SOLAR POWERED AVIATION: A NEW REVOLUTION?

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INTRODUCTION

The Solar Impulse-2 (SI-2), a solar powered aircraft, made by the Swiss duo Bertrand Piccard and Andre Borschberg, landed at the Sardar Vallabhai International Airport, Ahmedabad, on the night of March 10, 2015.[1] This aircraft thereafter left Ahmedabad and landed at Mandalay (Myanmar) via Varanasi on March 19, 2015.[2] The single seat aircraft is made up of carbon fibre, with a large wing span of 72 m and it flies at a maximum speed of 49 knots at sea level.[3] It houses 17,000 solar cells which charge lithium batteries during the day and can store up to 340kWh (kilowatt-hour) of energy per day and give it day and night flying capability. The lithium batteries power four 17.5 HP (17.5 CV) electric motors, which drive the propellers. The development of the solar powered SI-2 aircraft is the result of a joint effort by a team of experts from aviation and industry.

The SI-2 team is aiming to make it the first solar powered aircraft to go around the world. The landing in India is part of its journey across the

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1. http://info.solarimpulse.com/en/our-adventure/solar-impulse-2//. Accessed on March 12, 2015.
2. "Solar Impulse's Round the World Solar Plane Lands in Myanmar to Demonstrate The Potential of Clean Technologies", http://info.solarimpulse.com/en/our-story/pilots/#.VQ-GzPmUdDA. Accessed on March 23, 2015.
3. "Challenge1-Energy to Cross Oceans and Continents", http://info.solarimpulse.com/en/our-adventure/building-a-solar-airplane/#.VQ-Fj_mUdDA. Accessed on March 22, 2015.

SI-2 is aiming to become the first aircraft to fly across continents and demonstrate the viability of solar powered aircraft.

world. The aircraft would be flying during both day and night to demonstrate its capability. The around the world trip across continents would strengthen its case as a viable alternative to aircraft flying on conventional sources of energy. The partners involved in the development of this aircraft are exploring the commercial viability of their inventions/innovations by creating new products for automotive, engineering and other industries. This aircraft could prove to be a game changer in the aviation, space and industrial sectors. This paper will deliberate on the pioneering role played by the private sector entrepreneurs in the development of Solar Impulse-2 (SI-2), the Research and Development (R&D) challenges, the dual use technologies, the future of solar power in industry and aviation, the challenges to R&D in India, and a way ahead for India.

PIONEERING SPIRIT OF PRIVATE ENTERPRISE

The ingenuity, collaborative effort and pragmatism of the private sector were on display when the SI-2 landed at Ahmedabad on March 10, 2015, with the names of the main partners displayed on the aircraft and the pilots' and crew's uniforms. Solar Impulse is a privately financed solar powered aircraft project, which was envisioned and initiated by Swiss psychiatrist Bertrand Piccard. Andre Borschberg, a pilot, Chief Executive Officer (CEO) and co-founder, soon joined him.[4] Bertrand Piccard was earlier involved in an around the globe expedition in a hot air balloon in 1999. The first prototype SI-I was test flown in December 2009. The Solar Impulse's flying expeditions include the European Tour (May 2011 to July 2011), Switzerland to Morocco and back (May 25, 2012, to July 24, 2012), and the Across America trip (West to East from May 3, 2013 to July 6, 2013). The cost of developing the SI-2 was about $150 million over a period of 13 years, which is considered to be much

4. Neha Singh, "Solar Impulse-2: Watch Swiss Solar Plane's LIVE Landing and Takeoff from Ahmedabad to Varanasi", http://www.ibtimes.co.in/solar-impulse-2-watch-swiss-solar-planes-live-landing-takeoff-ahmedabad-varanasi-photos-625787. Accessed on March 12, 2015.

less vis-à-vis corresponding aviation projects.[5] The development of the SI-2 and its around the world trip across continents, demonstrates the pioneering spirit, pragmatic approach and enormous potential of the private entrepreneurs.

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VENTURING INTO AN UNKNOWN AREA

The field of R&D involves venturing into new areas, not explored before, and has the inherent danger of failure. Such endeavours require conviction and perseverance; however, their success can have favourable and disproportionate benefits. Bertrand Piccard envisaged development of a solar powered aircraft immediately after his return from a trip around the world in a hot air balloon in 1999. Andre Borshberg, an engineer and professional pilot of Ecole Polytechnique de Lausanne (EPFL) joined him in 2003. These two pioneers, during their journey to build a dream aircraft, were initially snubbed by the aviation majors for aiming to design a huge but extremely lightweight solar powered aircraft, which did not have the necessary strength of a conventional aircraft. Though the SI-2 does not meet all the standards of a conventional aircraft, it indicates a good beginning, and has given hope of developing into a viable clean energy alternative to conventional aircraft flying on aviation fuel.

The development of the SI-2 had its share of setbacks when its first wing spar, which was delivered in 2012, broke during testing. However, it is said that success has many fathers, which proved right even in the case of the SI-2. The Solar Impulse team did not find it easy to get partners initially. However, as they moved forward, they kept finding partners with every milestone/success. The partners who joined these pioneers during their journey include Solvey, Altran, Semper between 2004-06 followed by

5. "Solar Impulse-2: Technology of Aircraft has Huge Potential, "March 12, 2015 http://www.business-standard.com/article/current-affairs/technology-of-aircraft-has-huge-potential-115031200043_1.html. Accessed on March 12, 2015.

Omega and Deutsche during the period 2007-09. The SI-2 team has now enlarged with four main and 80 smaller partners. The four main partners, who supported the SI-2 project are Solvay, a chemical industry group, Omega, a watch brand, Schindler, an elevator and escalator provider, and ABB, a company dealing with renewable energy and transportation. While the partners involved in the development of the SI-2, with the exception of ABB, were not related to the aviation field, they played an important part in the realisation of such an ambitious aviation project. The development of the first prototype of the Solar Impulse took 10 years from formulation of the concept in 1999 to the actual flight of its first prototype in December 2009. It comprises a magnificent feat by a private entrepreneur considering that many aviation and government R&D agencies the world over are yet to achieve such a milestone. It is a perfect example of the private sector venturing into an unknown area and succeeding despite the odds.

CHALLENGES AND INNOVATIONS FOR AROUND THE WORLD TRIP

The world trip of the SI-2 is planned from Abu Dhabi to Abu Dhabi with enroute halts across the continents, which include Muscat (Oman), Ahmedabad and Varanasi (India), Mandalay (Myanmar), Chongqing and Nanjing (China), Hawaii, Phoenix and New York (USA), a location in Midwest US, cross-Atlantic, Southern Europe/North Africa before returning to Abu Dhabi. The world trip is spread over five months from March to August 2015, involving 500 hours of flying which would cover a distance of about 35,000 km.

The around the world trip had posed enormous technical and human challenges. The SI-2 aircraft was subjected to intensive testing. The pilots were given rigorous training and equipped to stay in the 3.8 m^3 cockpit continuously for five days and five nights in order to cross the Atlantic and Pacific Oceans. The SI-2, despite having a maximum operating altitude of 27,000 ft, is protected by thermal insulation only. It does not have a heating or air-conditioning system, thereby subjecting the pilots to extreme temperatures varying from +40 C to -40 C. The associated challenges include carrying suitable food and water, provision of toilet facilities, resting and

flying without endangering the safety of the flight. A lot of thought and innovative solutions were required to meet these challenges. The team has planned for every contingency with precision and perfection. The innovatively designed reclinable seat allows the pilot to do exercises, take rest, carries a parachute and dingy for bail out in case of an emergency, and has a provision for a toilet. The pilots flew a 72-hours-long training sortie in a simulator to prepare for the world trip. They were trained to take short naps of 20 minutes every two hours during which the aircraft would be flying on autopilot. The cockpit has been equipped with visual and audio alarms to wake up the pilot in case of an emergency.

DUAL USE TECHNOLOGY AND INCENTIVE FOR PRIVATE SECTOR

The advanced technological innovations associated with the development of the SI-2, have applications in civil, automotive, engineering and other industries. Solar energy has been in use for the last few years, but it has not been able to replace the conventional sources of energy due to the high initial cost of installation and lower efficiency. The solar panels used on the SI-2 have an efficiency of 22.7 percent.[6] According to the National Aeronautics and Space Agency (NASA) scientists, the efficiency of the solar panels in the last decade was about 8 percent and is likely to increase to 50 percent in the near future[7]. The creation of the solar powered aircraft is a result of improvements in the efficiency of solar energy panels and is the first step in finding clean energy solutions. The electric engine of the SI-2 operates with 97 percent efficiency.[8] The SI-2 electric motors will lose only 3 percent of energy (with 97 percent efficiency) compared to 70 percent of energy lost in the form of heat by a normal engine. The associated inventions/ developments resulted in improving the quality and efficiency

6. "Construction of HB-SIB", http://info.solarimpulse.com/timeline/view/6544#.VQ-FWvmUdDA. Accessed on March 23, 2015.
7. Joe Frost, "Interview with Nasa's Albion Bowers (Full Transcript)", March 11, 2015, http://www.techly.com.au/2015/03/11/interview-nasas-albion-bowers-full-transcript/. Accessed on March 12, 2015.
8. Marco D'Souza "Solar Impulse-2: The Aircraft and Visionaries Behind the Promise of Sustainable Energy", March 15, 2015, http://www.dnaindia.com/scitech/report-solar-impulse-2-aircraft-visionaries-sustainable-energy-solar-plane-circumnavigate-globe-2069035. Accessed on March 17, 2015.

of low powered LEDs, insulation of batteries and lightweight structures, which could also reduce the weight of the aircraft, vehicles and machines alike. The improved efficiency of electric appliances would reduce electricity consumption. The companies associated with the development of the SI-2 project are using their experience/expertise to create new products, which can be sold in the market. Bayer Material Science AG, a partner in the SI-2 project has applied for 12 patents. It has developed polycarbonate sheets for the cabin windows of aircraft, which has the potential to replace conventional glass windshields in cars and reduce their weight by about 30 percent.

The improved efficiency of the solar panels and electric appliances could reduce dependence on oil, which is one of the major contributors to environmental pollution, and preserve this perishable source of energy. The next challenge for the engineers/designers would be to make solar energy affordable, simple to manufacture, and easier to adopt in other fields. The countries/regions having maximum sunshine would benefit most from this innovation. This acceptance of solar energy would increase if it can be made a cheaper substitute for conventional sources of energy. There is need to explore the use of solar and other sources of energy to run/ operate automobiles and electric appliances like cars, cooking/electric appliances, air conditioning systems, etc. The inventors of the SI-2 aim to capitalise on the success of the world tour and make it a mega event in the Conference on Climate Change of the United Nations, which is scheduled to be held at Paris in December 2015.[9] The strategy of the team appears to be focussed on reaping benefits from the publicity they receive from the world tour and establish business links across the world.

WILL THE SOLAR AIRPLANE REPLACE CONVENTIONAL AIRCRAFT?

The Solar Impulse-2 aircraft reportedly experienced control difficulty in turbulent conditions prior to landing at Ahmedabad airport on March 10, 2015. A thunderstorm and cloudy conditions delayed the departure of the

9. Aaron Mamiit, "Solar Impulse Plane Begins Pioneering Around-The-World Solar Flight", March 9, 2015,http://www.techtimes.com/articles/38283/20150309/solar-impulse-plane-begins-pioneering-around-the-world-solar-flight.htmj. Accessed on March 16, 2015.

SI-2 from Ahmedabad to March 18, 2015.[10] India, as a goodwill gesture, waived off landing and parking charges to the Solar Impulse team for their extended stay at Ahmedabad due to bad weather.[11] The SI-2, with its 72 m wingspan has a larger wingspan than a Boeing 747 but weighs only about 2 tonnes compared to 447 tonnes of the Boeing 747.[12] In fact, the SI-2 is lighter in weight than a generic sedan car. The significant feature of its design is that one-fourth of the weight of the SI-2 results from housing the lithium batteries that weigh 633 kg. The large and delicate design would restrict flying in strong and turbulent winds. The requirement of large parking spaces and wing clearance would further restrict its utilisation due to the lack of the same at already congested airports. The need for sunny conditions would restrict its employability in countries/regions having shorter periods of sunlight and for lesser duration of the year. Selection of the United Arab Emirates (UAE) as the starting and ending point for the Solar Impulse-2's around the world trip appears to have been done in view of the favourable weather, its future employability and business interests.

Conventional commercial aircraft have the capacity to carry up to 500 people across the continents at transonic speeds. The solar powered aircraft is a promising and futuristic concept, however, the design and development of a commercially viable solar powered aircraft still has a long way to go. Such aircraft are not likely to replace conventional aircraft in the near future. However, the writing is certainly on the wall. Once the concept is proven, scaling it up for commercial applications will be just a question of engineering.

FUTURE OF SOLAR POWERED AIRCRAFT

The Solar Impulse-I had demonstrated in 2010 that it was possible to fly by day and night without fuel when it flew non-stop for 26 hours from San

10. "Solar Impulse-2 Aircraft Extends Stopover in Ahmedabad Once Again", http://zeenews.india.com/news/sci-tech/solar-impulse-2-aircraft-extends-stopover-in-ahmedabad-once-again_1562749.html
11. "After Many Hurdles, Solar Plane Finally On Way to Varanasi", March 18, 2015, http://www.ndtv.com/india-news/after-many-hurdles-solar-plane-finally-on-way-to-varanasi-747682. Accessed on March 20, 2015.
12. http://www.boeing.com/boeing/commercial/747family/pf/pf_400er_prod.page. Accessed on March 24, 2014

The development of the solar powered aircraft by China indicates its approach to becoming a leader in the development of new technologies.

Francisco to New York[13]. The SI-2 is expected to fly continuously for five days/ 120 hours non-stop to enable it to cross the Atlantic or Pacific Ocean. The around the world trip by the SI-2 demonstrates its long endurance and high altitude operations capability. Many countries in the world are developing solar powered aircraft. A Chinese website published an undated photograph of China's solar powered aircraft on March 12, 2015, which coincided with the arrival of the SI-2 in India. The aircraft has a 40 m wingspan, six propeller engines and has been designed by the China Academy of Aerospace Aerodynamics.[14] The release of the picture of their indigenous solar powered aircraft highlights the importance the Chinese have given to development of new technologies. The development of the solar powered aircraft by China indicates a drastic change in its approach from producing existing advanced technologies by following the reverse engineering route to becoming a leader in the development of new technologies.

The ability of the SI-2 to fly for days together coupled with the autopilot and slow speed poses human limitations in flying these planes on a regular basis and necessitates development of an unmanned version. According to Bertrand Piccard, the company aims to develop an unmanned version of this aircraft by 2016, which would be able to fly 20 km above the ground continuously for six months and carry out tasks which were till now meant only for satellites.. There have been similar experiments by the USA, Britain and other countries. NASA's Helios remotely piloted solar powered flying wing[15] and the Zephyr solar powered Unmanned Aerial Vehicle (UAV) of

13. "Solar Impulse Arrives at Starting Gate", January 6, 2015, http://www.swissinfo.ch/eng/solar-impulse-arrives-at-starting-gate/41201440?ns_mchannel=ps&ns_campaign=DSA&ns_source=adw&ns_linkname= _cat:swissinfo.ch&gclid=CL30w9j_q8QCFRcOjgodAoIAmw. Accessed on March 16, 2015
14. Yao Lan, "China's Solar Powered UAV Soars High into the Sky", March 12, 2015, http://www.ecns.cn/visual/hd/ 2015/03-12/60937.shtml. Accessed on March 12, 2015.
15. http://www.nasa.gov/centers/armstrong/news/FactSheets/FS-068-DFRC.html#.VRDcBfmUdDA. Accessed on March 24, 2015.

the UK[16] have already been test flown. Facebook is aiming to provide the internet by developing and deploying solar powered drones all over the globe — it is planning to test the drone some time in 2015.[17] These solar powered manned/ unmanned aerial vehicle projects were making slow progress till now and no urgency was being shown in the development of these technologies. However, the success of the SI-2 is likely to act as a catalyst in expediting the development of military and commercial solar powered UAVs.

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These lightweight solar powered UAVs could be employed in law enforcement, disaster relief, Intelligence, Surveillance, and Reconnaissance (ISR) and communication roles and would complement conventional unmanned aerial vehicles. The enhanced endurance and autonomous operation would enable them to provide round the clock data and communication relay coverage and could have applications in both civil and military fields. The envisaged development of the solar powered UAV could bring in a revolution in aviation, space and industry.[18] It could prove to be a game changer in future battles.

INDIA'S GAINS AND NEAR MISSES

The landing of the Solar Impulse-2 at Ahmedabad was coupled with some of its partner companies negotiating with Indian industry/clients. Indian industry too capitalised on the SI-2's visit, with the Aditya Birla Group becoming their host partner in India.[19] ABB India, a partner of the SI-2, had been in negotiations with Indian car companies like Tata Motors,

16. "Zephyr Solar-Powered HALE UAV, United Kingdom", http://www.airforce-technology.com/projects/ zephyr/. Accessed on March 24, 2015.
17. http://www.gizmag.com/facebook-testing-drone-enabled-internet/33964/. Accessed on March 24, 2015.
18. Chetan Kumar, "Next: Solar Impulse 3.0, A Drone That can Fly Non-stop for 6 Months", March 12, 2015, Chethan Kumar, http://timesofindia.indiatimes.com/india/Next-Solar-Impulse-3-0-a-drone-that-can-fly-non-stop-for-6-months/articleshow/46535411.cms. Accessed on March 20, 2015.
19. "Aditya Birla Group to Host Solar Impulse-2 In India", http://info.solarimpulse.com/timeline/view 7826#.VQ-FR_mUdDA. Accessed on March 23, 2015.

Ashok Leyland, Mahindra, Honda, etc. for replacing glass windows with polycarbonate windows, especially in their premium vehicles like the Jaguar, etc. It has also been supplying the products to many mining companies in India. The production and supply of solar pumps for farmers was also being explored. Schneider, a key partner of the Solar Impulse-2 project, and an elevator and escalator company, too announced testing of a solar powered escalator in Pune. India is looking to generate 100 Gigawatt of solar energy capacity up from the existing 3 Gigawatt, by 2022.[20] The Government of India has launched its ambitious Green Energy Corridor to encourage states to explore sources of renewable energy to meet their electricity/energy needs. Many state governments have started exploring exploitation of clean energy sources to meet their energy demands. In a pioneering move, the Rajasthan and Bihar governments have called for bids to supply solar energy to state electricity boards in a reverse bidding process[21] and are likely to benefit from these developments..

During its stay, the SI-2 was open to public viewing at Ahmedabad. Its team had visited India four years earlier when it met then Gujarat Chief Minister and present Prime Minister of India Shri Narendra Modi, and discussed the use of clean energy.[22] The present Gujarat government was equally enthusiastic about the visit of the SI-2 to Ahmedabad. It was a golden opportunity for scientists, business leaders, students/academicians of Indian Institutes of Technology (IITs), engineering colleges, as well as children to interact with the pioneers of the SI-2. People had come from different parts of Gujarat to see this flying machine. Our scientists/researchers could have used this opportunity to interact with the SI-2 team and exchange views on the nuances of the development of new technologies, and collaborate, if required. However, there has been no news of any interaction of the scientists/scholars with the SI-2 team and it is not certain whether they

20. Anindya Upadhyay, "How Narendra Modi Envisioned a Successful Solar Impulse 2 When Everyone Else was Sceptical", March 11, 2015, http://articles.economictimes.indiatimes.com/2015-03-11/news/60008722_1_solar-impulse-solar-airplane-andre-borschberg. Accessed on March 17, 2015.
21. "Bihar Bats for Solar Power for Aquaculture", March 16, 2015, http://www.renewableelectron.com/. Accessed on March 17, 2015
22. Upadhyay, n. 20.

benefited much from its stopover. The lack of enthusiasm among the academic institutions/ scientific community indicates a lack of Research and Development (R&D) culture in India and could be termed as a missed opportunity.

CHALLENGES OF R&D IN INDIA

India is dependent on foreign suppliers for aviation and military equipment and a large amount of money is spent on its procurement and maintenance. In the past, India had the disadvantage of being a late starter as it was under colonial rule when aviation was born and started prospering. Metallurgy and engine technology were other challenges to the development of indigenous aviation and defence equipment. The understanding of the research and design process, acceptance of failures, adequate funding, support of the government/users and persistence are key to the success of any R&D project. The media, in its enthusiasm for sensational news and/ or lack of understanding of the R&D process, sometimes misses the point, and inadvertently harms the strategic interests of the country. The public too sometimes gets swayed by the perception management campaign of big companies to discredit the indigenous R&D efforts, and blow their failures out of proportion. The rigid approach of the R&D agencies to review projects, and their reluctance to accept failures too is responsible for such perceptions. The lack of support from the government and future users further complicates matters and goes against indigenous R&D efforts, which is often exploited by foreign vendors/ suppliers.

India, with an investment of $ 40 billion is R&D, which amounts to 0.9 percent of the GDP is well short of the 2 percent target set by the Indian government in 2010.[23] The lack of adequate investment in the R&D sector is a key challenge in India, which is hampering indigenisation. China's investment of $ 16 billion for development related to design and manufacturing of jet engines for aircraft indicates its efforts in indigenising

23. Vikram Doshi and Vijay Gilde, "Budget 2014: Govt Should Extend Incentive to Boost R&D Activity in India", June 23, 2014, http://businesstoday.intoday.in/story/budget-2014-incentive-needed-to-boost-randd-activity-in-india/1/207478.html. Accessed March 25, 2015.

India's investment of 0.9 percent of GDP in R&D is much less compared to 1.76 percent of GDP by China.

critical defence technologies.[24] The Chinese spending on R&D had increased to 21.7 percent in 2010, raising the investment in R&D from 0.06 percent to 1.76 percent of the GDP, with an aim to further increase to 2.5 percent by 2020.[25] The Chinese had also increased spending on science and technological development to 4.58 percent of the fiscal expenditure. They have been investing heavily in the development of advance defence technologies, which include aircraft, UAVs, armed UAVs, Unmanned Combat Aerial Vehicles (UCAVs), aircraft carriers, Intercontinental Ballistic Missiles (ICBMs), etc. Their success in some of them, has placed China in the league of the US, UK and other leaders in the development of new technologies, that spend up to 3 percent of their GDP on R&D.[26]

However, despite these disadvantages, India has had its share of successes in the field of R&D and production of military hardware. India has developed the Marut, Ajeet, target drones, missiles, tanks, ships, etc in the past. The Marut was considered to be the best aerodynamic design at that time, though it failed to achieve its design performance due to lack of a suitable engine. There were plans to make a version powered by afterburning engines also, but India could not procure suitable engines and the efforts to produce an engine for this aircraft did not succeed. India is now making slow but steady progress in producing military hardware indigenously. The current military/ aviation projects include the Advanced Light Helicopter (ALH), Light Combat Aircraft (LCA), Light Combat Helicopter (LCH), Intermediate Jet Trainer (IJT-36), Rustom UAV, Akash Surface-to-Air Missile (SAM), Astra Air-to-Air Missile (AAM) and Kaveri engine. The LCA has joined the IAF fleet and the ALH is slowly becoming the backbone of the helicopter fleet of the three Services and paramilitary forces. The existing

24. "China Plans USD 16 billion R&D Project for New Jet Engines". March 1, 2013, http://www.deccanherald.com/content/315769/china-plans-usd-16-billion.html. Accessed on March 25, 2015.
25. "China Spending on R&D Rises 21.7%.", September 29, 2011, http://www.deccanherald.com/ content/315769/china-plans-usd-16-billion.html. Accessed on March 25, 2015.
26. Doshi and Gilde, n. 23.

pace of R&D in military hardware has not been able to meet the needs of the armed forces and there is need to expedite R&D and production in this sector.

Countries like India are often dissuaded from developing the same/similar technologies by the countries that have them, in order to be able to sell their own products. Some of the futuristic military projects in the past were shelved due to replacements offered by foreign vendors. It has often been seen that the technology which was initially refused by them was offered subsequently, when the country had already made progress in developing similar technology indigenously. The high procurement and maintenance costs of foreign military hardware also limit the numbers a country can procure, which creates deficiency. The participation of the private sector in the past was minimal due to restrictions on its participation and in allowing industrial use of by-products. However, there has been a rethink in the government circles on such an approach due to its economic unviability. The participation of the private sector is being encouraged now, which would be critical in developing state-of-the-art defence equipment.

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WAY AHEAD FOR INDIA

The development of the SI-2 is a result of 12 years of intensive research and testing, and is likely to prove a game changer in the aviation industry. With this innovation, countries across the globe are likely to reorientate their aviation development programmes. This machine is ahead of its time and offers a unique way ahead, hence, others will endeavour to catch up. The timelines of the SI-2 indicate that a large time period and persistence are required for the development of advanced technologies. The way the SI team went about carrying out research and development, planning, training and involving experts from the respective fields

of expertise is an excellent example of vision, investment in R&D, entrepreneurship of private players and utilisation of the knowledge base. It also shows that enormous potential and opportunities exist for the private sector due to their applicability in other industries, and their commercial viability.

One of the key lessons India and Indian industry can learn from the SI-2 is that invention is a result of vision, planning, preparation, collaboration, perseverance and well thought out execution. The SI-2 partners commercially using aviation innovations in other industries is a valuable takeaway for the Indian R&D agencies and private sector. Solar powered airplanes/UAVs comprise an emerging field and provide India an equal opportunity or a fair chance to develop them before other countries establish their monopoly. The development of solar powered aircraft/UAVs needs to be included in the overall development plan by the Indian R&D agencies/industry. Research and development is a time consuming process and needs the support of own people. India needs to have a proactive policy, set up long-term goals, enhance investment in R&D, involve the private sector and provide the necessary support to develop such technologies. The accountability and financial viability of the projects would be the key to the success of future R&D projects. India's private sector could play a key role in the success of such projects.

India has all the elements for encouraging innovation, including engineers, academicians, a strong industrial base and a sense of innovation. With its skilled manpower and competitive industry, India is capable of providing low cost innovative solutions. The Indian industry could play a key role in making India a manufacturing hub byindigenising and/or transfer of technology from foreign companies in the field of clean energy. The huge market in India is a big incentive for business, which could be leveraged to make India a manufacturing hub, thereby proving to be a win-win situation for both parties.

CONCLUSION

The journey of the development of the solar powered electric aircraft project, the SI-2, from its inception in 1999 to its around the world trip has a fascinating story behind it. The way the partners of the SI-2 team have looked at expanding their trade relationships with automobile, engineering and other industries shows the way to private industries for entering the high technology sector and yet making it viable. The pragmatic approach of the team of the SI-2 in utilising their by-products in other industries is a perfect example of making such programmes financially viable. The SI-2 team collaborated with, and/or hired, experts from different fields. The professionalism displayed in equipping, training and preparing for the world tour is worth emulating.

Solar power has the scope of expanding into the power and other industries to provide clean energy solutions. The key impediments in the proliferation of solar energy were the high initial costs and low efficiency. The improved efficiency of electric appliances and solar cells would enhance their utilisation in generating power and reduce electricity consumption. India would benefit immensely from the revolution in solar power and could provide electricity in far off places. The availability of solar power would reduce power deficits in the peak summer time and, thus, improve productivity. Researchers and engineers should endeavour to make solar energy a cheaper and viable replacement for conventional sources of energy.

While it may take some time to build commercially viable solar powered aircraft, a solar powered UAV is not a distant goal. The arrival of the SI-2 is likely to result in aviation manufacturers reviewing their plans for development and induction of future aircraft and UAVs. The development of the solar powered aircraft, UAVs and envisaged employment of the solar powered UAVs in roles meant for satellites may force countries to review their procurement plans, doctrines and R&D efforts.

The success of the SI-2 indicates that there is enormous potential for the private sector to venture into the unknown area of R&D and succeed. The Indian government and private sector R&D organisations could take a clue

or two from the SI-2 team. They should keep in mind the key issues when they invest is such niche technologies. Solar powered aircraft and UAVs comprise an emerging field and India should include the development of solar powered UAVs in the overall development plan of UAVs.. The R&D sector in India needs to be nurtured and investment in the R&D sector needs to be enhanced to 2 percent of the GDP. R&D culture can be improved in India by involving universities and the private sector as well as by improving the functioning, transparency and accountability of the R&D organisations of the government. The government should provide the right environment and incentives to encourage innovations/ inventions.