SPACE DEBRIS

SHIVAPRAKASH B

Space Books Series for Children
U R Rao Satellite Centre
Bengaluru-560017

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Chairman's Message

Scientific literature for children is an essential and distinctive literary work. It is to observe all the happenings around us from a scientific point of view and explain it in simple words. This endeavour can make a high school student understand complex subjects like astronomy, satellite and rocket technology, which is highly appreciable.

In this regard, U R Rao Satellite Centre, a prestigious research Institute in Bengaluru, has launched a new program called "Space Books Series for Children" through which it plans to bring out pocket-books on "Space Technology Space Science and Space Scientists". This book,

which is now in your hands, is one such work. This work a significant step toward enriching science literature for children.

Explaining various scientific and technical topics in simple language is necessary to inculcate interest in science among children. Similarly, it is essential to explain the scientific achievements of our organization to the masses and create awareness about it. The "Space Books Series for Children" programme will fulfil these requirements.

I congratulate the Director of U R Rao Satellite Centre for conceiving and implementing this programme. I hope more topics will be covered and reach more children and commoners in the coming days.

S. Somanath

Chairman, ISRO

Director's Message

Satellite, space science, technology and related topics should be explained in simple language so everyone can easily understand them. Such a literary effort will provide essential and authentic information, especially to the young talents of rural areas. Thus, it is a significant step in providing them with better opportunities and building a great future.

This work should be done by the skilled and experienced scientists of U R Rao Satellite Centre who have been working in this field of technology for five decades. To educate children about space science and technology, U R Rao Satellite Centre is

bringing out the "Space Books Series for Children".

Our enthusiastic colleagues have written books on these topics in response to this idea. It is a pleasure to put seven pocket-books of this series in your hands today. I congratulate the authors for their efforts and wish the program success. I want the students to develop interest and curiosity in these subjects. I also hope they understand the principles, get inspiration and create a better future, thereby contributing to the country's and society's overall development. I am confident that our objective will be realized and the desired result will be achieved.

M Sankaran

Director

U R Rao Satellite Centre

Editorial Board

Space Books Series for Children

Dear Children,

U R Rao Satellite Centre (URSC) celebrated its Golden Jubilee in 2022. On this occasion, the Karnataka Rajyothsava Committee of URSC had taken up the task of publishing a series of Kannada books on Space and Space Scientists which have been translated into English for the benefit of students across the country.

Our committee plans to publish pocket-books in simple language to make school children easily understand many topics like space science, rocket and satellite technology, etc. These books are written by the scientists of our organization. As the first set of books in this series, seven books are published. Our aim is to provide electronic version of the books to children through our website.

Our committee is grateful to Shri M Sankaran, Director, URSC who is the key person behind the successful realization of these books. Our heartfelt thanks to Shri HN Suresh Kumar, Shri KV Govinda, Dr. M Ravindra, Smt. Lalitha Abraham, Smt. Anuradha S Prakasha and Smt. Sreedevi S for having reviewed all seven books in detail and suggested suitable modifications.

We are grateful to all the authors who took time off from their work and authored the books. We are thankful to all colleagues of our Centre who helped us to bring out these books.

If you read them and give your suggestions and comments, we will be able to incorporate the same in the next set of books in this series.

Ramanagouda V Nadagouda

President

Prologue

UR Rao Satellite Centre (URSC) of ISRO is bringing out this booklet series on basics of space science and technology to school children. Realizing the multiple benefits of space, man started using space for the betterment of his life. The space age began in 1957 with the launch of Russian Satellite Sputnik-1. Since then, many types of satellites and rockets have flown into space.

As humans started using more and more of the Earth's natural resources, the garbage or waste that was produced also started increasing. Its disposal and management has become a major issue. Same way, as the use of space increased, the quantity of waste (garbage) in space is also increasing at a high rate. Scientists fear that a day may come when space will become unusable, due to increased Space Debris or Waste.

This little book gives a brief introduction to what Space Debris is, its current quantity, the problems it causes and the ongoing efforts to manage or to eliminate it. After reading this book, if children become curious about space science and are eager to learn more about it, then I think my efforts of bringing out this book is fruitful.

Heartfelt thanks to Shri M Sankaran, Director, URSC, for the opportunity given to me to write this book. My humble regards to the editorial board of this book series and all my colleagues at URSC who have helped me to bring this book to this shape.

– **Shivaprakash B**

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1. Preamble

4 October 1957

From Russia's Baikunur launch centre, a rocket-8K71PS carrying a glowing spherical shaped device which was about 2 feet in diameter, was tossed up into the space. After a few minutes this shining ball of 84kg was safely placed into the orbit at 215 km altitude. As soon as it reached the oval shaped orbit (215km x 939km), it opened its four antennas, which were looking like the whiskers of a cockroach! Through these antennas, this device sent its first signals to the Earth.

This marked the beginning of the 'Space Age'. This spherical ball was the first man made artificial satellite - Sputnik 1.

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Scene 1: October 1957

Imagine that you are driving your car from KR Market, Bengaluru to Mysore Bank Circle through Avenue Road. In the earlier days, we could find very few vehicles moving in Bengaluru. Especially on Avenue Road, you would probably see no other vehicle except your car! You will reach your destination without any problems within a few minutes.

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Scene 2: October 2021

Same Avenue Road. You must drive from KR Market, Bengaluru to Mysore Bank circle. Have you seen the Avenue road of 2021? People moving around in different directions without following traffic rules, autos and two wheelers barging in from every nook and corner and hand carts

crossing the road indiscriminately. Not just this, we can also find cattle and stray dogs napping on the road. In between all this, you have to drive your car on this road safely without hitting anyone! “Oh My God! This is ridiculous! Impossible!!”, Is this your reply?

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Are you wondering why I am talking about Bengaluru traffic problems in the book titled as ‘Space Debris’? Is it a relevant reference?

Yes, it is. Space scenario was like Scene 1 when Sputnik-1 was launched in 1957. Satellites which are being launched nowadays are facing situations similar to Scene 2.

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Understanding numerous benefits of satellites, man has launched thousands of satellites into space since Sputnik-1. Many of the satellites have completed their design life. Some have failed before their design life and some have even exploded.

The last stages of the rockets which launched these satellites and other spare parts of these rockets are still floating in space. Some of these objects have burnt to ash when they were falling towards the earth. The remaining objects in space which are of no use, form the space waste, which is widely known as 'Space Debris'. This Space Debris is creating a big headache to the present day rockets and satellites.

The threat of Space Debris is giving sleepless nights to space scientists. So, what is this Space Debris or Space Waste or Space Wrecks? What are the problems they create

in Space? How to eliminate this Space Debris? Is it possible to eliminate them? Let us discuss all these queries.

2. What is Space Debris?

Any man made object in Space - that is, in the Earth's orbit - and which is of no use to us, is called Space Junk or Space Waste or 'Space Debris'.

Do you know what this debris comprises of? Satellites which have completed their useful life, non-functioning satellites, exploded satellites, last stages of rockets, used up rocket engines, frozen fuel dusts, corpse of monkeys and dogs sent into space for experiments...! Not just these items, you could also see garbage bags discarded by astronauts, pliers, gloves…. and many more!!

Space Debris is abundant in Low Earth Orbit (LEO) of altitude 400km to 1000km. We can also find Space Debris in Geostationary Earth Orbit (GEO) which is above equator at an altitude of 35,786km.

The geostationary orbit contains all the communication satellites which are very useful to man. These GEO satellites are used for communication services like Television, Telephone, Internet, weather forecasting, predictions of natural calamities like hurricanes and cyclones. Hence, all the countries are competing to have their own satellite in this geostationary orbit. The satellites in this orbit are generally very huge. Their mass is about 4 to 6 tons and they are designed to work for 15 to 20 years. So, if they become non-functional before their design life, they form a huge Space Debris.

3. How much Debris is in Space?

In 2019, The United States Space Surveillance Network (SSN) identified that there are about 20,000 large objects that can be easily identified and tracked. This includes 2,200 operational Satellites. Everything else is classified as useless Space Debris. In addition to this, there are about 34,000 objects larger than 10 cm, about 9 lakh objects of size ranging from 1 to 10 cm and about 128 million objects which are less than 1cm in size! Pieces smaller than these are not accounted for. Such small debris may be called 'Micro Debris'. Although such micro debris is very small, it can also cause a lot of trouble to satellites!

Rockets and satellites that are launched now must reach their specific orbits without colliding with all this debris. In the orbit of 900 km, the speed of a satellite is about

27,000 km per hour. At such a high speed, even a small piece of debris of 1 cm size can cause as much disaster as a large rock. You might have heard about accidents caused to planes by bird hits? This is similar to that.

4. Space Debris – Its History

As already mentioned, the Sputnik-1 satellite was launched on 4 October 1957. It worked successfully going around in its orbit for about 25 days. It sent its last signals on 26 October 1957 and then it stopped functioning. Perhaps that is when the first Space Debris was produced! 25 days after the commencement of the 'Space Age', the era of Space Debris began.

After Sputnik-1, thousands of satellites have been launched so far. Many of these satellites have lived their useful life and stopped functioning. Some of them have

developed problems before their End-Of-Life. All those non-functional satellites are floating in orbit without any control. If they collide with any other useful satellite in orbit, they will turn that unfortunate satellite also into a Space Debris. This is like the proverbial saying.. 'One rotten apple spoils the whole barrel'!

One more new technology that is recently developed by several space faring countries has contributed to multiplying the Space Debris. That technology is known as ASAT - Anti Satellite Weapon. ASAT is a special missile to destroy an enemy country's satellite in its orbit! ASAT hits the satellite and explodes it into several fragments large and small, creating a huge cloud of space debris. This debris cloud remains in orbit for several months and disturbs the surrounding satellites.

There is an organization in the United States that keeps track of all the launches and satellites since Sputnik-1. Its name is NORAD (North American Aerospace Defense Command). This organization maintains a catalog of all objects launched into space. This information will be updated continuously. This data helps space agencies to plan their launches so that they can avoid the big-sized space debris hitting their rockets or satellites. Using a formula given by the scientist named John Gabbard, this organization has developed a system that can accurately determine the density of space debris and track them precisely.

5. Growth of Space Debris

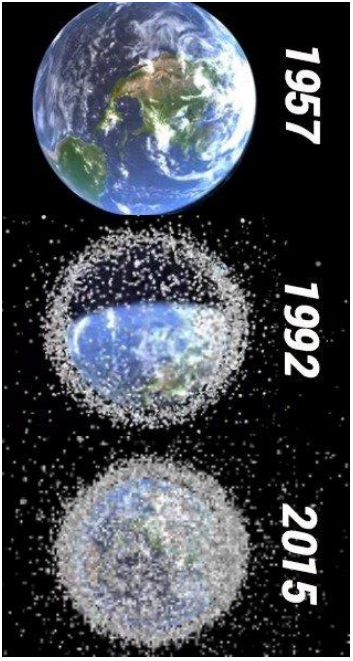

Fig. 1. Growth of space Debris

As per NORAD's estimate in 1990, there were approximately 8,500 pieces of debris

in space. By 2005, it had touched 13,000. In 2006, the number reached 19,000 and increased to 22,000 by 2011. Research by Hugh Lewis, a scientist at the University of Southampton, said that Space Debris could quadruple in five decades if it continues to increase at this rate. Scientists at The National Academy of Sciences have said that the amount of space debris in LEO, that is 400km to 1000 km orbit, has already reached its peak. This means that, the satellites in these orbits or those that are supposed to cross this orbit, are at a very high risk of colliding with any of the Space Debris.

If you look at Earth from another planet, you can see a ring of Satellites and Space Debris around the Earth. It looks like rings of Saturn! Density of Space Debris is high in LEO and GEO orbits (Fig.1).

6. Characteristics of Space Debris

According to an estimate, the mass of debris in space as on today is about 9,000 tons. This is enough to fill about 1,000 large trucks! 90% of this debris is in LEO. The rest of debris is in GEO. In GEO, there are massive communication satellites. While LEO satellites weigh between 1 kg and 1,000 kg, GEO satellites weigh between 3,000 kg and 6,500 kg.

If the satellite breaks down before the End-of-Life, they start floating out of control in the same orbit for several days/months and should be treated as Space Debris. Then they can collide with other healthy Satellites in the same orbit. In LEO, the non-functional satellites begin to slowly fall towards the Earth. It may take several months or years to enter the Earth's atmosphere. Once they enter the Earth’s atmosphere, they get

heated up by atmospheric friction, burn and then fall down to the Earth as ash. But, until that time they can cause trouble to other working satellites in LEO!

Non-functional satellites in GEO cause another problem. Since the gravity here is very low compared to LEO, these satellites can stay in orbit for many years. Because of their huge size, the extent of accidents they can cause is also huge! About 500 satellites are operating in this orbit.

7. Nightmare of Space!

About 2,000 satellites are operating in LEO. Imagine the disaster if these satellites orbiting the earth at high speeds (27,000 km/hr) collide with any debris! If such an accident happens, the exploding metal fragments could hit another nearby satellite. This can trigger a chain of collisions

in that orbit exponentially increasing the Space Debris and destroying most of the satellites in that orbit. Then, the entire LEO may look like post-war battle field!

If such a disaster occurs, then the entire low earth orbit may become unusable. The heap of debris created may make it almost impossible to even cross this orbit and reach higher level orbits.

One such theory was proposed by space scientist Donald J Kessler. This theory is known as 'Kessler Syndrome' (Kesler Syndrome – Fig. 2). This is the nightmare to every space scientist. With the increasing number of satellites being launched day by day, this nightmare could become a reality soon! So, measures have to be taken immediately to prevent this.

Keeping the Earth's surface and atmosphere

clean is everyone's responsibility. In the same way, it is our responsibility to keep Space clean and usable. No matter who is responsible for creating the Space Debris, everyone suffers its negative consequences. This can be compared to smoking a cigarette! Along with the smoker, neighbouring non-smokers also will have to face the ill effects of the cigarette. Hence, the thoughts of reducing and eliminating Space Debris has begun in the minds of all space scientists.

Fig. 2 Kessler Syndrome

8. What constitutes Space Debris?

If you are thinking that Space Debris consists only of parts of rockets and satellites, then you are wrong! Do you know what all Space Debris has?

Here is the list;

- Many monkeys and dogs were sent into space for experiments before the first human space flight. Some of their corpses are still floating in space
- In 1963, America launched about 480 million copper needles into space for its experiment called Project West Ford. Many of these needles are floating in about 3,500 km orbit
- In 2008, NASA astronaut Heidemarie Stephanyshyn Piper misplaced her instrument bag while returning from a spacewalk. The cost of the equipment in it was about 1 lakh dollars! It was

floating in space. Finally, it got burnt on 3 Aug 2009 during its fall to Earth.

- The Hasselblad camera lost by astronaut Michael Collins during the Gemini-10 spacewalk in 1966.
- In the past, astronauts used to dump their waste bags in space before returning to Earth! Some of them are still moving around in orbit. Now-a-days such practice of dumping waste has stopped.
- The biggest piece of junk which joined Space Debris recently is the old Tesla Roadster car of SpaceX owner Elon Musk. It was launched as a dummy payload for Falcon Heavy rocket FH-001 with a human doll at the driver seat! But as it is moving away from the Earth in a helio-centric orbit, there is very little concern for other satellites.

9. Some accidents caused by space debris

Space Debris has already caused many accidents to satellites and rockets. Many satellites are permanently damaged. Let's take a look at some of them:

- The Russian Cosmos-1275 satellite is said to be the first satellite to be damaged in such an accident. It was destroyed on 24 July 1981 by a collision with a Space Debris.
- In July 1996, France's Cerise satellite was damaged by an Ariane 1-H10 rocket's final stage.
- On 29 March 2006, Russian Express A.M. Communication satellite 11 was damaged.
- On 12 March 2010, a piece of debris hit the solar panel of the Aura satellite, damaging it. It lost 50% of its solar

power due to this accident.

- On 22 May 2013, the GOES-13 satellite was also destroyed by Space Debris.
- NASA's space shuttle Challenger's second vehicle, STS-7, was hit by a piece of debris, shattering its window. STS-59 also had to face a similar risk.

10. How is Space Debris cleaned?

The measures to clean up space debris can be mainly divided into two types;

1. Self Cleaning
2. External Cleaning (cleaning done using special equipment)

10.1. Self cleaning

This approach can be compared to a retiring employee! At the end of his service, the retiring person handsover his duties to the next person. Similarly, the satellite which

has reached its End-Of-Life will move away from its designated orbit slot and gives way to the new satellite. Let's see how this is possible.

The useful life of any satellite is decided at its design phase itself. Based upon the desired life span of the satellite the fuel is filled in satellite. For example, LEO satellites have a lifespan of about 5 to 7 years, while communication satellites in GEO have a lifespan of about 10 to 15 years. There are some special satellites like, military satellites, micro & mini satellites, experimental satellites, hobby satellites built by students, which will have a very short life of a few days to a few months.

In Self Cleaning method, satellites are filled with little extra fuel than what is required for useful life. This extra fuel is used for 'De-orbiting'. De-orbiting is the operation of

pushing the satellite out of its designated slot. At the end-of-life, the satellites are pushed into an unusable orbit using their on-board boosters (boosters are the small rockets built within the satellite). The unusable orbit is called ‘Graveyard Orbit’. About 100 km above GEO is generally used as the ‘Graveyard Orbit’. The switched off satellites remain in this orbit for many years. After pushing to the ‘Graveyard Orbit’, all the instruments of the satellite are switched off so it does not interfere with operation of other satellites.

In the case of LEO satellites, most of the operational satellites are placed in orbits of 400 km to 1,000 km altitude. At the end-of-life, the satellites are pushed down towards the Earth into an orbit of about 300 km during de-orbiting. After being pushed into this orbit, the satellite starts falling towards the Earth due to gravity. When it reaches an

altitude of about 100km, it will burn into ashes due to atmospheric friction. The final stages of the rockets can also be pushed into a similar orbit after the mission, so that they falls back to Earth or burn out.

Now all the countries which plan to launch the satellites have to follow the rule of de-orbiting the satellites at their end-of-life.

If the satellite is working till its end-of-life, then self cleaning (de-orbiting) can be planned and executed. But, what if the satellite fails before the end-of-life? In that case, the second method of External Cleaning has to be adopted.

10.2. External Celaning

In this method, special equipment and special robots are used to push large Space Debris into Graveyard orbit. However, such technologies are still under development

stages. In one such method, the debris would be captured by a device like a net or a robotic arm, then towed into unusable or 'Graveyard orbit' and released there (just like traffic police towing away the vehicles from a No-parking zone!).

But this method is very expensive and also involves maintenace cost of the cleaning system. Who should do this? Who has to manage and support such a system? To manage such matters, there have been thoughts of bringing Space Laws applicable to all countries that use space.

Busek Co. Inc. has developed a special concept involving two spacecrafts. Here a large tug called ORbital DEbris Remover (ORDER) would approach an object. ORDER will then deploy a smaller tethered satellite which would grab the object. Then the object is towed away to the 'Graveyard

orbit'. The company has plans to push 40 failed satellites into the 'Graveyard orbit'.

A private commercial firm of America is developing a plan to place a special satellite called Space Infrastructure Servicing (SIS) in geostationary orbit, where it will push the failed satellites into the Graveyard orbit. This is in a way, a plan to perform the cremation of unnaturally deceased satellites!

Switzerland is developing a strategy to de-orbit a nano-satellite using one more nano stellite, in a project called 'Clean Space One'. Europe's ESA (European Space Agency) is preparing to implement a waste elimination plan called 'Clear Space - 1' by the year 2025.

Research is also going on to develop a method where a powerful laser beam from

Earth is pointed to an orbiting Space Debris and it is made to move towards Earth. The purpose of this is to make the debris enter into atmosphere and burn to ashes. The American Air Force tested such a project called 'Project Orion' in the nineties. But it did not continue due to many reasons.

Another Space Debris disposal project called 'Space Net' is being developed by the scientists of England's Surrey Space Centre. Japan's space agency JAXA is planning a similar project. In this, a large trap made of aluminum & steel is launched from an orbiting satellite towards a Space Debris or failed satellite. After the net covers the object, it is magnetized so that the object starts to fall towards the earth (Fig.3). If this project is successful, scientists believe that by using such large nets many small Space Debris can be eliminated.

11. Eliminate! Or Avoid...!!

Small debris like rocket parts, bolt-nuts,

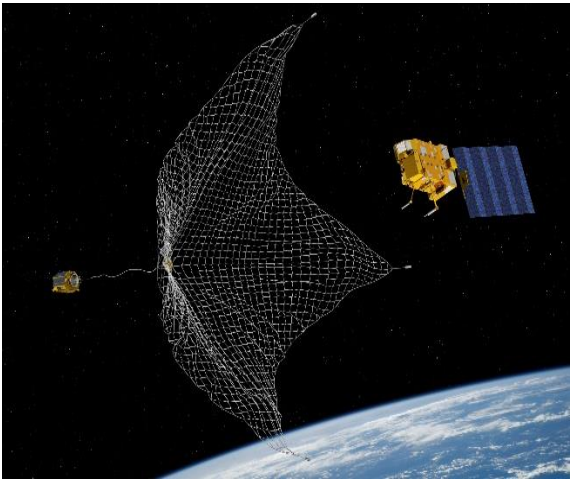

Fig. 3. Space Net

small pieces of broken metal, etc., are impossible to eliminate from space. Although they are small in size, the disaster caused by them is huge. A fragment of a

small bolt could hit a satellite's solar panel and destroy its electrical system. The only way to prevent disasters caused by such small wastes that cannot be eliminated is, to avoid them!

Large solar panels and antennas extending several meters outside the satellite are more likely to collide with such small debris (Fig.4). Many space agencies have already adopted the idea of getting information about the path of Space Debris and turning away the solar arrays and antennas from that path, as the debris approaches. The chances of hitting the debris is less when the thinner side of panels are in the path of debris rather than the wider portion.

For example, chances of hitting the ball is less if you hold the tennis bat such that its thinner side is facing the ball. After the debris has passed the satellite and has

moved forward, the panels and antenna are again turned in the right direction.

The largest man-made object in space is the International Space Station. It is bigger than a football field! 7-10 scientists live in it and do many experiments. If any waste material collides with this Space Station, the disaster will be immense. So the entire centre is shifted slightly from the orbit, and the Space Debris escape operation is performed. Outside the space station, sensors are installed to detect stray Space Debris. Special bunkers have been made for the scientists living in the Space Station to escape from such dangers. One such hazard was faced in November 2021 from the debris cloud of an exploded satellite. But luckily no accident happened.

Another defense method to avoid collision with Space Debris is to attach a shield to the

satellite. Such a shield is called "Whipple shield", named after the scientist who invented it. It can be compared to the bumper of a car. This reduces the speed of impacting debris and reduces damage. Such a shield has already been used in the International Space Station and on NASA's Stardust satellite (Fig.5).

Fig.5 Whipple Shield on Stardust satellite

12. Keep Space Clean, else, 'No More Space!'

If Space Debris or Space Junk is not eliminated or reduced, a day will come when space will become unusable for humans. Then all the benefits we are enjoying from satellites may be lost. In today's lifestyle, many of our daily tasks are done using satellite technology. Telephone, Mobile, TV, Banking, Internet, GPS, weather forecasting, town planning, Earth and ocean resource monitoring, military operations and many more things are done with the help of satellites. It is impossible to imagine a life without satellites. Action needs to be taken now to prevent any future damage due to Space Debris. In 2007, the United Nations created the Committee On the Peaceful Uses of Outer Space (COPUOS). This committee has formulated rules and laws applicable to all countries, to prevent the accumulation of debris in space. Indian

satellites in Geostationary orbits are also moved to graveyard orbit after completion of their useful mission life. India has many future plans of installing self-cleaning systems in its rockets and satellites.

Fig.6. Scene from film ‘Gravity’

The ISO organization which prepares International Standards, published a list of standards called ISO 24113 in 2017. It lists several rules to be followed for disposal of Space Debris. However, as of now, it has not yet become a mandatory rule. It is not easy to implement as all the countries have to participate. However, all the countries should agree to commit to complying with this as soon as possible.

You might have seen the movie 'Gravity' released a few years ago. In the movie, the disasters caused by a Space Debris hitting the Space Station were shown (Fig. 6). If measures to eliminate Space Debris and to keep space clean are not taken, then the day is not far-off for this movie to become true...!

Reader's Notes:

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Sri. Shivaprakash B, is presently working as Group Director of Power Systems Group in UR Rao Satellite Cente of ISRO. Earlier he has handled various responsibilities as Division head, Section Head, Deputy Project Director (Power) in many satellites. He has published Kannada Articles in the areas of popular science, space science, tourist places and Yoga.

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