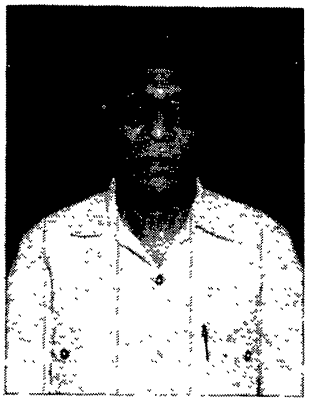
Bull. Astr. Soc. India (1997) **25**, 295–300

Silver Jubilee Article



Research, my passion

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In 1969, Prof. R.S.Verma, the then Head of the Department of Mathematics, University of Delhi, called me to his office and asked me, why I was not doing research. I had no valid reason for that except that I never thought of it. On his persuasion, I did my Ph.D. on a topic in Celestial Mechanics from the University of Delhi in 1970 at the age of 42. Earlier, I was totally dedicated to the teaching of Mathematics. And, now, research has become a compulsion of my mind. It gives me solace when I am depressed or find myself in a hopeless situation. It gives me joy which I cannot describe. The quality of my happiness has increased manifold with the passage of time.

During my student days, I had developed special interest in Mechanics and Astronomy and so my supervisor Prof. R.S. Verma suggested me to choose some topics in Celestial Mechanics but at the same time told me very frankly that he was an expert in the subject. There was hardly any book available on Celestial Mechanics either in my institution, Zakir Husain College (formerly Delhi College) or in the main library of the Delhi University. There were very few people in India who knew about the subject. Inspite of my serious and sincere efforts, I failed to make any progress. And then my supervisor asked me to contact Prof. R.K. Choudhary who had recently returned from Moscow after obtaining his Ph.D. in Celestial Mechanics. On contacting him, he readily agreed to help me provided I came to Bhagalpur. On the appointed day and time I reached his residence in Bhagalpur, but to my surprise and disappointment, he had left for Samastipur a day earlier and left a message for me that I should meet him there. I went to Samastipur, but again I was told that he had left for his village and had asked me to wait for his return to Samastipur. At last after a torturous wait for four days, I could meet Prof. Choudhary in Samastipur. His extremely affectionate behaviour immediately put me at ease. We went to Bhagalpur together. I was given four problems relating to 'Periodic orbit with a collision in restricted problem of three and four bodies'. Hardly had I solved one problem, I was summoned by my principal to Delhi and so reluctantly I had to cut short my visit. I stayed at Bhagalpur only for twenty one days. After returning to Delhi. I was lucky to solve the remaining four problems in one month's time. Initial frustration amply rewarded me in the everlasting friendship with Prof. Choudhary.

Unfortunately, my supervisor Prof. R.S. Verma died in Canada soon after, and he did not live to see me getting my Ph.D. degree. A simple remark by Prof. U.N. Singh, the new Head of the Department of mathematics changed the course of my life altogether. While congratulating me, he said, "Dr. Bhatnagar today, you are being initiated in research. It is just like a person who is initiated to sanyas, who casts-off his old garments and takes on new saffron robes and vows to live a life of dedication for the service of humanity. So, from now onwards, you should dedicate yourself completely to education and research'. His remark touched me deeply. After that there was no looking back. Research became a deep passion for me.

In these twenty five years I have been quite active in promoting research in Space Dynamics and Celestial Mechanics. We have produced a large number of research papers which are published in reputed national and international journals.

Our topics of research are : 1. N-Body Problem ($N \geq 2$), 2. Rigid Body Motion, 3. Periodic Orbits with the Characteristic of Collision, 4. Resonance, 5. Satellite Motion : Geostationary Satellite, 6. Scattering Problem, 7. Escape Theory : Formation of Binaries, 8. Chaos, 9. Fractals, 10. Non-linear Oscillations, 11. Relativistic Effect on Some Problems of Celestial Mechanics

I may state very briefly the most significant results discovered by us during these 25 years. We are all familiar with 2-dimensional Levi-civita transformation :

$$X_1 = \xi_1^2 - \xi_1^2 \quad , \quad X_2 = 2\xi_1\xi_2$$

which is widely used for regularising the equation of motion in problems of Celestial Mechanics. We could extend this to 3-dimension (Bhatnagar 1969) :

$$X_1 = \xi_1^2 - \xi_2^2 \quad , \quad X_2 = 2\xi_1\xi_2 \; ; \; X_3 = \xi_3$$

though having application only when $\xi_3 << 1$.

So far a general 3-dimensional transformation does not exist which regularises the equation of motion always except KS-transformation which of course changes 3D-space to 4D-space.

It is well known that the restricted problem of three bodies possesses five liberation points. The three collinear points L_1, L_2, L_3 are unstable and the two L_4 and L_5 are stable for the mass ratios of the finite bodies less than $\mu_0 = 0.03852$. Wintner (1941) showed that the stability of L_4, L_5 is due to the existence of coriolis terms in the equation of motion. The result was confirmed by Szebehely (1967). My first Ph.D. student R.K. Sharma (1975) while taking one of the primary as an oblate body, contrary to Szebehely, established that coriolis force is not always a stabilizing force. I presented this paper at the IAU-colloquim held in Cambridge in 1976 in the presence of Prof. Szebehely and other international experts. My guide Prof. Choudhary did not agree to our findings. The matter was referred to Prof. Szebehely. He

agreed with us but wanted to know the discrepancies in his paper. I, then studied the problems in depth with another student P.P. Hallan and resolved the mystery once and for all, discussing both the linear and non-linear stability not only taking one of the primaries an oblate body but by taking general perturbed potential and solving a large number of similar problems and even showing that Szebehely's case was a very special case of our work.

Our contribution towards the study of motion of rigid bodies is quite significant. We have modified various previous results and have extended the studies of Rusell (1928), Kopal (1938), Cowling (1938), Sterne (1939), Brouwer (1946), Johnson & Kane (1969), Kinoshta (1970), Misra & Choudhary (1974). While studying the motion of two-rigid bodies (Bhatnagar 1980 a) have shown θ_j, ϕ_j, ψ_j (j = A, B; Euler's angles), contrary to previous results, are linear functions of time. This was due to the fact that earlier researchers had not taken into account the contribution of a certain term. Our study towards the existence and stability of liberation points of one rigid body moving around another rigid body is shown in the following table.

Form of the rigid bodies	No. of Stationary Standard	Solutions
Both triaxial (Bhatnagar 1986)	36	L_i^j i, j = 1, 6
A spheroid and a triaxial (Bhatnagar 1980 b)	18	L_i^j i = 1, 3, 5; j = 1, 2 ... 6
Both spheroid (Bhatnagar 1978)	9	L_i^j i, j = 1, 3, 5
A spherical and a triaxal (Kinoshta 1972)	6	L_i^j i = 1; j = 1 ... 6
A sphere and a spheroid (Kinoshta 1970)	3	$L_i^j = L_i^j = L_{i+1}^j$ i, j = 1, 3, 5

We have studied in detail the motion of a geo - synchronous satellite under the gravitational force of the oblate earth (including its equatorial ellipticity), the sun (including solar radiation pressure) and the moon (taking into account the inclination of its orbit with the plane of the ecliptic). The equation of motion consists of 722-terms (Bhatnagar & Monica 1986) running to 64 pages. It was a herculean task to bring it in the following compact from

$$\dot{\alpha} = \dot{\alpha}_0 + \sum_{i=1}^{182} A_i \sin \omega_i t \tag{1}$$

$$\dot{\psi} = \dot{\psi}_0 + \frac{1}{\sin\alpha_0} \sum_{i=1}^{182} B_i \sin \omega_i t \tag{2}$$

$$\ddot{r} - r^2\ \dot{\theta} + \frac{G\,M}{r^2} = \xi + \sum_{i=1}^{179} C_i \cos\,\omega_i t \tag{3}$$

$$\frac{d}{dt}\,(r\ \dot{\theta})^2 = \eta + \sum_{i=1}^{179} D_i \sin\,\omega_i t. \tag{4}$$

When α, ψ determine the orbital plane and (r, θ) the position of the satellite in the orbital plane. I would like to emphasise the presence of the term $\dot{\alpha}_0$ on the R.H.S. of equation (1) which was not included in the earlier literature and is due to the earth's equatorial ellipticity. It was observed that the maximum contribution of $|\dot{\alpha}_0 t|$ in one year lies between 0.042° and 0.058° for a synchronous satellite. Another remarkable result which we found out was that the angular motion of a synchronous satellite is a large amplitude oscillation around the position of the minor axis of the earth's equatorial section. The period of this oscillation T = T (j_2^2) is a function of j_2^2, the term due to earth's equatorial ellipticity. This formula enables us to determine the value of $j_2^{(2)}$ very accurately as T can be observed with precision. Our work on non-linear oscillation determining chaotic zone and its application to the motion of satellite Hyperion have been appreciated internationally (Bhatnagar 1994).

In recognition of my research activities, I was elected to IAU-Commission 7 (dedicated to Celestial Mechanics) and later to its executive committee. I was also on the Editorial Board as International Editor for one of the most prestigious Journals 'Celestial Mechanics'. I was elected to various national and international academic bodies. I was elected a senior associate of IUCAA and elected to one of its statutory committees. I had also been on the nominating committee of the Kyoto Prize in Celestial Machanies.

I have undertaken various research assignments and projects which have been funded by UGC, DST, ISRO, Smithsonian and University of Texas at Austin. I have chaired the session and delivered presidential addresses at various national and international conferences. My academic activities have taken me to USA, UK, Holland, France, Germany, Austria, Italy, Spain, Finland, Kuwait and Russia. I got invitations to visit China & Japan. I had to cancel my visit to China due to unexpected disturbances there and could not go to Japan due to some technical difficulty in getting the visa in time. During my visits abroad I have had the privilege of coming into contact with giants in my field.

I have developed a very strong group of scientists (Appendix A) which is quite active in promoting research in Space Dynamics and Celestial Mechanics. We have organised two international meetings in Delhi, one in 1985 and the other in 1990. The meeting of 1985 (International Workshop on Space Dynamics & Celestial Mechanics) was organised under the joint sponsorship of University of Delhi, Vikram Sarabhai Space Centre, Trivandrum and the Space Programme of the University of Texas at Austin, Austin, U.S.A. The meeting of 1990 (IAU-Colloquim 132) was sponsored by Commission 7 (Celestial Mechanics) and co-sponsored by Commission 33 (Structure and Dynamics of Galactic System) and 37 (Star cluster and

Association). I was the chairman of both the above meetings. At both the meetings the need of establishing a Centre of Space Dynamics in India was emphasised.

In consequences of the above an autonomous Centre for Fundamental Research in Space Dynamics and Celestial Mechanics (CFRSC) has been established under a registered Trust at IA/47C, Ashok Vihar, Phase 1, New Delhi – 110 052 with myself as the first full-time Director of the Centre.

The aim of the Centre is to make the general public aware of the importance of fundamental research in space dynamics and celestial mechanics and to organize research in this field with individuals and institutions. This, we wish to achieve by arranging lectures by eminent scientists, by holding seminars and conferences, providing consultancy service and publishing articles, books, pamphlets and periodicals etc. We are devoting a good deal of our time and effort in achieving these objectives using the modest resources available to us.

Everybody has his or her share of the good, the bad and the ugly. I am no exception. My humble beginnings still haunt me. After my father's death I had to apply for full fee concession. I was then ten years old and a student of 6th class. There used to be a very humiliating system in those days. The fee had to be given from a poor-fund account. And the money had to be collected by the student himself holding a tin box in front of his own classmates after the morning prayers. I had to go through that ritual every month and bear the most agonising humiliation.

At present my only ambition is to see the CFRSC as one of the best academic institutions of the world. But financial constraints stand in my way. I pray and hope that one day some philanthropist will give his patronage to this noble task.

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Appendix A

1. Dr. K.B. Bhatnagar, 2. Dr. R.K. Sharma, 3. Dr. Z.A. Taqvi, 4. Dr. P.P. Hallan, 5. Dr. Usha Gupta, 6. Dr. Beena Gupta, 7. Dr. L.M. Saha, 8. Dr. S.C. Jethi, 9. Dr. Ayub Khan, 10. Dr. Arif Mohd, 11. Dr. B.D. Prasad, 12. Dr. Monica Mehra, 13. Dr. Rashmi Bhardwaj, 14. Mr. Virendra Mehra, 15. Mr. Navin Chandra, 16. Miss Mona Khana, 17. Mrs. Neeta Vij.