring the technology to the Indian industrial entities, DRDO provides the relevant 'know-how's & 'know-whys' to enable industries to add value[9]. However, the thoroughness with which the technology is handed over by the DRDO as a development agency and taken over by the DPSU, OF or the private industry as the PA – in terms of its assimilation, absorption and implementation, determines the quality of the product and systems delivered to the armed forces.

Moreover, despite the DRDO-DPSU/OF/Private Industry combined successes in high end technology areas related to fighter aircraft development, Integrated Guided Missile Development Programme (IGMDP), nuclear submarines, cruise missiles and the development of combined core competencies in other defence areas of Unmanned Aerial Vehicles (UAV's), radars, Electronic Warfare Systems (EWS), combat vehicles and bridges, underwater technologies, mines and torpedoes, stealth technology and so on[10], the R&D ecosystem in India and the DRDO in

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8 *"Government of India MOD Annual Report 2013-14"* p.102 available at http://mod.nic.in/writereaddata/AnnualReport2013-14-ENG.pdf (Accessed February 15, 2015).

9 "*Compendium of Industrial Partners of DRDO titled DRDO-Industry Partnership-Synergy &Growth"* p.514 compiled by the DRDO and available at http://www.drdo.gov.in/drdo/English/IITM/Industry_compendium.pdf (Accessed February 17, 2015).

10 "*About Defence Research & Development Organisation (DRDO)"* p. 11 *available* at http://drdo.gov.in/drdo/English/index.jsp?%20pg%20=policies.jsp (Accessed February 19, 2015).

particular has faced criticism for numerous reasons starting from projecting unrealistic cost and time estimates for indigenous projects[11], delays in completion of ongoing projects leading to steep escalation in cost and compelling the Forces to import expensive foreign equipment[12], not meeting the qualitative requirements as specified by the Services, unduly long developmental times, greater focus on technology demonstrator projects to gain publicity, inadequate experience of developing tactical military systems and so on. The report of the standing committee on defence tabled in the Parliament on December 22, 2014 brought out a few more concerns— the short falls in budget affecting technology development, state of S&T and development of infrastructure and facilities related to projects, no enhancement of scientific manpower in DRDO since 2001 while the number of projects have increased multi-fold, difficulties in retaining talent as there are increased opportunities/incentives available in other organisations/industries, time and cost overruns in projects, content of research programmes sponsored through universities, budgetary provision and actual allocation of funds to Universities, their system of monitoring and so on[13].

The likely reasons for the cost and time overruns of defence R&D projects have been attributed by the DRDO to a host of factors. These include ab-initio development of the state of the art technologies, non-availability of trained or skilled manpower in respect of ab-initio development projects, non-availability of required infrastructure or test facilities in the country, technical / technological complexities of system design leading to major mid-course redesigning, non-availability of critical components

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11 Joseph Josy *"Unprofessional HAL, DRDO slammed for lost decades"* The Times of India December 16, 2014 available at http://timesofindia.indiatimes.com/india/Unprofessional-HAL-DRDO-slammed-for-lost-decades/articleshow/45529978.cms (Accessed February 21, 2015).

12 Kumaraswami Sridhar *"Can't build it? just import it"* The Asian Age January19, 2015 available at http://www.asianage.com/india/can-t-build-it-just-import-it-669 (Accessed February 22, 2015).

13 *"Ministry of Defence Demands For Grants (2014-15) for Ordnance Factories and DRDO"* pp.18-20 presented by the Standing Committee on Defence to the Lok Sabha on December 22, 2014 and available at http://164.100.47.134/lsscommittee/Defence/16_Defence_5.pdf (Accessed February 23, 2015).

/ equipment / materials and the denial of technologies and sanctions by the technologically advanced countries. Other reasons cited include enhanced user's requirements, changes in specifications during development, an increase in the scope of work, extended and long-drawn user trials, failure of some of the components during testing and trials and in certain cases original PDC not being pragmatic due to under-assessment of the developmental effort owing to a lack of experience, and so on[14].

The remedial measures adopted by the DRDO include adoption of a consortium approach for design, development and fabrication of critical components, close interaction amongst the developing agency, user and the PA, change over from the phased development approach to a concurrent engineering approach, wherein, for example, Phase 2 development programme is launched concurrently with the Phase 1 programme or series production programme is launched concurrently with Phase 2 programme or the establishment of production facilities is progressed concurrently with the development activities, extensive outsourcing of developmental activities, incorporation of a three tier project monitoring and review approach for all major projects, and so on.

Yet, despite having carried out periodic introspection of their performance and, while holding an elaborate R&D infrastructure within the country for 57 years, the DRDO, as the main defence R&D organisation, has, on most occasions, been unable to provide in time, the right equipment and weapon system that incorporates the current technologies and as asked for by the three Services. Consequently, ever since independence, India has had a large import bill for its military hardware that should have been developed and procured ex indigenous sources? The obvious question that comes to one's mind is that 'Has the defence R&D infrastructure in India been able to deliver and truly augment the country's military technological capabilities? Given the fact that DRDO is a major recipient of public funds, has its research led to spillovers for civilian technologies

14 *"Ministry of Defence Demands For Grants (2014-15) for Ordnance Factories and DRDO"* pp.31-32 presented by the Standing Committee on Defence to the Lok Sabha on Dec 22, 2014 and available at http://164.100.47.134/lsscommittee/Defence/16_Defence_5.pdf (Accessed February 23, 2015).

in India? If not, is there a need to re-assess, re-align and re-model the requisite machinery and apparatus? Is the best way to address the problem by analysing the state of defence R&D in India? Will a study of international best practices in defence R&D help set benchmarks for India and suggest changes to our ecosystem? Can the Indian defence R&D programme be re-oriented to suit India's requirements?

The paper, first reviews the current state of global R&D. This is considered essential due to the strong inherent linkages of civil R&D to that of military and vice versa. Notwithstanding, the aim of the paper is to pre-dominantly address defence R&D and, introduce general civil R&D approaches only to the extent, where these have a direct influence and linkage. This is followed by identifying the best practices that are followed in defence R&D by the world R&D leading nations, i.e., the US and China. Hopefully, these will help India to know about their approch and resultant experiences. The paper finally concludes by bringing out the lessons and concurrently suggesting the way ahead for India.

Global R&D

The global R&D investments made by nations are closely linked to their economies or Gross Domestic Product (GDP) and are expressed in Gross Expenditure on R&D (GERD). For effective comparisons to be drawn both GDP and GERD are normalised in terms of Purchasing Power Parity (PPP). The 2014 global R&D funding forecast's the United States (US) with a GDP of 16,616 billion US $ as the world's largest R&D spender recording a GERD of 465 billion US $ (Table I)[15].This R&D investment is 2.8 per cent of the US GDP and accounts for 31.1 per cent of the global R&D spending of 1618 billion US $.The world's top 10 R&D investors can be grouped into three categories that invest beyond 100 billion US $ (US, China and Japan) between 50 to 100 billion US $ (Germany, South Korea and France) and between 30 to 50 billion US $ (UK, India, Russia and Brazil). Further, India's expenditure on R&D as a

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15 "*2014 R&D Magazine Global Funding Forecast*" December 2013 p.7 available at http://www.battelle.org/docs/tpp/2014_global_rd_funding_forecast.pdf (Accessed February 24, 2015).

percentage of GDP is a meager 0.9 per cent which is the least out of the top 10 spenders while, the Asian economies of China and South Korea spend more than two per cent.

Table I. Forecast Gross Expenditure On R&D

Ser	Country	GDP PPP bn US $	R&D as % GDP	GERD PPP bn US $	% Global R&D Spending
1	US	16,616	2.8	465	31.1
2	China	14,559	2.0	284	17.5
3	Japan	4,856	3.4	165	10.2
4	Germany	3,312	2.9	92	5.7
5	S Korea	1,748	3.6	63	3.9
6	France	2,319	2.3	52	3.2
7	UK	2,454	1.8	44	2.7
8	India	5,194	0.9	44	2.7
9	Russia	2,671	1.5	40	2.5
10	Brazil	2,515	1.3	33	2.0
Global Spending		**88,733**	**1.8**	**1,618**	**100.0**

Source: Adapted by the author from Battelle, R&D Magazine, IMF Fact Book, December 2013

International trends suggest that the Asian share of global R&D is driven by China, Japan and Korea and continues to increase, while, the US and European shares are on the decline. The US and Europe, however continue to remain the global leaders in high-quality research output.The trend is summarised by the 'Battelle Magazine' — *"Collaborations with technology firms and research organisations in the US and Europe are increasing as the Asian economies are seeking to leverage global scientific knowledge and capabilities. Major infrastructure investments continue to be made, often with the goal of creating an innovation ecosystem,* *with mechanisms for technology commercialisation and industry engagement, leading to amplified economic returns from research investment"[16].*

The research leaders worldwide have different national priorities which determine their inter-se investments between basic and applied research and product development activities. Accordingly, the inter-se investments in product development programmes is the most in China followed by Korea while the commitment to basic research is the most in India (Figure I.).

Figure I. Different Priorities Among Research Leaders

Source: Battelle, R&D Magazine, IMF Fact Book, December 2013

Developing countries like Brazil, China and India, which are striving for R&D based growth, need to build their talent and capabilities, identify technology markets and have the will to invest. India being the world's fourth-fastest growing economy, has developed substantial academic infrastructure, a large population dividend and enhanced its global

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16 "*2014 R&D Magazine Global Funding Forecast*" December 2013 p.12 available at http://www.battelle.org/docs/tpp/2014_global_rd_funding_forecast.pdf (Accessed Feb 25, 2015).

connectivity[17]. Yet, the social and political compulsions keep the investment away from R&D. *"According to McKinsey Global Institute (MGI) analysis, as the global economic growth slows down in future (as is projected), the supply of capital will fall short of demand by 2030. This is especially important for the economies with limited R&D infrastructures as, they could become even more restricted in building a foundation for R&D in the future than they are now"*[18].

US R&D

US annual commitment to R&D has been two and half per cent to three per cent of GDP for many decades. This has laid the foundation of US technological innovation. In addition, public and private research has performed complementary roles. These researches have diversified to meet social and commercial/civil market requirements. This has ensured a continuous R&D support. R&D funds in the US are available from four sources; the federal government, industry, academia and non-profit organisations[19]. All these sources also perform R&D. Additional funding is available to academia from the federal and local governments. R&D is also performed by government owned Federally Funded R&D Centres (FFRDC's), some of which are contracted to be operated by industrial firms, research institutes (of the non-profit kind) or universities.Through basic and applied research, these globally recognised institutions pursue missions in energy, security and other areas of national importance.

The US Department Of Defense's (DOD's) Research, Development, Test and Evaluation (RDT&E) programme supports the development of future military hardware

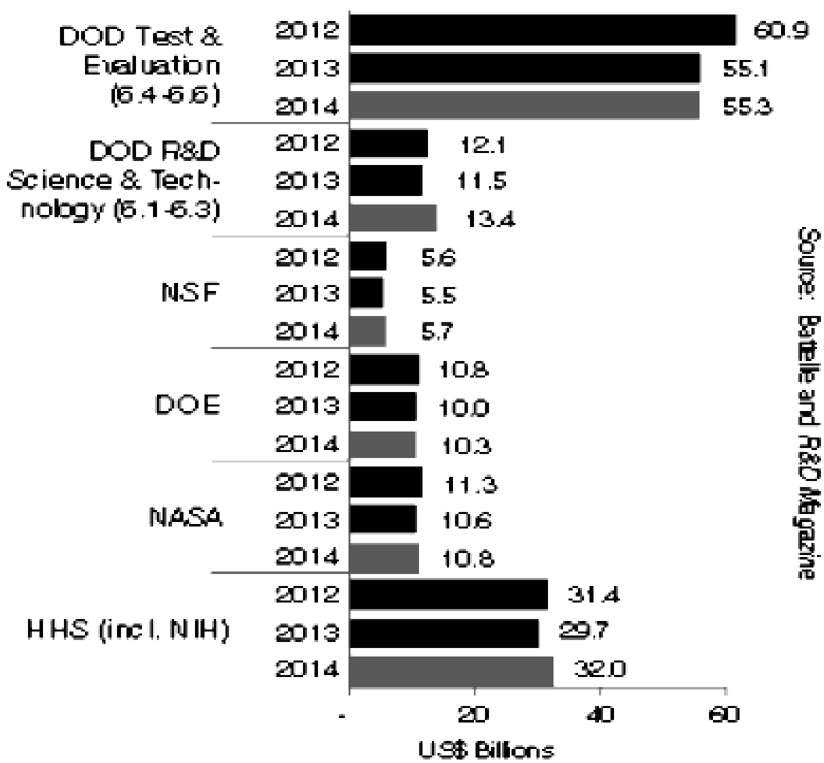
17 "The 20 Fastest-Growing Economies This Year" available at http://www.bloomberg.com/news/articles/2015-02-25/the-20-fastest-growing-economies-this-year (Accessed February 25, 2015).

18 "*2014 R&D Magazine Global Funding Forecast*" December 2013 p.19 available at http://www.battelle.org/docs/tpp/2014_global_rd_funding_forecast.pdf (Accessed February 27, 2015).

19 "*2014 R&D Magazine Global Funding Forecast*" December 2013 p.8 available at http://www.battelle.org/docs/tpp/2014_global_rd_funding_forecast.pdf (Accessed March 02, 2015).

and the knowledge and technological base which helps build the defence products. The RDT&E programme budget of approximately 66-73 billion US $ constitutes more than 53 per cent of the federal government's R&D budget. (Figure II.)[20]. The programme enables a range of activities from basic research in science and engineering to the development of complete weapon systems. The RDT&E budget is accordingly sub-divided into seven separate activities of Basic Research (6.1), Applied Research (6.2), Advanced Technology Development (6.3), Weapons Component

Figure II. Leading Federal Sponsors of R&D



Source: Battelle, R&D Magazine, IMF Fact Book, December 2013

20 "*Battelle and R&D Magazine,2013 Global R&D Funding Forecast*" December 2012 p.10 available at http://data.worldbank.org/indicator/GB.XPD.RSDV.GD.ZS/countries?order=wbapi_data_value_2012%20wbapi_data_value%20wbapi_data_value-last&sort=asc&display=default (Accessed March 03, 2015).

Developing and Prototyping (or Demonstration and Validation) (6.4), System Development and Demonstration (or Engineering Manufacturing Development) (6.5), Management Support (6.6), and Operational Systems Development (6.7) [21].

The US R&D investment and performance is now led by the Industry and followed by the academia, federal government, FFRDC's and nonprofit organisations (Table II.). The US academic research of $ 63 billion in 2014 (Table II.) is more than all the countries put together less the top four non US R&D nations that is China, Japan, Germany and South Korea. In the U.S., the government seeds innovation with investment in basic research and provides tax and policy incentives. However, which technologies to invest in (that will be deployed in the immediate future) are determined by the markets.

Table II. US R&D Investment Distribution (in Billion US $)

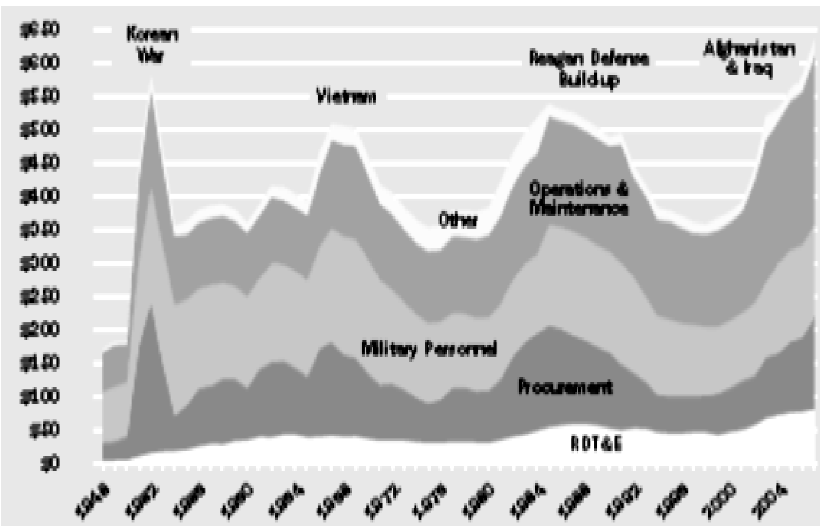
Ser	Source	Investment 2014	%Share	% Federal Funding	Remarks
1	Industry	330	71	08	-
2	Academia	63	13	60	Responsible for 50% of Basic Research
3	Federal Intramural	36	08	-	-
4	FFRDC's	15	04	-	39 FFRDC's (10 of DOD)
5	Non Profit	15	04	-	Organisations are Institutes/Universities
	TOTAL	**459**			

Source: Adapted by author from Battelle, R&D Magazine, IMF Fact Book, December 2013

21 Doom Travis R. "*Department of Defense R&D Funding 2014*" pp.3-7 Consortium for Science, Policy and Outcome available at www.aaas.org/sites/default/files/15pch05.pdf (Accessed March 04, 2015).

Figure III. shows US defence budget allocations or Total Obligation Authority (TOA) including RDT&E and procurement from Fiscal Year (FY) 1948 to FY 2007. The expenditures are in constant FY 2009 dollars, which means the effects of inflation over time have been eliminated. The RDT&E investments up to FY 2007 have gradually increased to 42 per cent of DOD's cumulative procurement spending implying, the Government's intent of increasingly investing in technology[22]. During the years 1948 - 60 investments in R&D and procurement occurred with the increase in defence budgets. RDT&E saw an average annual growth rate of over 18 per cent while procurement

Figure III. US DOD TOA by Major Appropriations Categories 1948–2007(Billions of Constant FY 2009 Dollars)



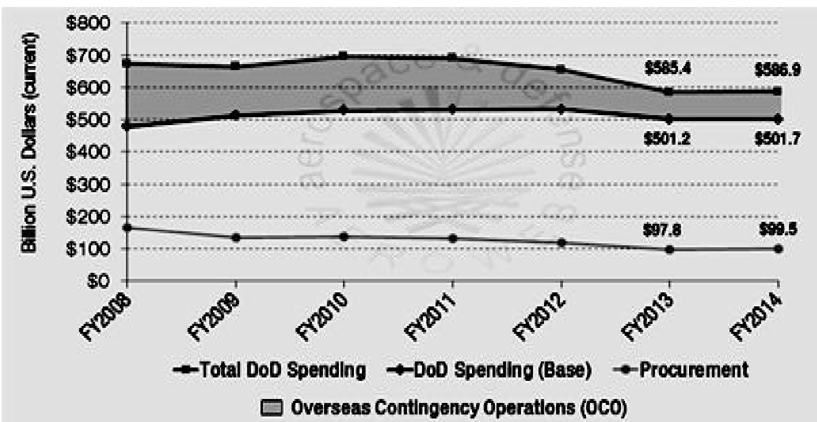
Source:"The US Defence Industrial Base Past, Present and Future" by Watts Barry D.

[22] Watts Barry D. "*The US Defence Industrial Base Past, Present and Future*" p. 11 available at www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA490689 (Accessed March 07, 2015).

increased only by 8.3 per cent[23]. From 1952 - 60, the high defence spending of 9 per cent to 13 % of US GDP saw the defence industry become one of the leading sectors. In 1960, the government funded 58 % of the nation's industrial R&D. Defence R&D regularly focused on new hardware and systems while the majority of R&D in the commercial firms was for product improvements. Private-sector technology investments increased post 1960 at such a rate that it eventually exceeded the government's levels in the 1970's.

More recently, from FY 2008 - FY 14, the US defence spending ranged between $ 585 billion to $ 700 billion (Figure IV.) As per the President's budget for FY 2015 (fiscal year starting October 01, 2014), the DOD is expected to receive around $ 569.3 billion[24]. (a reduction of $ 26.4 billion from FY 2014). Of this, an amount of $ 501.7 billion is for base funding (discretionary + mandatory) while the remaining $ 64.3 billion is for overseas contingency operations.

Figure IV. US Defence Budget Allocations FY 2008 to FY 2015



Source: Aerospace & Defence Intelligence Report 2014 Aero Web

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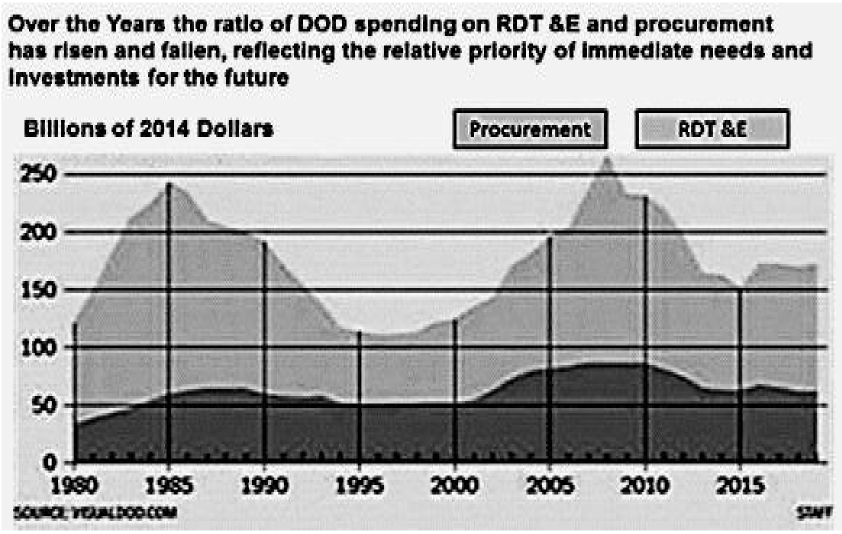
[23] Watts Barry D. "*The US Defence Industrial Base Past, Present and Future*" p. 14 available at www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA490689 (Accessed March 09, 2015).

[24] *"U.S.DOD Defense Spending & Procurement I FY 2014-15*" p. 2 available at http://www.bga-aeroweb.com/Defense-Spending.html (Accessed Mar 11, 2015).

The RDT&E programme in FY 2015 is to grow to around $ 65.2 billion (i.e. about 11.3 per cent of the defence budget)[25]. The total RDT&E budget at the DOD had earlier increased substantially after the September 11, 2001 attack (from 2001 - 11), exceeding the $ 80 billion mark. (Figure V.) The trend reflected a new focus on national security in the last decade, as defence R&D spending till 2012 was more than twice of what it was in the early 1980s (low point) and more than 25 per cent than at the end of the Cold War that is 1986-87 (high point).

Figure V. Total DOD's RDT&E Budget Increase Post 9/11



Source: Aerospace & Defence Intelligence Report 2014 Aero-web

The Weapon Development Activities (WDA's) are driving the increase, the big ticket ones being the Ballistic Missile Defence (BMD) and the Air Force's operational systems development. Moreover, it is seen that the long gestation periods for acquisition of major platforms and systems continue to drive the RDT&E budget costs up[26]. An example quoted is

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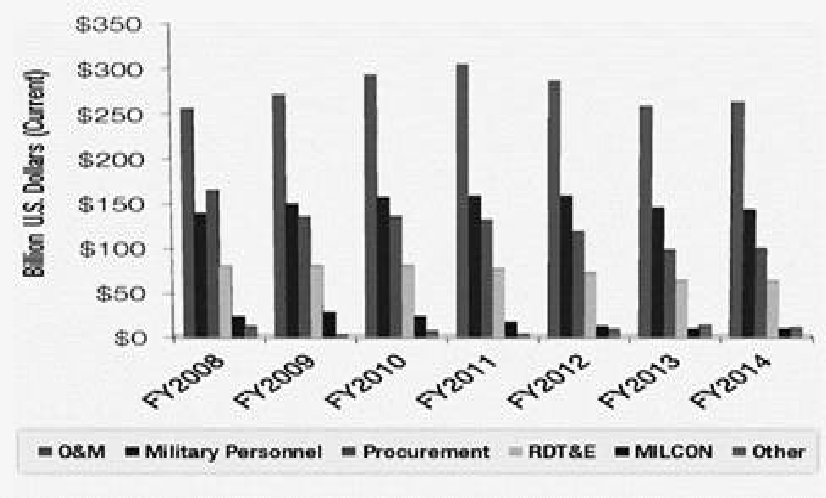
25 "*U.S.DOD Defence Spending & Procurement I FY 2014-15*" p. 4 available at http://www.bga-aeroweb.com/Defense-Spending.html (Accessed March 13, 2015).

26 "*U.S.DOD Defense Spending & Procurement I FY 2014-15*" p. 5 available at http://www.bga-aeroweb.com/Defense-Spending.html (Accessed March 14, 2015).

the acquisition development costs of the largest DOD programme (F-35 Joint Strike Fighter) (JSF) which in FY 2016 (October 01, 2015 - September 30, 2016), is expected to be about $ 11.01 billion, of which $ 1.85 billion (about 17 per cent) alone will be for RDT&E. In FY 2016, the DOD plans to purchase 57 F-35s (up from 38 in FY 2015, 29 in FY 2014, 29 in FY 2013, and 31 in FY 2012). Further, in the larger context, the operation and maintenance expenses like elsewhere in the world now overshadow the RDT&E budget[27]. (Figure VI).

Figure VI. DOD Operation & Maintenance Expenses Overshadow RDT&E Budget



Source: Aerospace & Defence Intelligence Report 2014 Aero Web

An analysis of US DOD's sub-allocation of RDT&E fund to the seven types of research activities during the last three FY's (2013, 2014 and 2015) has yielded the average investment to each of the activities and their inter-se priorities measured in terms of the percentage share of each activity as shown in Table III.

27 *"U.S.DOD Defense Spending & Procurement I FY 2014-15"* p. 3 available at http://www.bga-aeroweb.com/Defense-Spending.html (Accessed March 15, 2015).

Table III. US DOD RDT&E Fund Sub-allocation in FY 2013, 2014 and 2015

Ser	Research Activity	$ In Billions (Average of Last Three FY)	Inter-se Percentage Share
1	Basic Research	2.0	3.0
2	Applied Research	4.4	7.1
3	Advance Technology Development	5.0	7.9
4	Weapon Component Development & Prototypes	11.3	19.4
5	System Development & Demonstration	14.4	17.4
6	RDT & E Management Support	4.5	6.6
7	Operational Systems Development	28.3	38.9
	Total	**69.9**	**100.0**

Source: Adapted by the author from Department of Defence FY 2015, 2014 and 2013 President's Budget"

The US in the 1990's spent about $ 36 billion a year on the RDT&E programme which in 2014-15 (fiscal year starting October 01, 2014) is expected to grow to around $ 63.5 billion as base funding (discretionary + mandatory)[28]. Over 80 per cent of this goes towards the development or demonstration of specific military systems and components (called WDA's)[29]. The balance 20 per cent goes to primary R&D in sciences and technologies which are identified as vital for developing improved military capabilities and operations (called Science and Technology (S&T) activities).

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28 "*Department of Defence FY 2015 President's Budget March 2014*" p. 6 Office of the Under Secretary of Defence (Comptroller) available at http://comptroller.defense.gov/Portals/45/Documents/defbudget/ fy2015/fy2015_ Budget Request (Accessed March 17, 2015).

29 "*IB10022: Defence Research: DOD's Research, Development, Test and Evaluation Program* "p. 2 John D. Moteff, Resources, Science and Industry Division available at http://digital.library.unt.edu/ark:/67531/ metacrs939/m1/1/highresd/ IB10022.html (Accessed March 18, 2015).

As per the Strategic Guidance 2014,[30] the foundation of DOD's technological strength is its wide-ranging Research and Engineering (R&E) Enterprise which comprises of the military departments and their laboratories, all other DOD R&D product centers and laboratories, defence agencies as Defence Advanced Research Projects Agency (DARPA), Defence Threat Reduction Agency (DTRA), and the Missile Defence Agency (MDA), federal government laboratories, FFRDCs, university affiliated research centers, US and allied universities labs, US allied and partner government laboratories, and the US industrial base. Irrespective of the fiscal environment, the delivery of advanced technology remains a high priority, and requires the efforts of all the partners mentioned above.

The approach comprises of S&T activities and WDA's (up to the technology maturation i.e. final pre-production agency hand over stage) and risk reduction. The supporting organisation includes offices for basic research investment, DOD's science laboratories for applied research, science and engineering laboratories for advanced technology development, three Services systems engineering and development test activities (6.5) and, the acquisition programme offices. The DOD R&E enterprise develops new opportunities through science and demonstrations, reduces technology risks before concept exploration and develops protocol for testing to gain knowledge of programme definition (pre-production) and beyond.

DOD's Defence Technical Information Center (DTIC) serves the DOD community as the largest central resource for DOD and government-funded scientific, technical, engineering, and business related information. DTIC and its Information Analysis Centres (IACs) are research and analysis organisations established by DOD to support researchers, scientists, engineers, and programme managers. With a broad footprint, DTIC allows the DOD to reduce duplication and build on previous research, development, and operational experience.

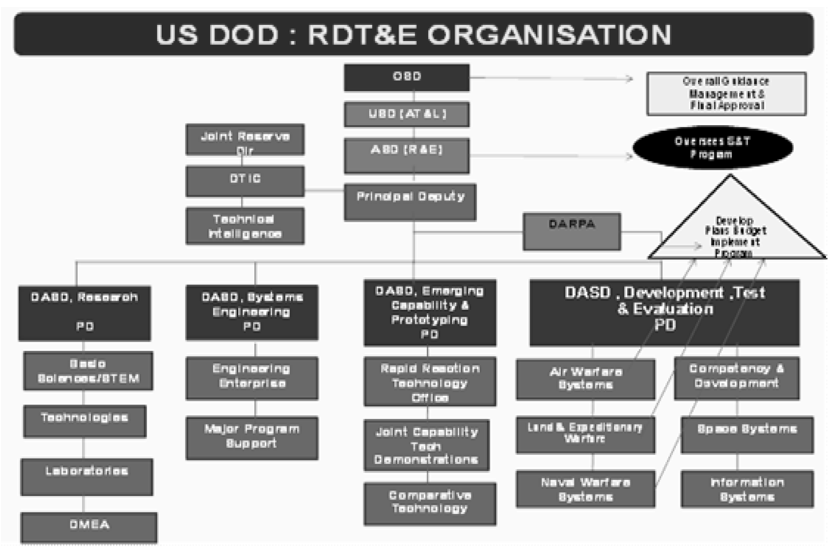
The secretary of defence, through the Under Secretary of Defence for Acquisition, Technology and Logistics (USD AT&L), erstwhile USD AT

30 "*Department of Defence Research & Engineering Enterprise*" p. 5 Distribution Statement A: Approved for public release; distribution is unlimited 1 May 2014 available at http://www.dtic.mil/dtic/pdf/success/ASD%28R&E%29_Strategic_Guidance_May_2014.pdf (Accessed March 19, 2015).

(i.e. then for acquisition and technology only), has the overall responsibility for managing the total RDT&E budget[31].Reporting to the undersecretary is the Assistant Secretary of Defence Research and Engineering (ASD R&E) (earlier Deputy ASD) who oversees the S&T programme. While the Office of the Secretary of Defence (OSD) provides guidance and final approval to the RDT&E programme and budget, it is the service departments (Army, Air Force, and Navy) and the defence agencies that develop the plans and budgets and implement the RDT&E programme.

The defence agencies that manage significantly large RDT&E programs include DARPA (which only supports S&T activities), the Ballistic Missile Defence Organization (BMDO), and the OSD itself (primarily through the ASD R&E). In addition, the defence special weapons agency, chemical and biological defence programme, and special operations command manage relatively large RDT&E programmes.

Figure VII. Organisation US DOD RDT&E



Source: Adapted by the author from US Research and Engineering Enterprise Leadership

[31] "*Research and Engineering Enterprise Leadership*" p.1 *available* at http://www.acq.osd.mil/chieftechnologist/ mission/bio/shaffer.html (Accessed January 09, 2015).

Finally, under the Deputy Assistant Secretary of Defence (DASD) there are the Principal Director (PD) of developmental test and evaluation and the PD of operational test and evaluation who receive RDT&E funds for carrying out their responsibilities of independent and/or joint testing of new systems (organisational chart at Figure VII.)

The S&T programme and the weapons development acquisition programme strategy and planning processes are independent and yet intimately related. The S&T activities, especially the technology base elements develop future generation(s) of technology, while the acquisition programs bring the same technology into the next generation of equipment.

Prior to 1989, US did not have a comprehensive DOD-wide S&T strategy or a plan to direct an integrated approach to technology development amongst the Services or to provide the Congress the required information to perform the oversight function. In 1988, as part of the FY 1989 defence authorisation, the Congress instructed the Undersecretary of Defence Acquisition and Technology (USDAT) to submit an annual plan of the technologies that the Office of the Secretary of Defense (OSD) felt was critical to be developed to ensure that the long term qualitative advantage of US weapons and systems were retained. The plan was also to bring out the rationale for selecting the technologies, the milestones and budgets allocated for developing them, and the contribution the industry and allies could make to their development.

Figure VIII shows the process for generating the S&T plan. The planning occurs at two levels (lower level and higher level) and in two directions (left to right direction and right to left direction of the figure as shown)[32]. At the lower level (bottom half of the figure), each Service has its own planning process to ensure that its S&T programme supports the long-term needs.

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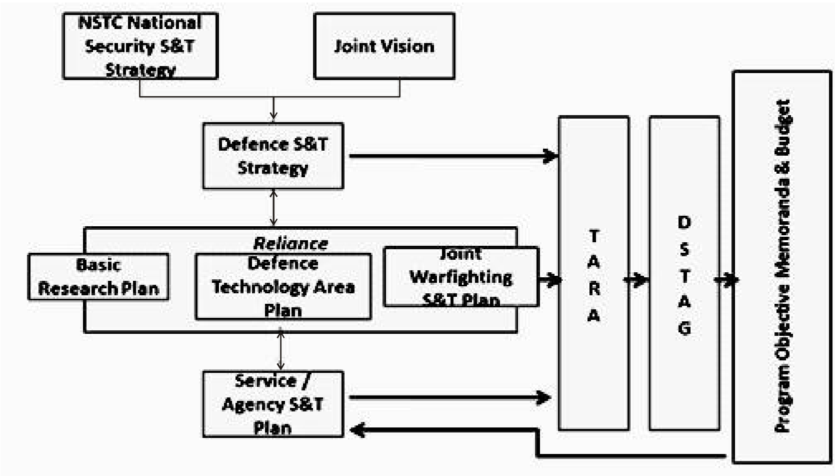
32 CRS report for Congress- *Defence Research: "A Primer on the Department of Defence's Research, Development, Test and Evaluation (RDT&E) Program"* pp.6-8 John D. Moteff Specialist, Science and Technology Policy available at http://www.google.co.in/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0CB8QFjAA&url=http%3A%2F%2Fwww.dtic.mil%2Fcgbin%2FGetTRDoc%3FAD%3DADA478217&ei=NEnkVNyeJ4yTuAToo4LgBg&usg=AFQjCNFQbPkxKqOBN3KEyNQ01E2sDLQe3A&sig2=ztyqTwOHxnSsaHTAMK8e5g&bvm=bv.85970519,d.c2E (Accessed March 20,2015).

Figure VIII. DOD S&T Planning Process



Source: US Resources, Science and Industry Division

At the higher level (top half of the figure), the ASD R&E is responsible for ensuring that all the combined S&T programmes complement each other, serve the joint-war fighting capabilities (as identified by the Joint Chiefs of Staff (JCS) and area Commanders-in-Chief's (C in C's) as stated in the joint vision and address the national security S&T strategy (also shown in figure) which is generated by the national S&T council. The ASD R&E is further responsible to ensure that the redundancies and deficiencies in individual S&T programmes of the Services and agencies are addressed. In this process, the Services needs are defined by the war fighting community (a top-down approach) while the S&T community provides the Forces with new opportunities as new technologies are conceived and matured (a bottom-up approach).

Inter-service and inter defence agency coordination is facilitated by the defence S&T project called "*Reliance*" which was formed in 1990, in response to the S&T planning process implemented in 1989. It includes the Services, DARPA, BMDO, the ASD R&E and the re-organised defence special weapons agency. "*Reliance*" is an inter-service/inter-agency forum where agreements on joint planning, co-location of in-house R&D, and lead-service/agency assignments are made for areas of common interest to more than one Service (e.g. aviation, electronics). US DOD has about

10,000 S&T projects with budgets of the order of $ 1 million or more (equate to $ 10 billion). "*Reliance*" breaks down the DOD S&T programme into 17 portfolios, or Communities Of Interest (COI), comprising of all people working in the specific technical areas. Each COI is headed by a steering committee with senior level personnel responsible for optimising their portfolio. Each COI is to report the overall state of their technical area to the S&T EXCOM annually, and approximately one-third of the COI's are to deliver a detailed strategic roadmap each year, aligning their objectives to department priorities. "*Reliance*" is responsible for developing three plans – the basic research plan, defence technology area plans and joint war-fighting S&T plan. These plans lay out roadmaps for achieving certain military capabilities. To achieve these in time, specific Strategic Research Objectives (SROs) in case of basic research and Defence Technology Objectives (DTOs) for others are identified. Each SRO/DTO identifies a specific level of technological advancement or gain in knowledge that will be made, including estimated dates, funding levels, the RDT&E Programme Elements (PEs) which will support that funding, and an explanation of how this effort will impact the war-fighter's needs. Together SROs account for about 67 per cent of DOD's total basic research funding while over 300 DTO's identified account for about 50 per cent of DOD's total applied research (6.2) and ATD (6.3) funding.

These plans and technology (strategic research) objectives are reviewed by Technology Area Review and Assessment (TARA) teams. Programme modifications or recommendations are forwarded to the Defence S&T Advisory Group (DSTAG) chaired by the ASD R&E, who then proposes any changes to the Programme Review Group (PRG), which is part of the Defence Resources Board (DRB) which prepares DOD's budget. Any changes approved by the PRG are sent back to the Service planners in the form of programme decision memoranda.

The deputy secretary of defence with the assistance of the DRB decides whether to acquire a new military system. The decision is based on military strategy, mission capabilities needed to carry out that strategy, equipment needed to achieve those capabilities and affordability of developing and operating that equipment. Once a new acquisition programme is begun, RDT&E weapon development activities (less management support activity) funds enable certain phases of that programme.

A broad outline of the acquisition process that is supported by the RDT&E budget is shown in Figure IX. It consists of phases, separated by milestone decisions. These decisions are made by the Defence Acquisition Board (DAB), chaired by the USD AT&L. Work done during the phases are managed by the Services or Agencies.

Figure IX. Outline Acquisition Process under RDT&E Budget

0	I	II	III
Phase – 0	**Phase – I**	**Phase - II**	**Phase - III**

Relevant RDT & E Activity	6.4	6.5	6.7

Phase -0	Concept Explorations
Phase -I	Programme Definition & Risk Reduction
Phase -II	Engineering & Manufacturing Development
Phase-III	Production, Deployment, Operational Support

Source: US CRS Report for Congress

DOD's RDT&E programme supports work at universities, research institutes, Federally Funded R&D Centres (FFRDCs), private firms and consortia, and at own RDT&E facilities. A large part of DOD's basic research programmme (almost 60 per cent) goes to universities while 25 per cent goes to DOD's own R&D facilities. Most of the 6.2 and 6.3 work is performed in industry (almost 50 per cent) while (30 per cent) is at DOD's own facilities. Just about all of the 6.4, 6.5 and 6.7, funding goes to private firms.

DOD's RDT&E infrastructure is divided into two groups: R&D laboratories and test and evaluation (T&E) centres. There are over 80 DOD R&D laboratory facilities (e.g. naval research laboratory).There are 26 T&E centres (e.g. the Army's white sands missile range). Each of the Services supports its own R&D laboratories and T&E centers. It should be noted that DARPA and BMDO do not have any R&D lab or T&E centres.

US DOD has established 10 FFRDC's[33]. These FFRDC's are listed at Table IV and each falls into one of the three categories defined by the National Science Foundation (NSF) of R&D Laboratories (three numbers) systems engineering and integration centres (two numbers) study and analysis centres (five numbers). DOD FFRDC's are operated by universities or privately organised (not-for-profit) corporations on long-term government contracts. Each DOD FFRDC has a specific DOD official designated as its primary sponsor, responsible for implementing FFRDC management policies and procedures, maintaining a DOD sponsoring agreement with the FFRDC, defining core competencies or capabilities that the FFRDC must maintain, and ensuring, all work performed by the FFRDC is consistent with its core competencies. The sponsoring agreement lists operational restrictions FFRDC's must follow as befitting their special relationship with the government, including operating in public interest with objectivity and independence, being free from real or perceived organisational and personal conflicts of interests, and having full disclosure of its affairs to its primary sponsor. FFRDC's are sponsored and funded by the US government to address research and development, engineering, and analytic needs that cannot be met as effectively by existing government or other contractor resources. FFRDC's are intentionally located outside the government to provide a long-term strategic relationship and management flexibility to attract and retain high-quality scientists and engineers.

33 *"Federally Funded Research and Development Centers (FFRDCs)* "April 2013 p. 5 available at http://www .acq .osd. mil/chieftechnologist/publications/docs/20130426_FFRDC_EngagementGuide.pdf (Accessed March 21, 2015).

Table IV. Federally Funded Research and Development Centers (FFRDC's)

FFRDC	Primary Sponsor	Parent Organisation	Location
R& D Laboratories			
Lincoln Laboratory	Air Force	MIT (Massachusetts)	Lexington, MA
Software Engineering Institute	ASD R&E	Carnegie Mellon University (CMU)	Pittsburgh, PA
Institute for defence Analyses (IDA) Computing & Centre (C&C)	National Security Agency (NSA)	Institute for Defence Analyses (IDA)	Alexandria, VA
Systems Engineering and Integration Centres			
Aerospace	Air Force	Aerospace Corporation	EI Segundo, CA
MITRE National Security Engineering Center (NSEC)	DASD (SE)	MITRE Corporation	McLean, VA and Bedform, MA
Study and Analysis Centre			
Centre for Naval Analyses (CAN)	Navy (ASN (RDA))	CAN Corporation	Alexandria, VA
Institute for Defence Analyses (IDA)	USD (AT&L)	IDA Corporation	Alexandria, VA
RAND Arroyo Centre	Army Staff/ PA&E	RAND	Santa Monica, CA
RAND National Defence Research Institute ((NDRI)	USD (AT&L)	RAND Corporation	Santa Monica, CA
RAND Project Air Force (PAF)	Air Force (SAF/AQ)	RAND Corporation	Santa Monica, CA

Source: US FFRDC Engagement Guide

FFRDC's are operated, managed, and / or administered by a university or consortium of universities, other (not-for-profit or nonprofit) organisation, or an industrial firm (as an autonomous organisation) or as an identifiable separate operating unit of a parent organisation.

Department of Energy (DOE) FFRDC's also perform a critical role in defence and national security research and development and offer unique resources and capabilities which are available for use by DOD on a work-for-hire basis. DOE has 18 FFRDC's that provide a broad spectrum of cutting edge research capabilities integration with the commercial sector. The DOD's technology base programme has not kept pace with the level of technology development in the commercial sector. DOD (and the space program) had provided an early market for the semiconductor and integrated circuits devices and pushed the subsequent development of those technologies. By the 1970s, however, DOD's market share reduced significantly and commercial demands pushed new developments. Soon commercial sector outperformed sectors made for DOD. Part of DOD's articulated S&T strategy over the 1990's was to fall back on the commercial sector's technology base efforts, wherever it could. It sought to do this by pursuing what it called dual-use programs. These programmes sought to cooperatively develop technologies of mutual benefit to DOD and the commercial sector, in a way that could accelerate their use by both. While DARPA was given the lead in initiating these kinds of programs, the Services too had been given the same authority. The Services, however, have been slow to make use of this authority. DOD's Dual-Use Applications Programme (DUAP) is meant to stimulate the Services into pursuing dual-use programmes.

DARPA is a non-hierarchical organisation whose primary role is to oversee creative research in short programmes that typically run for four to six years. Its role is to "sponsor revolutionary, high-payoff research bridging the gap between fundamental discoveries and their military use." DARPA has six technology programme offices with about 140 programme managers and a small support staff totaling to a workforce of around 250 personnel. It has an investment strategy in which programme managers define the programmes that might lead to a revolutionary change. DARPA's overall objectives are to "demonstrate breakthrough capabilities for national security" and "catalyse a differentiated and highly capable U.S. technology base[34]." For this, DARPA solicits and reviews proposals with the military services and awards grants for basic and applied research with the most innovative potential.

DARPA serves as a catalyst for developing disruptive capabilities, with support from the upper echelon of the defence acquisition community. The DARPA-run programs have the ability to reach into various sectors of industry by funding and the creation of new ideas—although some programmes can quickly become classified or 'black' because of the high pay-offs to the military. DARPA's success rests largely in its ability to steer high payoff research and convert new concepts and technology break through to military programmes. Consequently, DARPA has been successful in several radical innovations including in the areas of stealth, internet, Global Positioning System (GPS) and Unmanned Aerial Vehicles (UAV). However, it does not have any of its own R&D labs. Rather, it identifies talent and ideas from the industry, academia, government laboratories and individuals, and awards R&D contracts that are to be executed. DARPA's role is thus limited only to identify and shortlist projects and manage the programme.

R&D in China

China by increasing its R&D investments between 12 per cent to 20 per cent annually from the 1990's has been able to reach the $ 284 billion investment mark in 2014 and with the same kind of R&D intensity is likely to surpass the US by about 2022, when both the countries will invest close to $ 600 billion in R&D[35]. China's heavy investments are to create an R&D infrastructure that will enable it to develop, commercialise and market advanced technology-based products. China during its 12th FYP period (2011-15) is targeting to increase R&D spending to 2.2 per cent of GDP

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34 "*Assessing High-Risk, High-Benefit Research Organizations: The "DARPA Effect"* by Maggie Marcum in the book Getting To Innovation edited by Kevin Pollpeter p.30.available at http://igcc.ucsd.edu/assets/001/505314.pdf (Accessed March 21,2015).

35 "*2014 R&D Magazine Global Funding Forecast*" Dec 2013 p. 14 available at http://www.battelle.org/docs/tpp/2014_global_rd_funding_forecast.pdf , (Accessed March 26, 2015).

by 2015 and strives to transit from a manufacturing economy to an innovation driven economy by 2020.Chinese leadership has the perspective to drive the innovation vision, as eight of the nine members of China's Politicalbureau Standing Committee (PSC) have engineering degrees[36].China to become an innovation-based economy by 2020 has accelerated its research conversion into development and this is demonstrated by the large proportion of investment in both civil and military hardware development in comparison to the funding for basic and applied research. Further, according to the 'Battelle' R&D Magazine's Global Researcher Survey, China's advanced R&D (about 33 per cent and 25 per cent) is pursued in collaboration with the U.S. and European research organisations respectively.

China does not publicly disclose its allocation on military RDT&E, although IHS Jane's estimates 2013 allocation to be $ 8 billion (This is more than 6 per cent of its total defence budget)[37].This spending is further augmented by the RDT&E policy directive to the state-run defence enterprises to spend at least 3 per cent of annual revenues on R&D by 2020 and additional governmental spending authorised to defence R&D agencies as PLA and State Administration for Science, Technology and Industry for National Defence (SASTIND). It is also expected that several agencies and government departments invest in R&D as the Civil Military Integration (CMI) policy encourages dual sector integration. In addition, there are inflows from China's promotion of foreign investments in non-defence R&D sectors.

China in 2006 has also promulgated two separate National S&T programmes for the period 2006-20 as pertaining to the defence and its civilian counterpart. These are the development programmes of S&T for National Defence and the National S&T development programme for civilian counterparts. In line with China's military modernisation plans and its efforts to indigenously manufacture products related to information

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36 "*2014 R&D Magazine Global Funding Forecast*" Dec 2013 p. 15 available at http://www.battelle.org/docs/tpp/2014_global_rd_funding_forecast.pdf (Accessed March 27, 2015).

37 "*China-Defence Industry*" IHS Jane's World Defence Industry 2014 p.97

warfare, the defence R&D programme prioratises in terms of the efforts required in the various associated defence areas. The focus of defence R&D programme is on both basic and advanced defence technologies, early and advanced–stage applied R&D of next generation weapons and the development of dual-use high technologies and manufacturing for defence sector. The civilian S&T plan provides details of specific dual-use high technology projects underway with the defence industry that are receiving priority state funding.

China is following two types of innovation development strategies[38]. The first is the "good enough" affordable approach to produce and field large quantities of arms that are the high-volume, low-cost version(s) of the foreign product. Although their quality and performance are inferior but these are cheaper and meet the needs of the PLA. The second is the high-end, high-cost, "gold-plated" approach to develop sophisticated weapons that match those of advanced nations. This is a long-term strategy, as the defence industry at present lacks scientific and technological capabilities to execute higher-end innovation. Notwithstanding, Chinese defence S&T institutes are attempting R&D in increasingly advanced emerging technologies and weapons which include directed energy laser weapons, robotic systems, and miniature nano-based systems.

Chinese R&D processes were throughout relatively isolated from the world as the defence industrialisation process insisted on maximising self-sufficiency. Although the defence-related R&D in China benefitted from foreign inputs, the technological inflows did not generate long-term ties, including collaborative R&D arrangements[39]. This included technology transfers from Soviet Union during the 1950s. China's post-1949 defence-industrial model was centralised under State control and exhibited a bureaucratic structure. All arms production was by State Owned

38 Tai Ming Cheung *"The Current State of Defense Innovation in China and Future Prospects'* p.5 IGCC Defence Innovation Briefs January 2014 available at http://igcc.ucsd.edu/assets/001/505243.pdf (Accessed March 28, 2015).

39 Richard A. Bitzinger and J. D. Kenneth Boutin "China's defence industries: change and continuity- Defence industrialisation and autonomy p. 5 available at http://press.anu.edu.au//sdsc/rc/mobile_devices/ch11.html (Accessed March 30, 2015).

Enterprises (SOEs) and defence-related R&D was allocated to research institutes or undertaken by academic institutions that answered the State.

However, *"Since late 1990s, Chinese defence R&D apparatus has undergone a revamp and grown to conduct highquality work. The key goals of the reforms include enhancing basic research capabilities, diversifying the managements funding from the state to the corporate sector, bringing defence R&D system closer to the rest of the national innovation system, and maintaining close linkages with universities and civilian research institutes"* [40]. Further, China's 10 defence conglomerates own a large part of the R&D apparatus and invest heavily in innovation activities. Their collaboration with foreign companies and accessing of foreign markets has helped bring in external knowledge and technology. Seven universities are affiliated to SASTIND and are the principal source of human talent for the defence economy. The talent recruited by the defence S&T establishment is of a higher quality than the rest of the national innovation system and is transforming the demographic make-up of the defence economy. Much of China's defence technological development over the last two decades is attributed to the import and absorption of technologies and knowledge from abroad, especially from Russia. China acquired more than $ 30 billion of weapons and defence technologies from Russia between 1992 and 2009, involving mostly aviation and naval sectors. However, this also led to distrust because of Chinese efforts to illegally reverse engineer Russian weapons. "*China regularly produces near-replicas of foreign weapons systems based at least in part on Russian, Ukrainian, French, Israeli or U.S. designs but aspires to be more indigenously innovative. To the extent that this risk-averse approach to technology development remains profitable, it is likely to continue in both commercial and defence sectors and stymie efforts aimed at the acceptance of greater risks (both financial and technological) in developing indigenous and more advanced innovative capabilities"*[41].Further, since the late 1990s, the PLA has been an important factor in guiding defence S&T research and production activities for improving the performance of the defence economy.

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40 Cheung, Tai Ming "*The Chinese Defence Economy's Long March from Imitation to Innovation*" p.2 available at http://igcc.ucsd.edu/assets/001/500868.pdf-(Accessed April 04, 2015).

41 Walsh Kathleen A. "China's Defense Technology Acquisition System, Processes, and Future as an Integrator and Supplier" p.2 available at http://igcc.ucsd.edu/assets/001/505318.pdf-(Accessed April 05, 2015).

Competition was brought in the R&D system by deviating from the traditional practice of spreading funds across a large number of projects (with little consideration for performance) and allocating research budgets on select high-priority projects. Efforts were made to corporatise R&D institutes by allowing the major defence conglomerates to take them over. As the defence industry undertook major reforms and the General Armament Department's (GAD's) involvement grew, cooperation increased with the PLA and its trust in the defence industry got restored with the new generation of weapons that got locally developed.

Further, another noteworthy feature of the Chinese defence industrial innovation system is the need for close collaboration between the PLA, the defence industry R&D and the industrial entities throughout all the stages of the product development process. In the present arrangement, feasibility studies are a joint undertaking by PLA end-user units and R&D entities while R&D organisations are responsible for the project design and the engineering development. PLA organisations led by GAD, review and approve the work done before it is allowed to progress to the next phase. Testing is also undertaken by defence endplay organisations.

In the Chinese defence innovation system, imitation (where there is no research constituent), is the primary focus of actions, besides the effort to promote innovation, leadership and management are both top-down in nature. There is a limited interaction with the outside world and the state plays a dominant role in setting priorities, providing strategic direction, and overseeing management of the system[42].

The country's 10 state-owned defence corporations have powered the Chinese defence innovation. There is no data available to indicate how much profits are made from civilian versus military sales. Contractors however state there is hardly any profits on their defence operations because regulations limit the profit on military contracts to a fixed five per cent on top of actual costs. *"It is likely that around one-quarter of the income of the 10*

42 Cheung, Tai Ming *"The Role of Foreign Technology Transfers in China's Defense Research, Development, and Acquisition Process"* p.2 available athttps://escholarship.org/uc/item/4dp213kd (Accessed April 08, 2015).

defense corporations would be defence-related business and the rest would be civilian output". Further, total R&D corporate spending by the defence industry in 2010 was estimated to be around $ US 10.4 billion[43].

There are three Chinese Government and military organisations that manage defence science, technology, and industry. These are the state council's State Administration for Science, Technology and Industry for National Defence (SASTIND), the General Armament Department (GAD) of the PLA; and the Ministry of Industry and Information Technology (MIIT) with Civil–Military Integration Promotion Department (CMIPD)[44].

SASTIND and CMIPD were created through the March 2008 state council reforms. SASTIND was placed under the new MIIT. CMIPD was created as one of 27 MIIT departments. As per the new protocol, parity is between GAD and MIIT. SASTIND and CMIPD are both key regulatory agencies in the new State Council. SASTIND issues defence industry regulations and inspects their implementation, directly allocates research funds through programmes such as the defence basic research programme, and determines, with GAD, which enterprises may and may not engage in weapons and equipment research and production. SASTIND also certifies key defence research laboratories and technology centres. CMIPD is to develop an integrated system of standards for both military and civilian products. The department works to develop policies to promote Civil–Military Integration (CMI). Both SASTIND and CMIPD are subordinate to the new MIIT.

PLA-run GAD established post the 1998 reforms acts as the primary purchasing agent for the PLA and oversees defence procurement and new weapons programmes .It leads the military's R&D system and

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[43] Cheung, Tai Ming *"The Current State of Defence Innovation in China and Future Prospects* "p.3 available at http://igcc.ucsd.edu/assets/001/505243.pdf- (Accessed April 11, 2015).

[44] Francis Ed and Puska Susan M."*Contemporary Chinese Defence Industry Reforms and Civil–Military Integration in Three Key Organisations* "p.1 available at https://escholarship.org/uc/item/3dq7x6d2- (Accessed April 11, 2015).

manages the funding of programmes[45]. It's weapons and equipment development system is excessively based on the ground forces thereby, inhibiting comprehensive modernisation across China's armed forces. As a result, the air force and navy, has depended on the acquisition of foreign weapons from Ukraine, France, Israel, Germany, Switzerland, and the United Kingdom. GAD is the fourth general department for the PLA. It is the defence industry's main customer and has actively engaged with industry as a regulator. In particular, the GAD is supposed to ensure that local arms producers meet PLA requirements when it comes to capabilities, quality, costs and programme milestones. Its regulatory initiatives have implications for CMI and the current arrangements for licensing, R&D support through funding programmes and defence key laboratory accreditation, and collaboration with CMIPD on military–civilian dual-use technical standards development, and all encourage this trend.

There is considerable interaction between the military and government organisations managing defence science, technology, and industry. GAD and SASTIND jointly determine which enterprises may engage in weapons and equipment research and production. Both are involved in how the national defence key laboratories and defence industry advanced technology research and application centres are established. CMIPD works with GAD to prepare its civil–military integrated standards system. Since 2007 a series of regulations have liberalised the rules for civilian participation and investment in the defence industries. New GAD and SASTIND regulations for licensing weapons and equipment producers have opened up defence contracts to civilian enterprises, enabling private companies to provide R&D services directly to the military. The defence industry remains dominated by the ten defence conglomerates and their subsidiaries, but it is possible that in future the balance will shift more towards private actors, particularly if retired military personnel see increasing opportunities in a growing private sector contracting industry[46].

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45 Francis Ed and Puska Susan M."*Contemporary Chinese Defence Industry Reforms and Civil–Military Integration in Three Key Organisations* "p.3 available at https://escholarship.org/uc/item/3dq7x6d2- (Accessed April 12, 2015).

46 Francis Ed and Puska Susan M."*Contemporary Chinese Defense Industry Reforms and Civil–Military Integration in Three Key Organisations* "p.4 available at https://escholarship.org/uc/item/3dq7x6d2 (Accessed April 12, 2015).

Notwithstanding, China's DIB is now increasingly becoming decentralised, with enhanced scope for local State-Owned Enterprises (SOEs) and privately owned enterprises to contribute to R&D and production. However, the responsibilities for R&D, testing, procurement, production and maintenance are with different units thereby leading to major gaps in information sharing.

Way Ahead for India

Defence research and development activities in India, need to be driven with a clear vision, focus, planning and coordination while keeping the global trends and success stories in mind. R&D, be it for the civil or the military industry, is a long-term investment and is undertaken to seed new innovations for driving economic growth. The US, accordingly has consistently committed two and half per cent to three per cent of GDP annually for many decades while, China after improving its economy, increased the R&D investments by 12 per cent to 20 per cent annually, in the last two decades to achieve a high R&D intensity. This, however, was able to only partially bridge the gap created due to the absence of consistent R&D investment. Thus India, recently projected by the IMF to become the fastest growing economy by end 2016[47], must at the outset, increase the R&D investment from a meager 0.9 per cent of GDP to at least two per cent of GDP by FY 2018 and subsequently increase it to two and half per cent of GDP in the next 10 years thereafter. Further, as discussed earlier, the government and academia's share of R&D in industrialised countries like the US, is only 25 per cent (13 per cent and 12 per cent respectively), while the bulk of the contribution comes from the industry (71 per cent) and a small balance from non-profit institutions (four per cent). In other emerging economies like Brazil and China, government share although significant (just over 50 per cent and over 30 per cent (from universities and research institutions respectively), are declining and are still

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47 Panda Ankit "*IMF: India Will Be Fastest Growing Major Economy by 2016*" The Diplomat January 21, 2015 available at http://thediplomat.com/2015/01/imf-india-will-be-fastest-growing-major-economy-by-2016/(Accessed April 13, 2015).

much lower than that of India[48]. In India, the ratio reverses with private investment as a percentage of GDP being only 0.23 per cent[49]. This trend needs to be addressed to ensure greater private sector contribution. This could be achieved by introducing innovative policies and providing incentives to achieve it. As discussed, in case of China, several agencies and departments invest in R&D as the CMI policy encourages dual sector integration and inflows also come from China's policy on promotion of foreign investments in non-defence R&D sectors. A similar approach in case adopted by India can improve private sector participation.

Further, in the last few decades, more than 55 per cent of the GERD in India has been consumed by the strategic sectors of defence (DRDO), atomic energy (DAE), and space (ISRO)[50]. Consequently, India, with one of the lowest R&D to GDP ratios is spending resources in areas that have a weak connect to the industry, and thereby, is missing out on the opportunities for economic growth, as achieved in the case of South Korea, China or Israel.

The R&D investment in India must next be channelised into pre-selected areas of science and engineering which will help develop critical civil-military technologies that are either being denied or are expected to be increasingly employed in the future systems and products. The basic research activity must be so planned to be directed to develop new areas of knowledge in these pre-identified fields of science and technology. This research can then be adapted to specific civil and/or military applications

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48 Ghosh Arunabha" *Innovation needs an ecosystem*" Business Standard February 26, 2012 available at http://www.business-standard.com/article/opinion/arunabha-ghosh-innovation-needs-an-ecosystem-112022600045_1.html. (Accessed on April 13, 2015).

49 *"Whither Science Education* In Indian Colleges?" p.4 Observer Research Foundation Mumbai Ideas and Action for a Better India available at www.academia.edu/.../WHITHER_SCIENCE_EDUCATION_IN_INDIA. (Accessed April 14, 2015).

50 *"Whither Science Education In Indian Colleges?*" p.4 Observer Research Foundation Mumbai Ideas and Action for a Better India available at www.academia.edu/.../WHITHER_SCIENCE_EDUCATION_IN_INDIA. (Accessed April 14, 2015).

through applied research and where needed, further researched upon for advanced technology developments. All the three forms of academic research must be pursued with the intent to orient and focus the research on to industrial applications and must endeavour to provide solutions to the Indian industry's civil-military requirements and problems.

Although, as discussed earlier, national priorities such as social and political compulsions determine the inter-se investment's in basic research, applied research and product development activities, the inter-se commitment and investment in the case of India is most for basic research while it is higher for product development in China & South Korea. Further, in India more than 25 per cent of R&D investment goes towards basic research as against 17 per cent in the US and five per cent in China[51].There, however, is a need to correctly operationalise the basic, applied and advanced research activities in India in terms of appropriate selection of institution's for undertaking the research activity, their state of research infrastructure and capabilities, availability of the right talent to conduct the research, identification of the required fields of research, sourcing, allocation and monitoring of funds, the gestation periods needed to support fundamental research, industrial applicability of the research work for civil-military applications and so on.

Also, for the industry to benefit from the R&D activities, applied research has to be given priority. Once the share of private sector funding in R&D increases, this will happen automatically. Thus, there is all the more reason for the government to regulate and provide incentives to ensure increased private sector inflows into R&D. Further, academia's research facilities can be optimally utilised if it takes on the industries research projects on payment and consultancy terms. This will benefit both parties and give a fillip to applied research.

As far as advanced technology development is concerned, it was seen in the paper that both the US and China have increasingly looked at external

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51 Ghosh Arunabha" *Innovation needs an ecosystem*" Business Standard Feb 26, 2012 available at http://www.business-standard.com/article/opinion/arunabha-ghosh-innovation-needs-an-ecosystem-112022600045_1.html.(Accessed on April 15, 2015).

sources to harness their strengths in order to meet domestic requirements especially because, no country can afford to develop all the advanced technologies due to the associated prohibitive costs.

As far as product development activities are concerned, since the late 1990s/early 21st century, a growing trend observed has been the formation of global innovation networks. These "*integrate dispersed engineering, product development, and R&D across national boundaries*". Their rapid rise has led to far-reaching structural changes to the geography of innovation and production in the high-technology sector within a decade[52] and sooner India integrates with such innovation networks the better it is for the country.

The Indian S & T capacity is the net result of its national science policy, sectoral R & D priorities, educational structures and policies, national human resource for R&D in S&T which in turn, determines the capabilities of absorption and development of advanced military technologies. India in 2013 promulgated the latest version of its Science Technology and Innovation Policy (STIP). Notwithstanding, the same or its earlier avatars, the Scientific Policy Resolution (SPR) 1958 or the Science and Technology Policy (STP) 2002, the education policy in India has relatively failed to provide the requisite impetus to engineering and technology that is essential for R&D and consequently, the Indian research capacity is directed more towards the research on basic sciences which has meager relevance to advanced industrial applications.

The education system in India thus has to shift its focus from a theoretical bias to a more practical curriculum. Aim should be to develop the desired skillsets that will be required in the future timeframe. Attention is also required to be paid to encourage, build and develop a talent pool in Science, Technology, Engineering and Math's (STEM) skills, along with developing well equipped, quality technical institutes for diploma, degree and advanced level professional courses having industrial applications. These will help in building upon competencies and enable retaining a broad base of talent

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52 Cheung, Tai Ming "*The Chinese Defense Economy's Long March from Imitation to Innovation*" p.3 *available* at http://igcc.ucsd.edu/assets/001/500868.pdf- (Accessed April 16, 2015).

for system or product design, engineering, manufacturing, production, warehousing, marketing, and sales and so on to ensure commercial success.

The ultimate aim of undertaking research is to produce a new or upgraded product that incorporates latest upgraded features and technologies with a view to increase sales, profitability and revenue of the firm and the economy. The revenue so generated will help set up new industries that in turn will provide employment, help introduce and diversify into new products, and thus, generate more funds for socio-economic growth and development. Yet, while driving R&D projects, the Indian government needs to appreciate that there will be a few failures, and wherever justified, should accept and support these as inevitable sunk costs. The larger aim of the government should be to encourage R&D. As discussed in the paper, this is what was done by both the successful economies, that is, the US and China, in order to sustain an innovation-based growth.

Further, innovations had been fostered, nurtured and aligned to the military and export markets requirement ab-initio and provided a supportive R&D ecosystem network that enabled risk-taking and risk sharing. It also initially accelerated corporate and later enterprise formation in their defence industries. Another fundamental aspect was that both the US and the Chinese ecosystems operated in environments in which the talent and capital were developed and acquired, retained and redeployed for the successive phases of the innovation process (or for spiral development) and also for the commercial development[53]. The government's policies, regulations, incentives and taxes need to be put into place in India to support the growth of the R&D ecosystem. While formulating, finalising and revising these policies and regulations, the government needs to seek the views and inputs of the Industry to include their perspectives and changing requirements in respect of the ecosystem.

The RDT&E programme of the US DOD constitutes 65 per cent to 70 per cent of the federal governments R&D budget while in the last few

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53 "*2014 R&D Magazine Global Funding Forecast*" December 2013 p. 20 available at http://www.battelle.org/docs/tpp/2014_global_rd_funding_forecast.pdf (Accessed April 17, 2015).

decades, more than 55 per cent of the GERD in India has been consumed by the strategic sectors of defence (DRDO), atomic energy (DAE), and space (ISRO)[54].Thus the percentage of GERD in defence RDT&E in the US is 10 per cent to 15 per cent higher when it does not include the expenditure on strategic systems developed by NASA. Further, the allocation and percentage share of R&D in the defence budgets of US, China and India for FY 2015 stand at around $ 63.5 billion, $8 to $9 billion and $ 2 billion each which constitutes approximately 11 per cent, six per cent and six per cent of their defence budgets respectively. However, China's actual spending on military RDT&E is likely to be double of this figure (approximately 16 per cent to 18 per cent). This is due to firstly, it does not disclose these figures officially and secondly, there are additional governmental spending authorised to defence R&D agencies of PLA and SASTIND. The R&D policy directive to the state-run defence enterprises to spend at least three per cent of annual revenues on R&D by 2020 is expected to further augment Chinese military R&D spending in future. To boost its defence R&D, India too should consider issuing a policy to regulate its DPSU's and OF's to spend at least 10 per cent of their annual revenues/value of sales on R&D and at the same time increase the annual R&D budget allotted to the DRDO initially to seven per cent of the defence budget for FY 2017 and gradually increase it to 10 per cent of the defence budget by FY 2023. This will ensure DRDO's requirement of additional funds are met and the short falls in budget do not affect technology development, S&T and the development of infrastructure and facilities related to its projects, or causes other ongoing activities to be re-prioritised and its flagship programmes to suffer due to the lack of funds[55].

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54 "*Whither Science Education* In Indian Colleges?" p.4 Observer Research Foundation Mumbai Ideas and Action for a Better India available atwww.academia.edu/.../WHITHER_SCIENCE_EDUCATION_IN_INDIA. (Accessed April 17, 2015).

55 "*Ministry of Defence Demands For Grants (2014-15) for Ordnance Factories and DRDO*" p.18 presented by the Standing Committee on Defence to Lok Sabha on December 22, 2015 and available at http://164.100.47.134/lsscommittee/Defence/16_Defence_5.pdf (Accessed April 18, 2015).

The essential features of the DRDO's budget of the last five years and the current year; the share of R&D in the defence expenditure and the percentage of expenditure in relation to India's GDP during the last few years is compiled under Table V:

Table V. DRDO's Budget Last Five Years and Current Year (Rs in Crores)

Year	Total GDP (Rs in Crores)	Defence Expenditure	Defence R&D Expenditure	Defence R&D as % of Defence	Defence R&D Expenditure as % of GDP
2009-10	64,57,352	1,41,781	8,475	6.98	0.13
2010-11	76,74,148	1,54,117	10,148	6.59	0.13
2011-12	89,12,178	1,70,913	9,893	5.79	0.11
2012-13	1,00,28,118	1,81,776	9,794	5.39	0.10
2013-14	1,13,71,886	2,03,672	10,859	5.37	0.09
2014-15 (BE)	-	2,29,000	15,282	6.67	-
Average Last 5 Years	-	**1,81,209**	**10,742**	**5.96**	**0.11**

Source: Adapted by the author from MOD Demands For Grants (2014-15) for OF's and DRDO

There are certain similarities in the spending of the US and India on defence R&D and the categorisation of defence projects. As regards R&D spending, over 80 per cent of US RDT&E budget goes towards the development or demonstration of specific military systems and components (called weapons development activities) while the balance 20 per cent goes to primary R&D in sciences and technologies which are identified as vital for developing improved military capabilities and operations (called science and technology (S&T) activities). Similarly, in

India, nearly 80 per cent of the total DRDO budget is utilised for Mission Mode (MM) Projects with deliverables for the Armed Forces[56].

The mapping between the US and Indian defence R&D activities and projects is derived and brought out in Table VI. This has been done to facilitate a comparison of the two countries defence research work, their funding and inter-se priorities. The US research activities of 6.1 to 6.6 are similar to their Indian counterparts. However, the US Product Support (PS) activity of DRDO is a new category of project recently added to cater to the need for extending production / Transfer of Technology (TOT) support to DRDO's Production Partners (PA's) while the US operational systems development (6.7) has a wider scope. The latter supports the continued improvement and upgrading of products in production including classified programs[57]. Accordingly, the RDT&E budget unlike the DRDO budget allocates a major amount (about $28 billion annually constituting 38 per cent of the RDT&E budget) towards the operational systems development (6.7). More importantly, a large part of this allotment is for the efforts to upgrade systems that have been fielded or have received approval for full scale production. Such a requirement of funds in the Indian context too arises in post-production models. It is required at least on two occasions. Firstly, when product improvements are to be undertaken to overcome existing shortcomings in design, manufacturing process or performance and secondly, when certain upgrades or retro-fitments are to be introduced to overcome technological obsolescence. However, in the Indian system, there is sometimes a lack of clarity and the will to execute these. As far as DRDO developed systems are concerned the organisation is duty bound and committed to provide technical support to the PA as long as the system remains in service with the armed forces. To that extent, in the case of certain complex systems, the DRDO labs establish product support cell

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56 "*Ministry of Defence Demands For Grants (2014-15) for Ordnance Factories and DRDO*" p.18 presented by the Standing Committee on Defence to Lok Sabha on December 22, 2015 and available at http://164.100.47.134/lsscommittee/Defence/16_Defence_5.pdf (Accessed April 19, 2015).

57 "*Department of Defense R&D Funding 2014*" p.68 Travis R. Doom Consortium for Science, Policy and Outcome available at http://www.aaas.org/sites/default/files/15pch05.pdf (Accessed April 19, 2015).

to provide the necessary interface and technical support. These cells retain and maintain the technical

Table VI. Mapping US and Indian Defence R&D Activity and Projects

Ref	US Research Activity	Indian Research Activity	US Interse%	US Work Performer	Indian Performer
6.1	Basic Research	Extramural Research	3.0	Universities (60%) DOD's R&D Facilities (25%)	Academia Science LabsR&D Institutions/ Innovation Centers
6.2	Applied Research	Science & Technology	7.1	Industry (50%) DOD's R&D Facilities (30%)	DRDO in collaboration with Centers of Excellence
6.3	Advanced Technology Development	Technology Demonstration	7.9		
6.4	Weapon Component Development & Prototyping	Mission Mode	19.4	Private Firms	DRDO with Industry
6.5	System Development & Demonstration		17.4		
6.6	RDT & E Management Support	Infrastructure and Facilities	6.6	-	
6.7	Operational Systems Development	Product Support	38.9	Private Firms	DRDO extends TOT to PA

Source: Adapted by the author from *Department of Defence FY 2015,2014 and 2013 President's Budget"* documents necessary to provide product support. Notwithstanding, there have been instances where the PA's, who have been transferred the manufacturing technology and are equally responsible for extending the product support and upgrades to the Services, have been found to shirk away from their responsibility feigning ignorance of the DRDO developed system's design's and know why's thereby, either not coming forth or delaying the execution of product improvements, retro-fitments and upgrades to military systems. Another reason for this is that the PA's over a period of time have become more of assemblers of platforms and equipment and do not want to venture into the more challenging area of design. Consequently, this leads to a situation, where a sustenance void is created both, in terms of funding and the agency responsible for the execution of this task. Such an anomaly in the Indian DIB is required to be overcome by appropriating the necessary funds and issuing the necessary policy directive to ensure effective in-service sustenance engineering and management of DRDO developed systems.

The US DOD at an average spends $ 2 billion annually (three per cent inter-se share of RDT&E funding) on basic research. In comparison, the DRDO has instituted grants-in-aid schemes to nurture basic research talent in universities, academia and other research centers, including the industries in the country. The projects/ programmes identified by the DRDO are funded through Extramural Research (ER) in twenty three S&T thrust areas as identified by the DRDO**.** Since 2007-08, as on October 31, 2014, out of the 604 projects**,** 136 projects have been completed and 466 are underway at the various universities, IITs, NITs, colleges, R&D Institutions and CSIR labs. Also, eleven directed research projects, costing more than Rs 14 crore were sanctioned to Research and Innovation Centre (RIC), IIT Madras Research Park, Chennai[58]**.**

DRDO, for basic research, has also established four research boards. These encourage innovative research in defence related areas in the fields of armament, aeronautics, naval and life sciences. Both ER and research

58 *"Government of India MOD Annual Report 2013-14"* p. 102 available at http://mod.nic.in/writereaddata/AnnualReport2013-14-ENG.pdf, and "*Department of Defense R&D Funding 2014*" Travis R. Doom Consortium for Science, Policy and Outcome available at www.aaas.org/sites/default/files/15pch05.pdf (Accessed April 20, 2015).

board's support basic research in science and engineering as applicable to respective disciplines. For the purpose of funding, grants-in-aid scheme with each of the board's has been earmarked at Rs. five crore per year. This grant needs to be enhanced to further encourage basic research.

Besides the projects activities, DRDO has established seven Centres of excellence (CsOE) at various institutions/universities in Bangalore, Chennai, Hyderabad, Coimbatore, Mumbai and Kolkata for creating strong academic links[59]. The board promotes CsOE in selected identified areas e.g. for aeronautics in systems design & engineering, composite structures, computational fluid dynamics and so on. Intellectual property developed through the board's funding is shared with the grantee institution. The budgetary provisionary allocations available/allotted to the Universities (under ER) and by research boards, since 2007-08 and till October 15, 2014 is compiled in Table VII.

Table VII. DRDO Basic Research Budgetary Provision to Universities Under Extramural Research and Research Boards

Year	**2007-08**	**2008-09**	**2009-10**	**2010-11**	**2011-12**	**2012-13**	**2013-14**	**2014-15**
Allotted (ER)	31	30	30	36.50	46	50	60	65
Research Boards(4 invest 5 crores each)	20	20	20	20.00	20	20	20	20
Total	51	50	50	56.50	66	70	80	85
DRDO Budget	6,105	7,699	86,475	10,148	9,893	9,794	10,859	15,282
Basic Research (%)	**0.83**	**0.64**	**0.58**	**0.56**	**0.66**	**0.73**	**0.73**	**0.56**

Source: Adapted by the author from MOD Demands For Grants (2014-15) for OF's and DRDO

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59 *"Ministry of Defence Demands For Grants (2014-15) for Ordnance Factories and DRDO"* p.48 presented by the Standing Committee on Defence to Lok Sabha on December 22, 2015 and available at http://164.100.47.134/lsscommittee/Defence/16_Defence_5.pdf (Accessed April 20, 2015).

As seen, the annual spending on basic research varied between 0.56 per cent to 0.83 per cent of the DRDO budget and compares very poorly in comparison to US investing three per cent of the RDT&E budget. It also implies the budget for S&T and TD projects together is eating into the budget of basic research and this anomaly needs to be resolved. Hence there is an urgent requirement to increase the basic research funding to at least one per cent by FY 2017 and to three per cent by FY 2023. Also, applied research and advanced technology development projects for the US DOD is 50 per cent performed by the industry while 100 per cent of DRDO's S&T and TD projects are undertaken in house by the DRDO. Further, most weapon development research activity in India is performed by the DRDO with its development partners. These could be DPSU's / OF's / private sector players but in the US it is mostly with private firms. Also as discussed earlier, China's advanced R&D is largely pursued in collaboration with the US and European research organisations. Thus, increased private sector participation and investment in defence research in India is inescapable and has to be facilitated by the government by introducing enabling policies.

The success of a military R&D programme to a large extent depends on the extent to which the military R&D priorities are aligned and embedded into both the national security imperatives and the consequent S&T plans. Both the US and China have aligned and enunciated clear long term strategy's for developing their civil and military R&D systems in unison. While this exercise is more dynamic in the case of the US as it promulgates an annual defence S&T strategy which considers the national S&T strategy, joint vision and the defence S&T project "*Reliance's*" inputs, the Chinese have prepared a onetime long term national S&T programme for the period 2006 - 20, concurrently for the civil and the military but promulgated them separately. Accordingly, China's arms industry thus develops weapon systems using the dual-use high end technologies and manufacturing for the defence sector and the US's dual-use programmes seek to cooperatively develop technologies of mutual benefit to the DOD and the commercial sector, in a way that will accelerate their use by both .The US DARPA has been given the lead for initiating these kind of programmes. India although has promulgated its civil STIP-2013 but this unfortunately has been prepared on a stand-alone mode and has neither considered nor aligned the requirements of the defence and the civil R&D in India. Thus, there is a need to constitute a joint task force which must comprise of the representatives of all stakeholders, that is, to include the representation from universities, academia, research centres, research institutions, various ministries, defence public and private sector ,DRDO, Services and so on for formulating a comprehensive long term civil-military dual-use R&D strategy – 2027.This document in turn can provide the necessary direction, impetus and a unity of effort and purpose for all stakeholders to pursue a joint civil-military dual-use R&D strategy.

As far as the development of defence technologies are concerned, the annual plan of technologies asked for by the US Congress since 1989 requires the developers to bring out the rationale for selecting the technologies, the milestones and budgets allocated for developing them and the contribution the industry and allies could make towards their development. The Chinese defence R&D programme also further prioritises in terms of the efforts required in the various associated defence areas .The focus of China's defence R&D programme is on both basic and advanced defence technologies, early and advanced applied R&D of next generation weapons. In the Indian context, the headquarters integrated defence staff has identified the core technologies required to be developed for the armed forces over the next 15 to 20 year horizon[60] and promulgated this as the Technology Perspective Capability Roadmap (TPCR) in 2013. It is also in the process of refining it further. "*The Services have also provided the Long Term Integrated Perspective Plan (LTIPP) to the DRDO, which gives a wide idea about the requirements of the Services. Considering the LTIPP, DRDO has prepared a document on Long Term Technology Perspective Plan (LTTPP), which highlights the expected new technology developments in various areas. The LTTPP of DRDO is aligned with the LTIPP of the Services. The technology development plan covers the 12th, 13th and 14th FYP (2012-27). The document also covers the new technologies which are not mentioned in the LTIPP but will be useful and of interest to the Services and covers a period beyond 2027".*[61] In addition, DRDO has identified

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[60] *"Formation of Horizon Core Technology (HCT) Group at HQ IDS" –Core Capabilities para 11*. available at http://ids.nic.in/horizoncore.htm (Accessed April 21, 2015).

[61] *"Ministry of Defence Demands For Grants (2014-15) for Ordnance Factories and DRDO"* p. 39 presented by the Standing Committee on Defence to Lok Sabha on December 22, 2015 and available at http://164.100.47.134/lsscommittee/Defence/16_Defence_5.pdf (Accessed April 21, 2015).

24 critical technologies that they want to obtain as offsets. However, in the above, unlike the US, the milestones and budgets allocated for developing all the identified technologies by the Services and the DRDO and the contribution of the industry should be similarly mapped as done in the US system.

The US concept of DOD-wide S&T strategy or plan to direct an integrated approach to technology development through project "*Reliance*" discussed earlier is worth emulating in India. This can ensure close monitoring, control and coordination between the stakeholders associated with technology development, especially for areas of common interest to more than one Service and agency. Project *"Reliance"* as discussed earlier, is responsible for developing the basic research plan, defence technology area plans and joint war-fighting S&T plan. What is important is that the plans lay out roadmaps for achieving certain military capabilities. To achieve these in time, specific Strategic Research Objectives (SROs), in case of basic research and Defense Technology Objectives (DTOs) for other researches are identified. Each SRO/DTO then identifies a specific level of technological advancement or gain in knowledge that will be made during the year, including estimated dates, funding levels, programme elements which will support that funding & explanation as to how the effort will impact war-fighter's needs. This is somewhat similar to the concept of 'performance budgeting' and 'outcome budgeting' and if introduced for the DRDO may enable closer monitoring, control and coordination.

The Indian defence R&D agencies must follow the US system for reducing the inherent technological risk of failure that are associated with weapon development programmes. This, in the US system, is attempted very early, that is, at the zero milestone, first concept exploration phase itself. It is achieved by developing the necessary protocols for testing and thus gain an early knowledge of the programme definition and attempt risk reduction in failure at the prototype stage itself.

The Defence Technical Information Center (DTIC) serves the US DOD community as the largest central resource for DOD and government-funded scientific, technical, engineering, and business related information. Further, it allows DOD to reduce duplication & build on previous research, development, and operational experience. In case of China, open source information collection is an element of the Information Analysis and Dissemination (IAD) system. For technology assimilation/concept refinement of foreign inputs, a S&T IAD system has been built with around 400 analysis and diffusion centers within the S&T system. However, in the case of India, there is no national technology repository or a technology exchange mechanism for the effective dissemination and flow of information between stakeholders, especially, between the users, developers and the policy makers with regards to the availability of specific technology in India or across the globe. Unfortunately both these aspects in the Indian context have either not been thought of or institutionalised and thus must be adopted without any further delay.

There is also very little flow of technological information between the military R&D stakeholders i.e. the developers, policy-makers and users. This, as in the case of the US and China is one of the major strengths with regards to the technology policy making and probably would be so with most of the countries that are considered as technology leaders.[62] In the Indian context technology information does flow partially between the DRDO, ISRO or CSIR laboratories engaged in advanced technology research (developers) but the same is barely available to the armed forces (users) and the technology decision makers. Moreover, the armed forces have to actively associate themselves as equal partners in the national technology development process and take a long term view of the technologies that affect their military R&D priorities. Unless this happens, there will always be mutual disagreements between the stakeholders with regards to the plans for acquisition of military technology by the country.

The US RDT&E set up has two Principal Directors (PD) for undertaking the developmental and operational tests and evaluation. They receive RDT&E funds for carrying out their responsibilities of independent and/or joint testing of the new systems. The efficacy of carrying out the

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62 "*An Assessment of Indian Science and Technology and Implications for Military Research and Development*" Economic and Political Weekly Jul 2000, p.2770 by Ravinder Pal Singh available at http://www.jstor.org/stable/4409563 (Accessed April 21, 2015).

evaluation by an independent agency vis-a-vis the organisation that is developing the military system is apparent and this since long has been effective in the US system. In case the same is introduced in the Indian system, it will simultaneously satisfy the concerns of the developer, the PA, the user, sustainer, inventory and logistics manager as it will provide an impartial and comprehensive trial evaluation of a DRDO developed product or a product that is planned to be acquired from indigenous or foreign sources and thus, will meet the expectations of all stake holders on all accounts.

The US concept of FFRDCs being operated by a university/nonprofit organisation/an industrial firm on a long-term government contract is paying rich dividends. These are sponsored and funded to address R&D, engineering, and analytic needs that cannot be met as effectively by the existing government or contractor resources. FFRDCs are intentionally located outside the government to provide a long-term strategic relationship and management flexibility to attract and retain high-quality scientists and engineers. The DRDO's Centres Of Excellence (CsOE) established for specific technological areas with the academic institutions of repute in the country, probably come closest to the concept of FFRDC's. However, in the Indian context the DRDO has to adhere to the government rules with regards to the funding process and the management style in respect of such CsOE will be different when compared to that of US FFRDC's. Notwithstanding, more of these CsOE can be established with other universities/nonprofit organisations and industrial firms for the Indian R&D system. The concept must be exploited for the Indian eco-system to attract and retain R&D talent. The CsOE established by the DRDO can be upgraded to "Equivalent FFRDCs of the USA". The DRDO's C'sOE can then be provided an independent body which can be tasked to undertake periodic reviews and monitor the performance of each of these centres. The agency being from outside the DRDO will be able to provide a true assessment of the performance of these C'sOE. This seems

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[63] Turse Nick *"The Wild and Strange World of DARPA"* p.1 Mason History News Network available at http://historynewsnetwork.org/article/3894 (Accessed April 22, 2015).

in-escapable especially when considering that the DRDO is too busy and does not find much time to harness the strengths of these CsOE.

Both Chinese and US DOD's articulated S&T strategy over the last two decades has been to depend on the commercial sector's technology base efforts, wherever possible. Their dual-use programmes have endeavoured to cooperatively develop technologies of mutual benefit. In the US, DARPA is given the lead to introduce such programmes that have the ability to reach into various sectors of industry by funding the creation of new ideas— and where feasible integrating the high pay-offs to the military. Many national security committees constituted in India for recommending reforms have repeatedly suggested the DRDO to follow the DARPA model without realising that actually there needs to be a separate agency from either the DST/CSIR/ISRO or any other separately nominated agency which should be asked to perform this function. The DRDO with its 46 labs and four T&E centres can best be compared with the US DOD's RDT&E's 80 R&D labs and 26 T&E centers. As far as the functioning of DARPA goes, it needs to be remembered that DARPA unlike the DRDO enjoys enormous freedom to award R&D contracts to any agency without having to go through protracted bureaucratic approval processes. It must also be appreciated that 85 per cent to 90 per cent of DARPA's projects fail to meet their full objectives[63] and this is well understood and accepted by the US government. Moreover, it need not be reiterated that a significant reason for the delay in most DRDO programmes is also the restriction of operating with the government processes and regulations which by themselves are extremely time consuming.

The most path breaking structural and organisational defence reform undertaken by China was probably in July 1999 which created the 10 new Defence Industry Enterprise Groups (DIEGs). These functioned as true conglomerates, integrating R&D, production and marketing. Moreover, each defence conglomerate was divided into two entities to promote limited competition within their industrial sectors and thus make them more efficient and technologically innovative. The reforms transformed the conglomerates into profit-oriented, shareholding entities with operational autonomy while remaining entirely state owned. The US DIB also underwent mergers and acquisitions before stabilising into five to six major conglomerates.

The functioning of India's DIB today has a stark resemblance to what the Chinese defence industry was fifteen years back, prior to its first major reforms in 1998. The DRDO, functions independently and on most occasions is oblivious of the requirements of the User and the PA's. The PA's are the state controlled DPSU's and OF's which are inefficient and unproductive and yet been unnecessarily shielded and sheltered by the Indian bureaucracy and the Department of Defence Production. The Indian private industry although enthusiastic is still naïve and yet to be tried out and thus is being kept out of the defence sector deliberately. The User, that is, the armed forces has minimum faith in the DRDO and consequently is not keen in what research is being undertaken. Thus, has the time come when India, like China, also needs to initiate serious and meaningful reforms in its research and development, design and engineering and manufacturing and production segments of the defence sector?

The answer certainly is an emphatic and resounding yes.

The Occasional Paper attempts to analyse the performance of India's defence research and development machinery and especially that of the Defence Research and Development Organisation (DRDO). It first reviews the current state of global R&D and considers the strong and inherent linkages of civil R&D to that of the military and vice-versa. This is followed by identifying the best international practices that have been adopted in defence R&D by the world's leading R&D nations i.e. the US and China. Such an examination helps in bringing out crucial and important experiences. The Paper finally concludes by bringing out the lessons and concurrently suggesting the way ahead for India.

Ranjit Ghosh is a Senior Fellow at the Defence Economics and Industry Centre of IDSA. He has had varied operational and staff experience of around 32 years in the Army. As Commandant & Managing Director of an Army Base Workshop he was responsible for planning and executing the re-capitalisation programme of Infantry Combat Vehicles and Armoured Recovery Vehicles of the Indian Army. As Deputy Director General at the Integrated Headquarters of MoD (Army), he was associated with the ongoing defence procurements and handled the Ordnance Factories, DPSU's, DRDO and the Private Sector, on issues relating to induction and sustenance engineering activities of military equipment and systems. He is an alumni of IIT Madras and stood first in order of merit while specialising in Maintenance Engineering and Management during the M-Tech programme. He also has a Masters in Management Studies from the Osmania University in Defence Management.

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रक्षा अध्ययन एवं विश्लेषण संस्थान

Institute for Defence Studies and Analyses
No.1, Development Enclave, Rao Tula Ram Marg,
Delhi Cantt., New Delhi - 110 010
Tel.: (91-11) 2671-7983 Fax: (91-11) 2615 4191
E-mail: contactus@idsa.in Website: http://www.idsa.in