XIX Brazilian Colloquium on Orbital Dynamics (2018): a solid path to the 21st century

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Abstract. The Brazilian Colloquium on Orbital Dynamics (CBDO) is a scientific meeting that takes place every two years since 1982. Its main goal is to bring together researchers, professors, undergraduate and post graduate students who develop works on pure and applied Celestial Mechanics in the same lectures and discussions atmosphere, and thus to drive collaboration between these areas. The XIX CBDO 2018 took place at the Test and Integration Laboratory (LIT) of the National Institute for Space Research (INPE), in São José dos Campos (SP), Brazil, between December 03 - 07, 2018, and more than 230 attendant from South and North America, Europe and Asia presented works of which 31 were selected for publication in this volume of the Journal of Physics: Conference Series. The highlight of this issue is the consolidation of the research groups on Celestial Mechanics in several Brazilian universities.

1. Introduction
The Celestial Mechanics is a branch of Astronomy which studies the motion of bodies under gravitational attractions. Besides, forces of other nature as Solar Radiation Pressure, Drag, tethers etc. also are present in models that analyse the motion from planetary rings up to artificial satellites and interplanetary probes. This, therefore, justifies the meeting of researchers from pure and applied Celestial Mechanics areas to discuss and identify common ground among their works and, this away, foster collaborations to further the ongoing development of this Science. Promoting professional exchange of knowledge between the Celestial Mechanics’ areas has been one of CBDO’s main objectives since its first edition, in 1982. The main areas the CBDO deals with are theoretical celestial mechanics, dynamical and planetary astronomy, planetary science and Solar System dynamics, astronautics and dynamical systems and chaos applied to space research.

The CBDO history also show another important goal, the encouraging cooperation among Brazilians and foreign researchers. Therefore, in all CBDO since 1982, the presence of researchers from other countries has been constant [1].

During the CBDO days, lectures and poster sessions on pure and applied Celestial Mechanics occur in an orderly manner. Researchers groups have work meetings, while other new ones are created. This has been important and essential for consolidation of research groups on Celestial Mechanics in Brazil.

2. Celestial Mechanics: legacy and future
As all branches of Science, the Celestial Mechanics has originated from the everyday needs of humanity. The observation of periodicities in the celestial bodies’ motion allowed the ancient
civilizations (Babylonians, Egyptians, Greeks, Arabs, Chinese, pre-Colombian cultures etc) to build calendars and to develop agriculture. They were able to forecast phenomena such as eclipses, the seasons and the precession of the equinoxes [2,3,4].

From the 16th century, the Celestial Mechanics received important contributions from countless scientists. The list is big and constantly growing; it has names as N. Copernicus (1473 - 1543), J. Kepler (1572 - 1630), G. Galilei (1564 - 1642), I. Newton (1642 - 1727), L. Euler (1707 - 1783), J. R. d’Alambert (1717 - 1783), G. Lagrange (1736 - 1813), H. Poincaré (1854 - 1912), W. Hohmann (1880 – 1945), G. P. Kuiper (1905 – 1973), G. Colombo (1920 – 1984) and many others [5]. These contributions form a solid legacy to which scientist of the present days inevitably turn to investigate the motion of Earth satellites, probes and natural celestial bodies around the corners of Solar System.

The future brings challenges to the Celestial Mechanics. New satellites constellation promise “overpopulates” the space near the Earth, as the Starlink, Galileo, OneWeb and Telesat projects, for instance. On the one hand, these constellations will provide fast communications, global positioning, weather forecasting capability, business and entertainment, all essential to the current lifestyle adopted by mankind, for the other hand, they will bring problems related to the space pollution.

In a few decades, we could start the effective Solar System colonization which only will be possible with the development of techniques capable of balancing appropriate flight time for the crews and low fuel consumption. The discovery of exoplanets by terrestrial and space telescopes and of new rings and natural satellites around far planets and asteroids, in turn, will inspire researches to understand the origin and the evolution of these structures. Thus, the Celestial Mechanics will follow its development.

3. The role of the Brazilian education and research institutions in the development of the Celestial Mechanics

Generally speaking, the research and the teaching on Celestial Mechanics in Brazil were first concentrated at the Institute of Astronomy, Geophysics and Atmospheric Sciences (IAG) [6], founded in 1927, and belonging to the University of São Paulo (USP) located in São Paulo city (SP), and at the National Observatory (ON) [7], founded in 1827 in Rio de Janeiro city (RJ). With the foundation of the Institute of Aeronautical Technology (ITA) [8], in 1950, and the National Institute for Space Research (INPE) [9], in 1971, both in São José dos Campos city (SP), new centres dedicated to the teaching and the research on Celestial Mechanics applied to the motion of artificial satellites and rockets emerged in Brazil. Still in the same period, in 1958, specifically, the Observatory of Valongo (OV) [10], belonging to the Federal University of Rio de Janeiro (UFRJ), was founded also in Rio de Janeiro city; and, in 1980s, a research group focused in pure Celestial Mechanics was created at the University of São Paulo State (UNESP) at the Rio Claro Campus (SP).

In the 1990s, an important group focused in researches and training of university professors on pure and applied Celestial Mechanics emerged at the UNESP, Guaratinguetá Campus (SP) [11]. As can be seen from Figure 1, all these institutions are preponderantly located in a specific region of the Brazilian territory, between the cities of São Paulo and Rio de Janeiro, so-called Rio-São Paulo axis. In this region is also concentrated the majority of the Brazilian Aerospace and Defence Industries, as EMBRAER and AVIBRAS, for example.

From the mid-2000s, students formed by the post graduate programs of IAG/USP, ON, OV, ITA, INPE and UNESP started their professional activities in other higher education and research institutions spread throughout the Brazilian Territory, besides replacing the staff of these same institutions. Thus, new research groups on Celestial Mechanics emerged in several Brazilian universities, for example:
- Federal University of ABC (UFABC), Santo André (SP);
- Federal University of São Paulo (UNIFESP), São José dos Campos (SP);
- UNESP, São João da Barra Campus (SP);
- USP, Lorena Campus (SP);
- Rio de Janeiro State University (UERJ), Resende Campus (RJ);
- Federal Fluminense University (UFF), Niterói (RJ);
It is interesting to note that USP, ON, OV, ITA, INPE and UNESP also trained students from other countries, and this allowed the development and maintenance of collaborations involving foreign research organizations, especially in South and North America and Europe.

Considering what is described in this section, we can conclude that the research and teaching on Celestial Mechanics in Brazil have followed an irradiating path. At first, they were concentrated in a few institutions located in a small, but important, region of the country and that invested in post graduate programs for researchers and professors training. This way, they were successful in maintaining a good number of motivated researchers in their team and still allowed the consolidation of research groups in more than 20 universities spread throughout the Brazilian territory. Therefore, these pioneer institutions left as legacy a solid path to the 21st century and, of course, they also continue in this path towards the future.

Figure 1. Distribution of higher education and research institutions on Celestial Mechanics areas in Brazil.
4. Introducing the papers

In this section, we present the 31 selected papers of this special issue. We also take this opportunity to thank all the authors for their valuable contributions, and for investing a lot of work and effort into the results of their research work. Special thanks go to reviewers who dedicated their precious time in providing numerous comments and suggestions, criticism and constant and enthusiastic support. The papers are presented one by one in sequence.

The paper “Formation of the CF radical in comets”, by Almeida, Boice, Andreazza and Araújo, describes some recent discoveries regarding chemical components found in the surface of comet 67P/Churyumov-Gerasimenko, based in data obtained from the European Space Agency’s Rosetta spacecraft, that passed just 15 km from the comet center.

The paper “Perturbation of Electromagnetic Radiation of Downlink in Orthogonal Components on the GOES 16 Satellite by Planar Antenna Phase Array”, by Heilmann, Tertuliano Filho, Dartora, Clistenes and Adams, used numerical methods to integrate the equation of motion of the GOES 16 Satellite, which can be used for both keplerian and perturbed motion. The goal is to measure the electromagnetic disturbance suffered by the spacecraft as a function of its position in space.

The paper “Extending Geostationary Orbit Missions for Lunar Observations”, by Silva, Terra, Celestino and de Melo, investigates an alternative strategy to exploit future communications satellite that includes a final stage of lunar observations. It describes impulsive transfers between geostationary orbits and lunar gravitational capture orbits using a model given by the full 4-body dynamical model with the Sun, Earth, Moon and spacecraft. Time evolution of solutions are analyzed, and the fuel are computed.

The paper “Orbits around the dwarf planet Haumea”, by Carvalho, shows an analysis of orbits around the dwarf planet Haumea. The mathematical model considers the effects of the perturbations due to the nonsphericity of the body ($J_2$; $J_4$; $C_{22}$). It is also considered the presence of the two natural satellites, the moons Namaka and Hi’iaka.

The paper “An implementation of the weighted essential non-oscillatory scheme for numerical approximations of the pressureless gas dynamics equations”, by Jung, used the Weighted Essential Non-Oscillatory (WENO) scheme to study the pressureless gas dynamics equations. The goal is to make numerical testes for one-dimensional problems in the presence of captures of the delta shock waves and vacuum.

The paper “Dynamic propagation of space tether system motion”, by Zanardi, Livio, Prado, Silva and Baroni, has the goal of solving the equations of motion for a Spatial Tether System composed by a main satellite and a sub-satellite. The translational motion of the sub-satellite around the main spacecraft is described in spherical coordinates. The rotational motion of the sub-satellite is studied using the Euler’ equations and the cinematic equations for 3-2-3 Euler angles. The results show that the subsatellite moves around the main satellite in a precessing anticlockwise motion. It also vertically oscillates throughout this motion, with an amplitude of approximately 10 degrees.

The paper “Equilibrium points stability analysis for the asteroid 21 Lutetia”, by Mota and Rocco, studies the stability of the equilibrium points around the asteroid (21) Lutetia. The model assumes that this body has a constant velocity of rotation and an irregular mass distribution. An expansion of the potential in series associated with decomposition in tetrahedral elements is used to model the asteroid. The zero velocity curves are made, and the results were validated by simulations of trajectories around these equilibrium points.

The paper “Effects of the mass parameter in the optimum direction of impulse and energy variation in a Powered Swing-By”, by Ferreira, Moraes, Prado and Winter, studied the effects of a close approach maneuver combined with an impulse applied during this close encounter with the secondary body. It is the so called “Powered Swing-By maneuver” The objective is to quantify the effect of the mass parameter in the optimum direction to apply the impulse and in the energy variation of this maneuver.

The paper “Particle-in-cell model of the helicon plasma thruster experiment at the University of Brasilia”, by Miranda, Trindade, Luz, Costa, and Ferreira, describes a numerical model of a helicon plasma thruster device that is under development at the Laboratory of Plasmas at the University of Brasilia. The device is described based in a cylindrical geometry neglecting variations in the azimuthal
direction. The model predicts the emergence of a structure like a current-free double-layer in the plasma that was detected in similar experiments.

The paper “Tension force in nanosatellite tethers systems”, by Moia, Santos and Formiga, studies the equilibrium and stability of the motion of space systems connected by tethers. It derives the mathematical formulation for a system formed by two-point masses connected by a tether in the central force. The Lagrangian formulation was used to describe the dynamics of the system. Tension and kinetic energy were presented for different situations.

In “Tension force in nanosatellite tethers systems”, by Moia, Santos and Formiga, the authors give a brief review on the use of large cables in space structures to connect spacecrafts and satellites, where they present the mathematical approach using the Lagrangian formulation.

Concerning the space debris problem, in the work entitled “Propagation of the trajectories for reentry spherical debris including rotation, melting fragmentation and voxel method”, by Murcia, Guedes and Prado, is implemented a computational code to propagate the dynamics and kinematics of spherical debris or propellant tanks as they enter the atmosphere. A voxel method is adopted to analyze the tanks heat transfer, surface temperature and structures stress. They considered three different materials and the results show a good approximation with cases reported in the literature.

The paper “The use of Design of experiments to calculate the influence of planet oblateness in the temporary gravitational capture”, by Siqueli, prado and Solorzano, presents a study of the influence of the oblateness of a planet in the problem of temporary gravitational capture. The system considered is the Sun-Jupiter-Particle three-body problem. To determine the effects of the oblateness in the dynamics of the particle, it is used the design of experiments to generate the data for a global analysis of the model. They explore the effects of the oblateness in the capture of the particle for a wide range of values.

Having in mind the technology of electric propulsion devices for future Brazilian space missions, in the work “Particle-in-cell numerical simulation of the Phall-Iic Hall thruster”, by braga and Miranda, is made a comparison of the performance of two types of Hall thrusters, namely, the SPT-100 and the PHall-IIc, the latter being developed by the Plasma Physics Laboratory at the University of Brasilia.

The satellite of Jupiter, Europa, with the intriguing hypothesis of having oceans below its icy surface, is the subject of the paper “Evaluating the disturbances acting on a spacecraft on orbit around Europa”, by Araújo and Rocco. Along the work, the authors study the perturbations on a spacecraft in an orbit around Europa, considering the gravitational attractions of the Sun, Jupiter, Io, Ganymede and Callisto.

With a focus on binary asteroid type dynamics, the author of the work “Simple parameters spaces analysis of roto-orbital integrable Hamiltonians for an axisymmetric rigid body”, by Santos, presents a test of two Hamiltonians that produce integrable models to study the roto-orbital motion of an axisymmetric rigid body under a central gravitational field. The parameters space analysis show comparisons of two recently proposed intermediaries with respect to the original non-analytically integrable model and with respect to each other.

The recently launched Brazilian satellite SGDC - Geostationary Satellite of Defense and Communication is considered in the study “Computational analyses of perturbative effects on geostationary satellites: Case SGDC”, Perroni and Solórzano. Using numerical simulations, the authors analyze the influence of the perturbations of the terrestrial gravitational field, the solar radiation pressure and the lunisolar gravitational force. By checking the combination of these perturbations, it is evaluated which of the effects presents predominance.

In the work “Orbital maneuvers to form a constellation of small satellites from a single large spacecraft”, by Cavalcà, Prado, Gomes, Sanchez, it is studied how to form a constellation of small satellites when all small satellites leave from a larger spacecraft. A search for initial conditions of the small satellite is performed to find the best ones to move it away from the larger satellite such that it is allocated in a co-orbital orbit with respect to the larger satellite. These initial conditions intend to minimize the consumption of an impulsive maneuver.

The large moons of Saturn, Dione and Enceladus are the subject of the work “Trajectories of a spacecraft aiming to approach at a near-regular cadence of the Enceladus and Dione moons”, by Gonçalves, Rocco and Moraes. The main goal is to evaluate strategic trajectories aiming to approach
an artificial satellite to these moons, in a near-regular cadence. Considering continuous propulsion, the simulations consider the gravitational potential of Saturn and of the 13 largest moons.

Genetic algorithms are a particular class of evolutionary algorithms that use techniques inspired by evolutionary biology such as heredity, mutation, natural selection, and recombination. In the paper “Orbital maneuvers for asteroids using genetic algorithm”, by Neves, Santos, Domingos and Formiga, the authors present a work that aims to use this method to optimize the consumption of fuel in Rendezvous maneuvers in interplanetary missions.

The paper “Simulations without data updates using analytical attitude propagator GSAM for spin stabilized satellites”, by Zanardi, Mota and Borderes-Motta, brings results about the work for validation of a propagator GSAM using new data provided by the National Institute of Space Research (INPE) from the Data Collection Satellites SCD1 and SCD2 with emphasis on long interval simulations without daily data updates.

The paper “A test and calibration environment for the Brazilian star tracker”, by Fialho and Fernandes, presents an overview of the test and calibration infrastructure built for an autonomous star tracker (AST) being developed by the Electro-Optics group of INPE as effort to increase the competence of the Brazil in attitude control systems.

The paper “The impact of Space Law and space debris mitigation measures on the debris scenario around the Earth”, by de Paula and Celestino, brings studies about Space Law based on legislations and discussions on space debris mitigation and the possible consequences of non-compliance with these standards for orbits around the Earth have.

The paper “Parametric study of polar configurations around binaries”, by Giuppone and Cuello, shows results of an extend dynamical studies for circumbinary discs (CBDs) and considers polar configurations around detached close in binaries through N-body simulations.

The paper “Database on detected stellar occultations by small outer Solar System objects”, by Braga-Ribas, Crispim, Vieira-Martins, Sicardy, Ortiz, Assafin, Camargo, Desmars, Lecacheux, Santos-Sanz, Duffard, Benedetti-Rossi, Gomes-Júnior, Morgado, Rommel, Margoti and Pereira, presents a database as an electronic table (http://occultations.ct.utfpr.edu.br/), where the main information obtained from any stellar occultation events by small outer solar system objects are listed. The structure and term definitions used in the database are presented, as well as some simple statistics that can be done with the available results.

The paper “Preliminary Experimental Results of the PHALL II-C with Improved Magnetic Circuit Design and Hollow Cathode”, by Martins, Porto, Coelho, Ferreira, and I S Ferreira, presents preliminary experimental results for a PHALL thruster of the annular type, which has been greatly improved with a new magnetic circuit design that allows operation with the magnetic field perpendicular (normal configuration) or parallel (magnetic shielding) to the thruster walls. Tests of the PHALL II-C operation up to 620 W with the generation of up to 41.39 mN of force and 2286.22 s of specific impulse, using a hollow cathode are also described.

The paper “Hall plasma thruster development for micro and nano satellites”, by Ferreira, Martins, Miranda, Porto and Coelho, brings studies about the development of a Permanent Magnet Hall Thruster (PHALL) for the Brazilian Space Program since 2004, at the Plasma Physics Laboratory of the University of Brasília (UnB). This paper also presents experimental results of generating a force above 40 mN with powers around 620 W, and it discuss possible applications of this thruster to nano and microsatellites with powers above 50 W.

The paper “Evaluation of orbital decay of a satellite at low altitude due to atmospheric drag as a function of solar activity”, by Macêdo and Rocco, provides an initial approach, through simulation, as an engineering effort to deal with atmospheric drag and Solar storms perturbations.

The paper “Perturbation of the Sun on Frozen Orbits Around Mars”, by Oliveira, Domingos, Silva, Prado and Sanchez, presents studies related to the perturbation of the Sun and the nonsphericity of Mars in the orbital evolution of artificial satellites on frozen orbits around this planet, using the method of the integral of the disturbing accelerations to calculate the magnitude of the total velocity variation due to each perturbation, as well as the degree and order of the most significant spherical harmonic over a long time.
The paper “The role of the mean and forced eccentricities in the secular dynamic of circumbinary planets”, by Zoppetti, Beaugé, and Leiva, considers the Restricted Three Body Problem (RTBP) to study the orbital evolution of a circumbinary (CB) planet from a simple analytical model to explain the mean behaviour of the planetary eccentricity and better identify the nature of the main contributors of eccentricity oscillations. The analysis also considers dissipative forces and compare with a N-body simulation in which the dissipative force is the interaction with a protoplanetary disc.

The paper “Natural Quasi-Rendezvous and Evasive Maneuvers assisted by Atmospheric Drag”, Jesus, Ferreira, Sousa, presents studies on evasive maneuvers of spacecraft in the face of the danger of collision with space debris at low-earth altitudes (LEO). Numerical simulations for collision dynamics and evasive maneuvers between spatial objects and space vehicle considering the atmospheric drag environment.

References
[1] http://www.astro.iag.usp.br/~dinamica/historic.html. Accessed on October 03, 2019
[2] de Melo C F et al 2015 J. Phys.: Conf. Series 641
[3] de Melo C F et al 2017, J. Phys.: Conf. Series 911
[4] Macau E E N, de Melo C F, Prado A F B A and Winter O C 2014, Comp. Appl. Math.
[5] Szebehely V G, Mark H 1998 Adventures in Celestial Mechanics 2nd edition John Wiley & Sons, Inc
[6] https://www.iag.usp.br/international/iag-history. Accessed on October 01, 2019
[7] https://www.on.br/index.php/pt-br/conheca-a-identidade-digital-do-governo.html. Accessed on October 01, 2019
[8] https://ov.ufrj.br/informacoes/historia-e-memoria/. Accessed on October 01, 2019
[9] http://www.ita.br/aconcepcio. Accessed on October 01, 2019
[10] http://www.inpe.br/institucional/sobre_inpe/historia.php. Accessed on October 01, 2019
[11] https://www.feg.unesp.br/#!/ensino/departamentos/matematica/apresentacao/. Accessed on October 01, 2019

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