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Abstract

Purpose – The purpose of this paper is to study and analyse the authorship pattern, degree of collaboration, prepare list of prolific authors and test Lotka's law of scientific productivity in spacecraft technology research.

Design/methodology/approach – Data are collected from the print versions of three journals in the field of spacecraft technology for the period 2001-2011. In all 154 volumes containing 1,907 papers have been analysed, and data are presented in different table headings.

Findings – Study reveals that 4,355 authors have contributed 1,907 papers. *Journal of Spacecraft and Rockets* has published maximum (1,487) number of papers during the study period. Multi-authored papers with 87.15 per cent of contributions have dominated this field of research. *Journal of Spacecraft Technology* has recorded highest degree of collaboration of 0.90. James M. Longuski has published 20 papers in *Journal of Spacecraft and Rockets* during the period 2001-2011. Lotka's law of scientific productivity is tested and conforms only partially.

Research limitations/implications – Study is restricted only for the period 2001-2011, and the data are collected from the print versions of three journals in the field of spacecraft technology research.

Originality/value – As far as space science and technology is concerned, there are not many bibliometric studies reported in the published literature. The present study will add value to the bibliometrics literature and provide publishing trends in spacecraft technology research.

Keywords Authorship pattern, Scientometrics, Degree of collaboration, Lotka's law

Paper type Research paper

1. Introduction

The Space Age started with the launch of the first artificial satellite, Sputnik I, by the Soviet Union on 4 October 1957. The 12th of April 1961 marked the beginning of manned spaceflight with the launch of the first cosmonaut Yuri Gagarin into space. On 20 July 1969, history was made when Apollo 11 astronauts Neil Armstrong and Buzz Aldrin set foot on the Moon. As the developments in space technology continued, many nations such as France, China, India, Japan and others embarked on systematic space programmes, keeping in view their political, military, national security, technological and scientific ambitions. To get independent access to space, national security, enhancing technical and scientific capabilities and economic and social benefits through space technology programmes, there was an ongoing Space Race. Japan launched its first satellite in February 1970, China in April 1970, India in 1980 and Israel in 1988 (Harvey *et al.*, 2010). Space technology has a unique place in the history of technology, as it concerns the application of technology beyond the confines of the Earth

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(Williamson, 2006). The history and evolution of space technology is well-documented in literature published around the world.

As more and more nations started building and launching spacecraft, economic burdens reduced the budgets of space organisations across the globe, and this has resulted in international space cooperation activities. Broniatowski *et al.* (2006) pointed out that international space cooperation saves money, generates diplomatic prestige, increases political sustainability and enables workforce stability. The International Space Station is a great example of space cooperation by countries such as the USA, Russia, Europe, Canada and Japan. Collaboration in modern science is a well-established fact, and spacecraft technology research is no exception. Every space-faring nation has some kind of cooperation in their space research activities. India has formal cooperative arrangements with the space agencies of 33 countries, including Australia, Canada, China, France, Germany, Italy, Japan, Russia, the UK and the USA, to name a few, and 3 multinational bodies. The maiden mission to the Moon by the Indian Space Research Organisation (ISRO), Chandrayaan-1, launched on 22 October 2008, has been an exemplary case of global cooperation with its international payloads. It has also earned several national and international laurels and was instrumental in the ISRO-NASA joint discovery of water molecules on the Moon's surface, a discovery unattained by any of the previous missions of a similar nature.

Space technology is a very complex and highly technical subject. Space scientists form a small group compared to other fields of research. There are a good number of journals published in this research area by reputed publishers to communicate the findings of space missions and experiments. Whether it is a research article or a high-profile space launch, collaboration has played a pivotal role. Smith (1958) observed that experimental research involving the use of complex scientific instruments produces papers with more co-authors than theoretical research. For example, during the phases of planning, execution and later analysing the data collected from the Chandrayaan-1 mission, a huge amount of literature was generated, published in various journals and presented in different scientific assemblies in the form of the experimental results carried out by the scientific instruments and payloads on board the Chandrayaan-1 spacecraft. Almost every field of research has witnessed the rise in collaboration at individual, organisational, national and international levels. Scientometric methods are useful in understanding collaborative research trends and authorship patterns in any field of research. There are a good number of studies that have shown that collaboration enhances research productivity and cost effectiveness in view of the global economic downturn and budget cuts to space agencies around the world. Price de Solla (1963) in his book *Little Science Big Science* was the first to study the pattern of publications. Apart from highlighting the growth of scientific literature, he also covered the most important aspect of authorship and collaboration patterns. Analysing the data from the Chemical Abstracts database for the period 1910-1960, he concluded that the number of multiple author papers increased from under 20 per cent in 1910 to over 60 per cent in 1960. He also showed that the number of three-authored papers was accelerating faster than two-authored papers, four-authored papers more quickly than three-authored papers and so on. He further prophesised that looking at the growth of multi-author papers at that time and, if it continued at that rate, by the year 1980, the single-authored paper would be extinct.

Journals are known to publish and disseminate the latest research trends in a given field of research. Scientometric studies have time and again proved that journals are the most preferred choice of medium for the communication of research. In the field of space science and technology, many peer-reviewed journals are published by reputed publishers, but not many journals are published specific to spacecraft technology. Moreover, the subscription costs of spacecraft technology journals are very high and not many libraries in India have a subscription to these journals due to limited budgets. Hence, in the present study, only three important journals pertaining to spacecraft technology were selected based on their subscription availability in the library at ISRO headquarters to explore the authorship pattern and collaborative research activities in the field of spacecraft technology research. Among the three journals selected for this study, two journals are of international repute and the other journal is the in-house publication of the ISRO. The selected journals are known to publish highly technical papers pertaining to complexities involved in spacecraft technology design and realisation.

2. Source journals

2.1 Journal of Spacecraft Technology

Started in the year 1991, this journal is published by ISRO Satellite Centre (ISAC), in Bangalore, India. This is a bi-annual journal published in the months of January and July every year. *Journal of Spacecraft Technology* (*JST*) publishes original works in the form of review, technical papers and short communications, along with book reviews. The journal has well-defined instructions for authors which are published in each issue. Articles submitted for publication are peer-reviewed by the board of editors. The journal is indexed and abstracted in a host of databases, including International Aerospace Abstracts, Indian Science Abstracts, Meteorological and Geo-astrophysical Abstracts, NCI Current Contents, Engineering Index/Ei-Compendex, Cambridge Scientific Abstracts, Aerospace Database and INSPEC. It is also listed in the *Directory of Indian Scientific Periodicals* and the *Directory of Periodicals Published in India*.

2.2 International Journal of Satellite Communications and Networking

This journal was first published in the year 1983 as a bi-monthly publication with the title *International Journal of Satellite Communications* by John Wiley & Sons, Ltd., UK. In 2003, the title of the journal was changed to *International Journal of Satellite Communications and Networking* (*IJSCN*). It is a premier journal in the field of satellite systems, networks, components and services. The journal is covered by a host of abstracting and indexing services, including Cambridge Scientific Abstracts, Compendex, Computing and Technology, INSPEC, Science Citation Index, Scopus and Web of Science, to name a few.

2.3 Journal of Spacecraft and Rockets

Journal of Spacecraft and Rockets (*JSR*) was started as a bi-monthly journal in 1964 by the American Institute of Aeronautics and Astronautics, USA. This journal is devoted to the advancement of the science and technology of aerospace propulsion and power through the dissemination of original archival papers contributing to advancements in air-breathing, electric and advanced propulsion; solid and liquid rockets; fuels and propellants; power generation and conversion for aerospace vehicles; and the application of aerospace science and technology to terrestrial energy devices and systems. It is intended to provide readers of the journal, with primary interests in

propulsion and power systems, access to papers spanning the range from research through development to applications. This journal is indexed in Aerospace and High Technology database.

3. Objectives

These are the following objectives:

- to examine and analyse the authorship pattern in spacecraft technology;
- to study the proportion of single-authored against multi-authored papers;
- to determine the degree of collaboration in spacecraft technology;
- to study author productivity;
- to test Lotka's law of scientific productivity in spacecraft technology research; and
- to identify and prepare a list of prolific authors.

4. Methodology

As far as scientometric studies are concerned, it is observed from the published literature that different source selection methodologies are followed, as listed below:

- single journal studies;
- selecting a few journals on the same subject;
- exploring the research output on a particular subject/topic by retrieving data from different citation databases;
- exploring the research output on a particular subject/topic by a particular country/organisation/institution by retrieving data from different citation databases;
- exploring the research output and collaboration pattern of individual personalities such as scientists or engineers; and
- exploring publishing trends of scientists or engineers of a particular field of research such as chemistry, physics and so forth

In this study, three journals belonging to the field of spacecraft technology research were selected. The data required for the study were collected from the print version of the journals for the period 2001-2011. Each article published in the three journals selected for this study was carefully studied, and required details were entered in the MS-Excel format. The details regarding number of articles, authorship pattern and author productivity were collected to fulfil the objectives of the study. Only research articles are considered for this study, excluding book reviews and letters. The present study is a simple scientometric study carried out to understand the authorship pattern and degree of collaboration in spacecraft technology research. The authorship pattern has been analysed by using Subramanyam's (1983) degree of collaboration in quantitative terms. Average author per paper and productivity per author have been calculated by using the formula given by Yoshikane *et al.* (2009). Each author is given one point, thus multiple authorship articles were given multiple data entries. Required scientometric measures were considered to carry out this study. Lotka's law of scientific productivity is tested for its applicability to spacecraft technology research.

5. Literature review

It is observed from the published literature that a number of studies have been carried out following different data collection methodologies as listed in the Methodology section. Here an attempt is made to discuss a few published studies concentrating on authorship pattern and degree of collaboration in different subject fields.

Karisiddappa *et al.* (1990) analysed 37,637 documents published in different sub-fields of psychology and found that single-authored documents published in 1988 (39.43 per cent) were comparatively far less than the 84.00 per cent in the 1920s. They reported that the degree of collaboration in psychology was 0.60 during the study period. Sangam (2000) carried out a scientometric study on collaborative research in psychology in India for the period 1974-1997 and reported that two-authored papers (39.43 per cent) are the highest with the degree of collaboration in psychology in India being 0.60 for the study period. Zafrunnisha and Pullareddy (2009) surveyed 141 PhD theses in the field of psychology submitted to three universities in Andhra Pradesh, India, and showed the decreasing trend in single-authored papers compared to multiple-authored papers, and the degree of collaboration was 0.53. In the field of zoology, the two-authored paper contribution was 37.5 per cent and the degree of collaboration was 0.75, as revealed by Vimala and Pullareddy (1996) in their study with a sample of 19,323 journal citations and 120 zoology theses submitted to Sri Venkateswara University (Andhra Pradesh, India) during the period 1964-1995.

In the field of chemistry, Kannappanavar *et al.* (2004) conducted a study on publishing trends of Indian chemical scientists by retrieving 13,587 entries from Indian Science Citation Abstracts for the period 1996-2000. The authors reported that 76.18 per cent were multi-authored papers compared to single-authored (23.81 per cent), and the degree of collaboration was 0.76 among Indian chemical scientists. In a 10-year (2000-2009) study consisting of 53,977 journal articles published by Indian authors in the field of chemistry and retrieved from Science Citation Index, Pradhan *et al.* (2011) revealed that multi-authored papers dominated with 96.97 per cent and the degree of collaboration was 0.97.

A total of 419 articles published in the field of astronomy were retrieved from the ScienceDirect database for the period 2000-2004 by Osareh (2006). The collaboration coefficient in astronomy was reported as 0.494. Another study, consisting of 98,713 papers retrieved from CAB Abstracts for the period 2006-2010, highlighted the collaborative research in the field of veterinary sciences with 83.55 per cent multi-authored papers and a degree of collaboration of 0.84 (Arya and Sharma, 2012). Rana and Agarwal (1994) reported that single-authored papers decreased from 63.68 per cent in 1980 to 52.74 per cent in 1989 in their study of 2,612 papers gathered from *Wildlife Review and Fish Review* in the field of wildlife and fisheries and showed that the degree of collaboration varied between 0.36 to 0.51 during the period 1980-1989. Cunningham and Dillon (1996) surveyed authorship patterns in information systems by selecting five journals. The study consisted of 975 articles published during the period 1989-1995. It revealed that approximately 38.00 per cent of the articles have a single author, and the majority of the papers are co-authored with two and three authors.

Udofia (2002), in his paper on African trypanosomiasis research literature, analysed 3,644 articles abstracted in the journal *Tropical Diseases Bulletin and Tsetse and Trypanosomiasis Quarterly* from 1990-2000. Multiple authorship was the most productive with a total of 2,587 (70.99 per cent) papers while single authorship had 1,057

(29.10 per cent) papers. By applying the weighted average index method, the degree of collaboration was calculated as 2.87 for the period 1990-2000. Collaborative research trends in demography were studied by Sangam (2004) by gathering 20,224 records from the Population Index for the years 1998-1999. It was observed that 51.28 per cent were single-authored and 48.72 per cent are multiple-authored papers, and the degree of collaboration was 0.51. Analysis of 8,302 records retrieved from the Ei-Tech Index database on fibre optics for the period 1999-2003 showed that multiple-authored papers (88.63 per cent) dominated this field of research (Rajendran *et al.*, 2005). Another study collected 3,401 records on herbal literature from Biological Abstracts for the period 1990-2004 and found that single-authored papers were only 480 (14.11 per cent) and two-authored papers constituted the maximum with 22.29 per cent of contributions (Vinayagamoorthy *et al.*, 2009). Jain and Kumar (2011) explored the Indian contributions to world soybean research by retrieving 22,326 papers from the International Crop CD database from 1989-2008. Out of 3,045 Indian contributions, only 210 (6.9 per cent) were single-authored. The collaboration coefficient increased from 0.899 during the block period 1989-92 to 0.955 during the block period 2005-08 with an average of 0.931 and revealed the predominant trend was team research in the field of soybeans. A study of 8,051 articles retrieved from the Web of Science database in the field of network security for the period 2002-2011 by Amsaveni and Vasanthi (2013) showed that multi-authored productivity was dominant with 95.86 per cent contributions and the degree of collaboration in network security research was 0.95.

There are a good number of studies in the field of library and information science (LIS), and a few of them are included in this literature review. In the field of LIS research, the trend of exploring authorship patterns and degrees of collaboration are mostly by selecting few journals. Buttlar (1991) selected 16 journals containing 1,725 publications during the period January 1987 to June 1989. This study revealed the dominance of single-authored papers with 60.58 per cent contributions. An analysis of 894 papers by Davarpanah and Aslekia (2008) in 64 LIS journals indexed in the Social Science Citation Index for the period 2000-2004 showed that there is not much difference between single- and multiple-authored contributions. There were 457 (51.11 per cent) papers contributed by single authors and 437 (48.89 per cent) were multi-authored. The degree of collaboration in LIS was 0.49. A study conducted by Walia and Kaur (2012) revealed that 127 (47.21 per cent) papers are single-authored and 142 (52.74 per cent) papers are multi-authored out of 269 papers published in 2008 in 9 journals from the USA, the UK and India. Nazim and Ahmad (2007), in their paper on research trends, retrieved 607 papers in the field of information literacy indexed in the LISA Plus database. Their study revealed the dominance of single-authored papers with 63.15 per cent contributions, and the degree of collaboration in the field of information literacy was 0.39. Suradkar and Khaparde (2012) analysed 12,263 articles published in the field of library management research retrieved from the LISA database for the period 2000-2009. It was revealed from this study that the single-authored papers contributed 67.90 per cent (8,327 articles), and the degree of collaboration in library management research was 0.277. The studies covered under LIS showed the dominance of single-authored contributions.

In the field of space science and technology, which is the main highlight of this study, there are quite a few studies reported in the published literature. Sridhar (1985) explored 224 papers published by the ISAC (Bangalore, India), scientists and engineers, and concluded that 80 per cent of the papers have two or more authors. He concluded that collaboration in

space research was high due to the fact that there was high collaboration in publishing. An analysis of 1,525 items related to space neuroscience published during the period 1999-2012 and retrieved from the Web of Science database revealed that 91.68 per cent of contributions are multi-authored, and the degree of collaboration in space neuroscience research was 0.91 (Raja, 2012). Anilkumar (2013) surveyed 2,518 records of the Physical Research Laboratory (PRL, Ahmedabad, India) of which 1,318 were research articles published in journals, 436 were published in conference proceedings and 704 were invited talks collected for the period 1997-2006 from the annual reports of PRL. As far as research articles published in journals, it was noted that single-authored papers were only 13.13 per cent and the dominance of multi-authored contributions was revealed.

6. Analysis

The following section discusses the analysis of the data collected and presented under different table headings as per the objectives of the study.

6.1 Year-wise distribution of publications

Table I and Figure 1 depict the number of papers published from 2001 to 2011 in the three journals selected for this study. In all, 1,907 papers were published in the three journals. The highest number of 1,487 (77.97 per cent) papers are published in *JSR*, followed by 282 (14.79 per cent) in *IJSCN* and 135 (7.24 per cent) in *JST* during the period 2001-2011. Individual analysis of each journal reveals that the highest number of 183 papers was published in *JSR* in the year 2006 and the least number of 10 papers was published in the journal *JST* in the year 2002. On average, during the publication period of 2001-2011, 135 papers were published in *JSR*, 25 papers were published in *IJSCN* and 12 papers were published in *JST*. The number of papers published in the journal *JSR* was very high compared to other two journals, *IJSCN* and *JST*. The number of papers published each year was also not consistent for the period 2001-2011.

6.2 Authorship pattern

The data related to all three journals are presented in Tables II-IV. The authorship pattern is analysed to understand the percentage of single- and multiple-authored papers. It is clear from a collective analysis of the three journals that there are 245 (12.85

Year	*JST*	(%)	*IJSCN*	(%)	*JSR*	(%)
2001	12	8.70	30	10.64	121	8.14
2002	10	7.25	26	9.22	126	8.48
2003	12	8.70	32	11.35	125	8.41
2004	12	8.70	29	10.29	140	9.42
2005	12	8.70	20	7.10	142	9.55
2006	14	10.15	31	11.00	183	12.31
2007	16	11.60	29	10.29	137	9.22
2008	13	9.42	28	9.93	138	9.28
2009	13	9.42	14	4.97	145	9.76
2010	11	7.98	16	5.68	115	7.74
2011	13	9.42	27	9.58	115	7.74
	138		282		1,487	

Table I. Year-wise distribution of publications

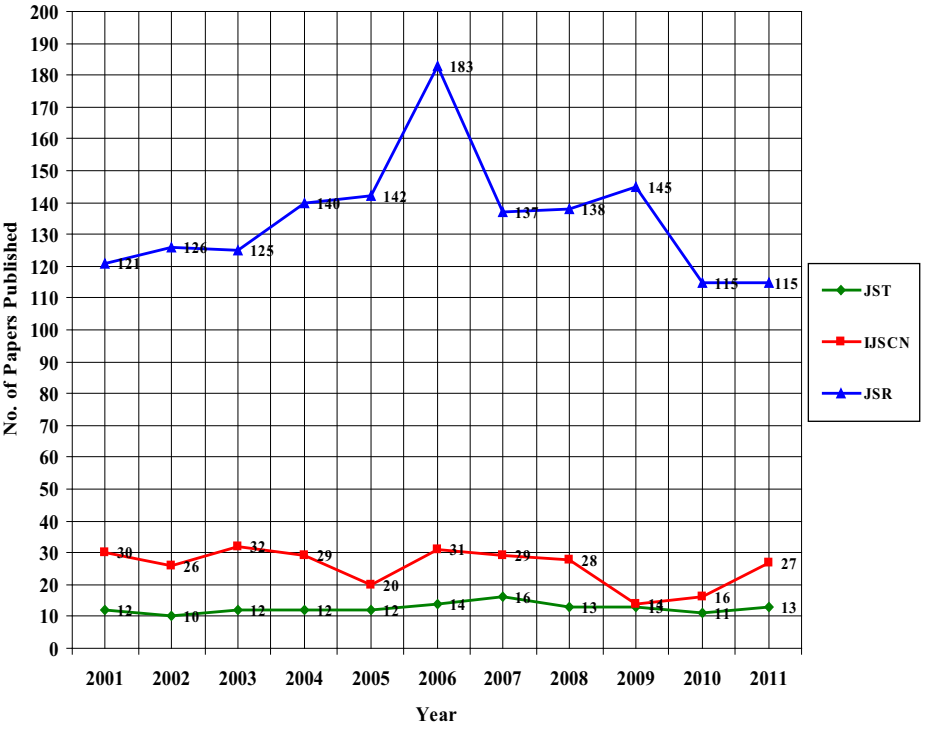

Figure 1.
Year-wise distribution of publications

Year	No. of papers	1	2	3	4	5	6	7	8	9	10
2001	12	4	1	5	0	1	1	0	0	0	0
2002	10	1	2	3	2	1	1	0	0	0	0
2003	12	3	2	4	1	1	0	1	0	0	0
2004	12	2	1	6	1	1	1	0	0	0	0
2005	12	1	3	6	1	0	0	0	1	0	0
2006	14	2	2	6	1	2	0	0	0	0	1
2007	16	0	3	4	4	2	2	0	1	0	0
2008	13	0	2	4	2	3	2	0	0	0	0
2009	13	0	1	1	7	1	2	1	0	0	0
2010	11	0	1	3	3	1	0	0	1	2	0
2011	13	0	3	4	1	2	2	1	0	0	0
	138	13	21	46	23	15	11	3	3	2	1

Table II.
Authorship pattern in *JST*

per cent) single-authored papers and 1,662 (87.15 per cent) multi-authored papers. Hence, it is revealed that collaborative research has dominated the field of spacecraft technology research. Out of 539 two-authored papers during the period 2001-2011, 444 (82.37 per cent) were published in the journal *JSR*, followed by 74 (13.73 per cent) papers in *IJSCN* and 21 (3.90 per cent) in *JST*. It is interesting to note that the number of three- and four-authored papers are more than two-authored papers in *JSR* compared to the

Year	No. of papers	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2001	30	6	6	5	5	6	1	0	1	0	0	0	0	0	0	0
2002	26	1	12	5	6	2	0	0	0	0	0	0	0	0	0	0
2003	32	2	18	4	4	3	0	0	0	0	1	0	0	0	0	0
2004	29	5	6	9	4	1	1	2	0	0	0	0	0	0	0	1
2005	20	6	7	1	3	0	1	0	0	1	1	0	0	0	0	0
2006	31	3	3	13	6	4	1	1	0	0	0	0	0	0	0	0
2007	29	3	7	6	8	1	0	0	1	0	0	0	2	1	0	0
2008	28	4	7	8	3	2	2	2	0	0	0	0	0	0	0	0
2009	14	1	2	4	2	2	1	1	0	0	0	0	0	0	0	1
2010	16	0	2	1	6	1	2	1	0	1	1	0	0	1	0	0
2011	27	2	4	9	4	1	2	3	1	1	0	0	0	0	0	0
	282	33	74	65	51	23	11	10	3	3	3	0	2	2	0	2

Table III. Authorship pattern in *IJSCN*

Year	No. of papers	1	2	3	4	5	6	7	8	9	10	11	12	13	14
2001	121	17	29	35	17	11	9	1	1	1	0	0	0	0	0
2002	126	16	42	36	18	7	4	1	0	2	0	0	0	0	0
2003	125	38	37	26	15	2	4	1	1	1	0	0	0	0	0
2004	140	20	40	30	26	9	5	3	4	0	0	2	0	0	1
2005	142	15	55	33	15	8	7	4	2	3	0	0	0	0	0
2006	183	19	45	53	29	17	11	4	5	0	0	0	0	0	0
2007	137	16	45	42	22	8	4	0	0	0	0	0	0	0	0
2008	138	22	43	30	21	7	10	2	2	0	1	0	0	0	0
2009	145	14	47	34	15	15	16	4	0	0	0	0	0	0	0
2010	115	13	36	31	20	10	5	0	0	0	0	0	0	0	0
2011	115	9	25	29	22	9	18	1	2	0	0	0	0	0	0
	1,487	199	444	379	220	103	93	21	17	7	1	2	0	0	1

Table IV. Authorship pattern in *JSR*

other two journals. There are a maximum of 15-authored papers published in *IJSCN* and 14-authored papers in *JSR*, whereas *JST* published a maximum of 10-authored papers during the publication period of 2001-2011.

6.3 Author productivity

Yoshikane *et al.* (2009), in their paper published in *Scientometrics*, gave a formula to calculate average author per paper and productivity per author. The formula is mathematically represented below:

- Average author per paper = number of authors/number of papers.
- Productivity per author = number of papers/number of authors.

Data pertaining to author productivity and average author per paper are presented in Table V for the three journals selected for this study. It is revealed from Table V that the average number of authors for the period 2001-2011 is a maximum (3.62) for *JST*, followed by *IJSCN* (3.52) and *JSR* (3.07). It can be concluded from individual analysis of each journal that the average author per paper is highest for *IJSCN* (5.44), followed by *JST* (4.91) for the year 2010 and *JSR* (3.56) for the year 2011.

Table V.
Author productivity

	JST				*IJSCN*				*JSR*			
Year	Total no. of papers	Total no. of authors	AAPP	Productivity per paper	Total no. of papers	Total no. of authors	AAPP	Productivity per paper	Total no. of papers	Total no. of authors	AAPP	Productivity per paper
2001	12	32	2.66	0.375	30	97	3.23	0.310	121	380	3.15	0.318
2002	10	33	3.30	0.303	26	74	2.85	0.351	126	364	2.89	0.346
2003	12	35	2.92	0.343	32	91	2.84	0.352	125	308	2.46	0.406
2004	12	37	3.08	0.324	29	100	3.45	0.290	140	458	3.27	0.306
2005	12	37	3.08	0.324	20	60	3.00	0.333	142	437	3.08	0.325
2006	14	48	3.43	0.292	31	105	3.39	0.295	183	604	3.30	0.303
2007	16	64	4.00	0.250	29	117	4.03	0.248	137	384	2.80	0.357
2008	13	51	3.92	0.255	28	90	3.21	0.311	138	417	3.02	0.331
2009	13	57	4.38	0.230	14	63	4.50	0.222	145	469	3.23	0.310
2010	11	54	4.91	0.204	16	87	5.44	0.184	115	338	2.94	0.340
2011	13	51	3.92	0.255	27	108	4.00	0.250	115	41	3.56	0.280
	138	499			282	992			1,487	4,569		

The average productivity per author for the period 2001-2011 is a maximum for *JSR* (0.32). The journals *JST* and *IJSCN* have the same average productivity per author (i.e. 0.28). Individual analysis of each journal reveals that *JSR* has the highest productivity per author of 0.406 for the year 2003, followed by *JST* (0.375) for the year 2001 and *IJSCN* (0.352) for the year 2003.

6.4 Study of Lotka's law (individual journals)

The data are collected for a period of 11 years for the 3 journals and serves as a reasonable period to make an attempt to study Lotka's law of scientific productivity.

Lotka's law describes the frequency of publication by authors in a given field by using the formula:

$$Y_x = \frac{C}{X^n}$$

Where Y is the number of authors credited with X number (1, 2, 3, 4 […]) of papers, C is the number of authors contributing one paper, and n is the rate (usually $n = 2$).

According to Lotka's law of scientific productivity, the number of persons making two contributions is about one-fourth of those contributing one, the number of others making n contributions is about $1/n^2$ of those making one and the proportion of all contributions who make a single contribution is about 60 per cent.

Individual analysis of each journal reveals that 366 authors have contributed 138 papers in *JST*, 704 authors have contributed 282 papers in *IJSCN* and 3,285 authors have contributed 1,487 papers in *JSR*. To test Lotka's law of scientific productivity, the value of n is calculated for the three journals individually and presented in Table VI.

The value of n (2.63) is the same for the journals *IJSCN* and *JSR*. For the journal *JST*, the value of n is 2.33. It is clear from Table VI that Lotka's law of scientific productivity conforms only partially for the three journals selected for this study. The reason for this could be due to the fact that the journals selected for this study have published more collaborative papers than the single-authored papers; hence, each author gets the count of one paper instead of the first author only.

6.5 Testing Lotka's law of scientific productivity in spacecraft technology research

Lotka's law of scientific productivity is tested taking into account the data from all three journals together. There are 4,355 authors contributing 1,907 papers in all three journals together. The value of n is calculated to 2.62 using Lotka's law of scientific productivity. It is clear from Table VII that Lotka's law of scientific productivity conforms only up to three papers (i.e. only partially). The earlier research carried out by Vinayagamoorthy *et al.* (2009), Jain and Kumar (2011) and Khatun and Ahmed (2011) have reported non-conformity of Lotka's law of scientific productivity in their studies. Anilkumar (2013) has also reported on the partial conformity of Lotka's law of scientific productivity.

6.6 Degree of collaboration

The degree of collaboration among authors in the three journals selected for this study is presented in Table VIII. To calculate the degree of collaboration among authors, the formula given by Subramanyam (1983) is used which is expressed mathematically as:

Table VI.
Study of Lotka's law (individual journals)

	JST				*IJSCN*				*JSR*			
No. of articles X	No. of authors (observed)	Observed (%)	No. of authors (expected) $n = 2.33$	Expected (%)	No. of authors (observed)	Observed (%)	No. of authors (expected) $n = 2.63$	Expected (%)	No. of authors (observed)	Observed (%)	No. of authors (expected) $n = 2.63$	Expected (%)
1	282	77.04	282	73.82	558	79.26	558	78.26	2,609	79.42	2,609	77.62
2	56	15.30	56	14.66	89	12.64	90	12.62	417	12.69	421	12.53
3	17	4.64	22	5.76	29	4.11	31	4.35	151	4.59	145	4.31
4	6	1.63	11	2.90	9	1.27	14	1.96	47	1.43	68	2.02
5	3	0.81	6	1.57	5	0.71	8	1.12	19	0.57	38	1.13
6	0	0.00	0	0.00	3	0.42	5	0.70	14	0.42	23	0.68
7	1	0.27	3	0.78	4	0.56	3	0.42	6	0.18	15	0.45
8	1	0.27	2	0.52	3	0.42	2	0.28	3	0.09	11	0.33
9					2	0.28	1	0.14	0	0.00	8	0.24
10					2	0.28	1	0.14	4	0.12	6	0.18
11									4	0.12	4	0.15
12									1	0.03	4	0.12
13									5	0.15	3	0.09
14									1	0.03	2	0.06
15									3	0.09	2	0.06
20									1	0.03	1	0.03

No. of articles X	No. of authors (observed) 4,355	Observed (%)	No. of authors (expected) $n = 2.62$	Expected (%)
1	3,449	79.20	3,449	77.43
2	562	12.90	561	12.60
3	197	4.52	194	4.35
4	62	1.42	91	2.04
5	27	0.62	51	1.14
6	17	0.39	31	0.69
7	11	0.25	21	0.47
8	7	0.16	15	0.34
9	2	0.04	11	0.25
10	6	0.14	8	0.18
11	4	0.09	6	0.13
12	1	0.02	5	0.11
13	5	0.11	4	0.09
14	1	0.02	3	0.07
15	3	0.06	3	0.07
20	1	0.02	1	0.02

Table VII. Testing Lotka's law for all three journals collectively

	JST			*IJSCN*			*JSR*		
Year	No. of co-authored papers	(%)	DC	No. of co-authored papers	(%)	DC	No. of co-authored papers	(%)	DC
2001	8	66.70	0.67	24	80.00	0.80	104	85.95	0.86
2002	9	90.00	0.90	25	96.16	0.96	110	87.31	0.87
2003	9	75.00	0.75	30	93.75	0.94	87	69.60	0.69
2004	10	83.34	0.83	24	82.76	0.83	120	85.72	0.86
2005	11	91.67	0.92	14	70.00	0.70	127	89.44	0.89
2006	12	87.50	0.87	28	90.33	0.90	164	89.62	0.89
2007	16	100.00	1.00	26	89.66	0.89	121	88.33	0.88
2008	13	100.00	1.00	24	85.72	0.86	116	84.06	0.84
2009	13	100.00	1.00	13	92.86	0.93	131	90.35	0.90
2010	11	100.00	1.00	16	100.00	1.00	102	88.70	0.89
2011	13	100.00	1.00	25	92.60	0.93	106	92.18	0.92

Table VIII. Degree of collaboration (DC)

$$DC = \frac{Nm}{Nm + Ns}$$

Where,

DC = degree of collaboration,
Nm = number of multi-authored publications in a discipline during a specific period and
Ns = number of single-authored publications in a discipline during a given period of time.

It is revealed from Table VIII that the value of the degree of collaboration is highest for *JST* (1.00) for the years 2007-2011, as there were only multi-authored papers published for this period. *IJSCN* has also recorded a degree of collaboration of 1.00

for the year 2010, and *JSR* has recorded a degree of collaboration of 0.92 for the year 2011. The least of degree of collaboration is recorded for *JST* (0.67) for the year 2001, followed by 0.69 for *JSR* for the year 2003 and 0.70 by *IJSCN* for the year 2005.

The average degree of collaboration for *JST* is 0.90, for *IJSCN* is 0.88 and for *JSR* is 0.86. In all, 1,907 papers are published in the three journals during the period 2001-2011. Out of which, 243 (12.74 per cent) are single-authored papers and 1,664 (87.26 per cent) are multi-authored papers. The degree of collaboration for spacecraft technology research is 0.87. The high degree of collaboration also reveals there are more multi-authored contributions and the dominance of collaborative research.

6.7 Ranked list of prolific authors

Table IX represents the list of prolific authors having contributed a maximum number of papers to the selected journals for this study during the period 2001-2011. For the journal *JST*, Nataraju contributed eight papers, followed by seven papers by Vishwantha. For the journal *IJSCN*, Perez-Fontan and Corazza contributed ten papers each, followed by nine papers by Giambene and Werner. For the journal *JSR*, Longuski contributed 20 papers, followed by 15 papers by Hollis, Boyd and Desai. Longuski emerges as the most prolific author among the 4,355 authors who published in the three journals selected for this study for the publication phase of 2001-2011.

Table IX.
Ranked list of prolific authors

Name of the journals	Name of the authors	No. of papers
JST	Nataraju, B.S.	8
	Vishwanatha, N.	7
	Parameswaran, K.	5
	Surendra Pal	5
	Suryanarayana Rao, K.N.	5
IJSCN	Perez-Fontan, F.	10
	Corazza, G.E.	10
	Giovanni Giambene	9
	Markus Werner	9
	Luglio, M.	8
	Vanelli-Coralli, A.	8
	Fairhurst, G.	8
JSR	Longuski, J.M.	20
	Hollis, B.R.	15
	Boyd, I.D.	15
	Desai, P.N.	15
	Braun, R.D.	14
	Hastings, D.E.	13
	Spencer, D.B.	13
	Lewis, M.J.	13
	Cho, M.	13
	Lane, S.A.	13

7. Major findings

The following are the major findings:

- During the publication phase of 2001-2011, a total of 1,907 papers are published with an average 173 papers per year. It is revealed in the above discussions that the journal *JSR* has published the highest number (1,487) of papers, followed by *IJSCN* (282) and *JST* (138) during the study period.
- A collective analysis of all three journals shows that the two- and multiple-authored papers dominate the field of spacecraft technology research. This finding also correlates with many of the earlier studies mentioned in the Literature Review section of this paper. There are 245 (12.85 per cent) single-authored papers and 1,662 (87.15 per cent) multi-authored papers published during the period 2001-2011. The two-, three- and four-authored papers accounted for 69.40 per cent of total contributions with two-authored papers dominating with 28.26 per cent of contributions. The journal *IJSCN* published 4 papers authored by 15 authors, and the journal *JSR* published 2 papers authored by 14 authors. Hence, contributions in spacecraft technology ranged from single-authored publications to a maximum of 15 authors in all three journals during the study period.
- The average productivity per author for the period 2001-2011 for all three journals together is 0.30, and the average author per paper is 3.20 which show the dominance of collaborative research in spacecraft technology. This figure also correlates with Newman's (2004) findings that the authors per paper in three disciplines (biology, physics and mathematics) ranged between 1.45 and 3.75.
- The journal *JST* recorded the highest degree of collaboration of 0.90, followed by the journals *IJSCN* (0.88) and *JSR* (0.86). The average degree of collaboration for all three journals taken together for the period 2001-2011 is 0.88. The degree of collaboration reported by Anilkumar (2013) in her study of PRL scientists was 0.87, and Raja (2012) in his study on space neuroscience research reported it as 0.91. The degree of collaboration reported in the present study (i.e. 0.88) is very close to the one found in these other two studies.
- Longuski emerged as the most prolific author with 20 publications during the publication period of 2001-2011. All his papers are published in the *JSR*.
- It is also revealed from this study that Lotka's law of scientific productivity conforms only up to three papers (i.e. only partially). This could be because of the fact that the journals selected for this study have published more two- and multiple-authored papers compared to single-authored papers. This result correlates with the findings of other studies reported in this paper where Lotka's law either did not conform or conformed only partially.
- *JST*, unlike the other two journals (*IJSCN* and *JSR*), is an in-house publication of ISAC, and the major contributors to this journal are all ISRO scientists or engineers. Hence, the reach of this journal to international researchers is limited and yielded low contributions from other countries.

8. Conclusion

The primary aim of the present study is to understand the authorship pattern and collaborative research in the field of spacecraft technology using data gathered from three important journals in this field. Authorship pattern and collaborative research are important aspects of citation analysis. In the field of science and technology, the increasing trend in multiple authorship and collaborative research are well-established by various bibliometric studies. The necessary scientometric measures were used to fulfil the objectives of the study. It is revealed from this study that multiple-authored papers have dominated this field of research. A high proportion of multi-authored papers is characteristic of the physical, experimental and life sciences. Two-authored papers are published more in number, followed by three- and four-authored papers. The degree of collaboration is high and could be attributed to the interdisciplinary nature of research, the high cost of space missions and a common interest of scientists in the same research fields. The extent of multiple authorship or collaboration in published papers depends on many factors, such as the nature of the research, the nature of financial support, the interdisciplinary and heterogeneous nature of the subject, the need for team work, informal networks among research workers and so on (Sridhar, 1985). The increasing cost of technology development and shrinking budgets of space agencies are other reasons for embarking on space cooperation. The growth of multi-authored papers has also increased the degree of collaboration in spacecraft technology research. Lotka's law of scientific productivity is tested and conforms only partially for spacecraft technology research.

The literature survey carried out in this study revealed that very few scientometric studies are conducted as far as space technology research is concerned. The results of this study to a greater extent correlates with results reported by other studies referred to in this paper. The findings of this study will be useful in understanding the importance of research and development activities, measuring the productivity of different countries and the performance of space scientists. Though this study has been conducted with a small sample of journals, future researchers can consider larger data samples to arrive at better conclusions, and an understanding of authorship pattern and collaboration in spacecraft technology.

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