Capítulo 78

Feasibility study of the propulsion force generated from the induced vibratory response of structures

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ABSTRACT
This work brings a brief physical and computational analysis on a mechanical system patent, whose authors claim to be able to generate movement from the vibration of its structure. This type of invention fits into a larger category of systems called reactionless engines, which have been shown to be unfeasible due to the violation of fundamental laws of motion. In order to demonstrate this, this study aims to bring a physical formulation of the proposed system's mechanism and the inspection of its structure's behavior when subjected to vibration at natural frequencies using finite elements modal analysis (FEA). Additionally, the discrepancies observed in the results for different models are pointed out. Through this methodology, the results obtained are complementary to each other, and, qualitatively, it was possible to conclude that the proposed system is not capable of producing propulsion once it disregards the conservation of momentum principle, like the others in the category.

Keywords: Vibration, Finite Elements, Propulsion

1 INTRODUCTION

Propulsion, in general, is defined by the act of moving a body (Sutton, 2010). In other words, the movement of propulsion or traction is a change in the inertial state of any body through a force that generates impulse. Throughout history, propulsion has become a fundamental technology for the development of civilization. Initially, forms of propulsion external to the means of transport were employed, such as animal traction for carts; the force of the wind for ships and the use of catapults and gunpowder for projectiles. With the advent of the steam engine, it was possible to create the first self-propelled transports. Since then, technology has evolved, and new methods have been developed. The search for new forms of propulsion is one of the main engineering challenges today.

In this sense, the propulsion generated from the vibration of a body appears, as proposed by Charette et al. (2006) in their patent. The proposed system is based on the vibratory stimulus of a rotating body. With a stimulus equal to the angular velocity of the body and close to one of its natural frequencies, the resulting acceleration is amplified and channeled in only one direction. Since the propulsion of the body does not result from interaction with the environment, it becomes an attractive technology for applications in space.

Currently, satellites use forms of propulsion for orientation correction (rotation) and orbital maneuvers (translation), with the use of reaction jets being more common. It is a jet of gaseous material expelled by a nozzle that, despite the speed and magnitude of the impulse, has the disadvantage of being limited to the amount of propellant available, which in turn represents more mass and less useful internal volume. For orbital maneuvers, other forms of propulsion are ion reaction, nuclear and solar wind, and for attitude control are reaction wheels and electromagnetic coils.

The propulsion produced without reaction on another body is a concept present for decades and independent. Its premise of producing a small amount of impulse capable of propelling a body without interaction with the environment led several people to register patents all over the world, with the one by Charette et al. (2006) among these. Given that such technology potentially finds great application in the space sector, it becomes the object of investigation in this study.

1.1 BIBLIOGRAPHIC REVIEW

The subject of the present study is mainly addressed in the text by Millis (2005) presented by the North American space agency (NASA), which evaluated fourteen potential propulsion proposals, judged by observing the reliability of their statements and their credibility to the detriment of viability. One of the themes of these proposals, among others, is oscillatory inertial propulsion.

Previously, in 2004, the same author had already commented on the plausibility of oscillatory motors in the context of space, considering questionable the conversion of oscillatory forces into external forces from moments internal to the system (Millis, 2004). In his later work, Millis classified this category of proposed oscillatory, gyroscopic, and reactionless motors as "unfeasible approaches". In this category are mechanical devices that use the vibration movement of internal components to produce external movement, with no interaction with the environment. Still according to the author that the design of these devices is based on wrong interpretations of physical phenomena.

Loukanov (2015) briefly comments on this type of propulsion and presents his own version for terrestrial oscillatory propulsion. According to him, most patents registered for motors of this type do not work and generate distrust on the part of the scientific community, since, without reaction (reactionless drive), they violate Newton's Laws. Loukanov presents his study based on the patent registered by Dean (1959), one of the precursor proposals for reactionless engines. The device presented by the patent under investigation fits into the general class of reactionless thrusters and, more specifically, into the category of oscillatory inertial motors.

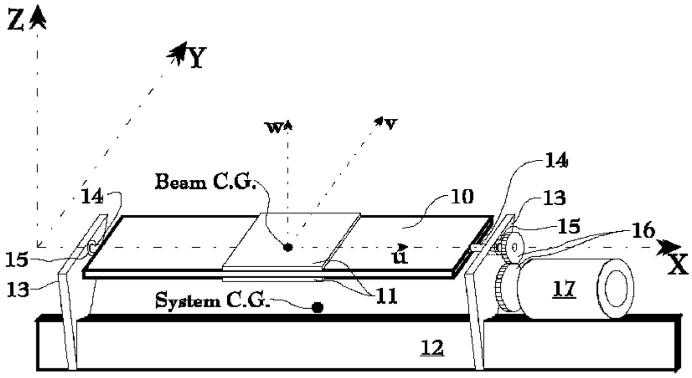
2 METHODOLOGY

The investigation methodology employed is presented in this section, consisting of a brief formulation of the physical phenomenon and a verification of the vibration modes and behavior of the proposed structure by computerized analysis. It is important that the operating principle indicated in the patent under study is initially presented so that the results are understood.

2.1 ENGINE OPERATION

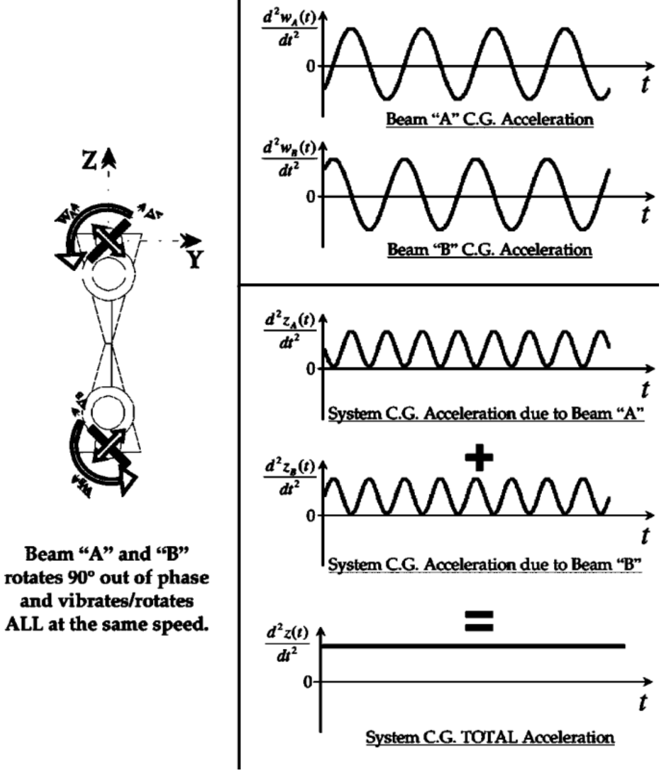
The engine proposed in the patent by Charette et al. (2006) is presented as a means of propulsion capable of producing acceleration through the vibratory response of the body induced by piezoelectric transducers. In this way, it is stated that its operation does not require any interaction with the environment, being a simple and low-cost solution for space vehicles.

Figure 1 – Illustration of the proposed configuration. Source: Charette, et al. (2006).



The configuration provided in the patent is shown in Figure 1 and is initially described as a flat plate (10) containing piezoelectric transducers (11) on a shaft (14) connected to a rigid structure (12) by two bearings (13). The plate is rotated around the axis by means of a set composed of an electric motor (17) and a gear reduction (16).

Figure 2 – Oscillation scheme of proposed engine components. Source: Charette, et al. (2006).



The transducers on the rotating plate generate vibration, with sinusoidal acceleration in two directions of the w direction. The direction w, as shown in Figure 2, is taken from a reference fixed at the center of gravity (CG) of the plate and which follows its orientation. This oscillation can be described, therefore, through the following equation:

$$w(t) = D\, sen(\omega t) \qquad (1)$$

where D is the amplitude, ω is the angular frequency, and w(t) is the displacement in w.

By rotating this plate at the same angular frequency as the vibration, the acceleration promoted by the oscillation of its internal components would become unidirectional in relation to the system (z direction). In other words, due to the rotation, the vibration would occur in only one direction, always being positive. Figure 2 also shows the presence of a second plate in the system operating in phase, in order to add unidirectional oscillatory accelerations and generate a constant acceleration in the z direction.

2.2 PHYSICAL STUDY

Since the engine brought by the patent addressed in this study presents itself as a reactionless engine, capable of propelling itself only from internal movements and without any interaction with its environment, it can be said that, like the others of the type , violates the principle of conservation of momentum. A more in-depth approach to the problem is not necessary, since the error in its driving principle can be easily demonstrated. The author of the patent correctly states that the harmonic oscillation of internal parts of the engine results from the exchange of kinetic and potential energy.

According to Shames (2003), for a given energy level of the system, the sum of these internal energies must be constant, disregarding any energy loss due to friction and damping. According to the principle of conservation of energy, these internal energies cannot leave the closed system, that is, they cannot be converted into energy external to the system from its interior. Equation 2 shows that the sum of kinetic energy (EC) and potential energy (EP) must be constant for a given energy state of a closed system.

$$EC + EP = cte \qquad (2)$$

Considerando, ainda, o motor de massa m totalmente em repouso em z em um momento $t = 0$, pode-se ter que seu momento linear p é nulo.

$$p(t) = m\dot{z}(0) = 0 \qquad (3)$$

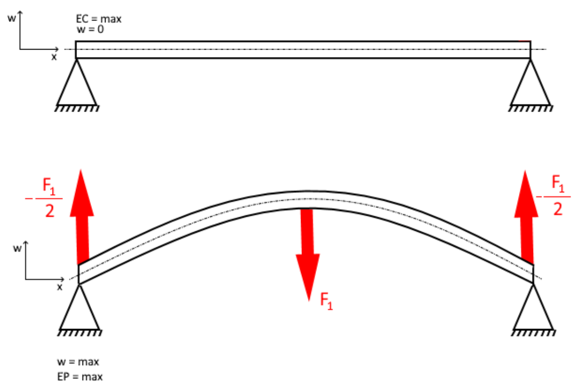
According to Newton's First Law, this initial momentum must remain constant over time unless an external force F_int is exerted on it. As already mentioned, the internal energy of the closed system cannot leave it, and there is no external force capable of changing its inertial state. In reaction engines (rockets), the propulsion is given only to a body of interest internal to the closed system, which ejects matter in the opposite direction to the intended movement. In both cases, the center of gravity of the system remains at the same point.

$$\sum F_{int} = 0 \quad (4)$$

Since the sum of forces internal to the closed system must be null, the appearance of an external propulsive force would violate Newton's Third Law due to the lack of an external reaction that is also opposite to the intended movement, and therefore the equipment is named "engine". without reaction” (or reactionless engine, in English). Thus, every propulsive force exerted on one part of the system is also exerted in the opposite direction on another part. As in the proposed model there is no ejection of matter, every force acting on the structure will result in a reaction in itself, without changing the position of the CG of the system in space. With this, the oscillatory movement produced will be stationary, and may be either deflection or translation of parts of the engine structure.

Disregarding the rotation, the motor oscillator can be approximated by a bi-supported beam, where each support is the bearings of its larger base, as shown in Figure 3. It shows the oscillator component (number 10) in the position of original equilibrium (above), in which no forces act and kinetic energy is maximum; and in the position of maximum deflection of the standing wave (below), in which all the kinetic energy is converted into potential energy and a restoring force arises resulting from the elastic property of the material, which creates a reaction in each of the bearings (numbered 13) , represented as supports.

Figure 3 – Scheme of the phenomenon of active action and reaction. Source: Prepared by the author.



When considering perfectly rigid materials, these forces would translate into requesting efforts in the contact region of the components. The rotation of the oscillator, as already stated, would not affect the position of the CG of the system, but would give more direction to these efforts.

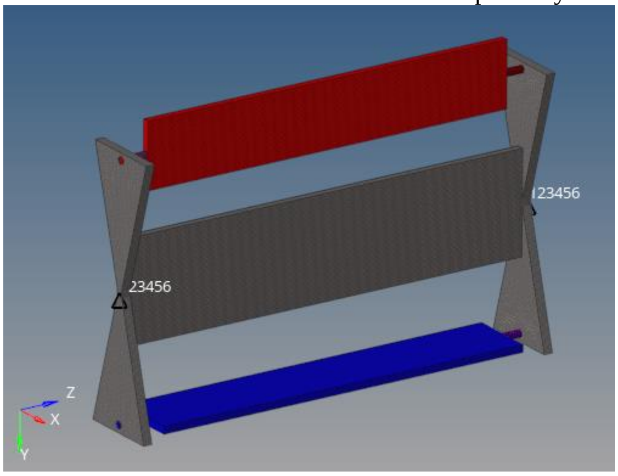
Also, centripetal (Fitzpatrick, 2011) and Coriolis (Apostolyuk, 2002) inertial forces would appear in the component, which in turn would lead to an additional expenditure of energy by the driving elements. Considering also that the physical damping of the structure dissipates energy in an irrecoverable way, the energy expenditure would be even greater. The proposal by Charette et al. (2006) of taking advantage of the system's resonance to obtain larger oscillation amplitudes would also have a negative effect on the structure, since, if not damped, increasing amplitudes would generate increasing internal stresses that would eventually lead to structural failure.

2.3 MODELING TO OBTAIN VIBRATION MODES

In order to observe the impacts of vibration on the natural frequency of the engine under analysis in its structural characteristics, the modal analysis is necessary. Thus, it is also possible to verify the oscillatory behavior of the components in three-dimensional space. In order to carry out a modal analysis using computational resources, a model was initially built in the computerized design program (CAD) SolidWorks®. For this, the preferable configuration shown in the patent was taken as a basis and, as dimensions are not informed, a size was arbitrated following the proportion of the components according to the drawings in Figures 1 and 2. Peripheral parts, such as transducers, gears, motor electrical and transducers, were disregarded in the model.

The model was then imported into HyperWorks® Hypermesh finite element analysis (FEA) software for mesh generation, property definition, and analysis. Initially, it is only of interest to analyze the vibration behavior of the engine structure as a whole in its normal vibration modes. For this, models were created with two-dimensional meshes (mesh 1) of the shell type (shell) with square and triangular elements (trias) and models with three-dimensional meshes (mesh 2) with tetrahedral elements (tetras), both preferably with a side of 2 mm. The analysis using meshes 1 and 2 allows the comparison of the result between them. This modeling was done using the software's default mesh material (steel) and quality parameters. In mesh 2, between the axes of the rotating plates and each hole a contact surface was created, allowing sliding and rotation, while in mesh 1 the connection was made using rigid elements.

Figure 4 – Finite element mesh model. Source: Prepared by the author.



The modal analysis in HyperWorks® Hypermesh is performed through an algorithm that employs the Lanczos method, characterized by the EIGRL property in the program. In this way, the eigenvalues are obtained for each mode of vibration, each of which, in turn, is associated with a degree of freedom (DOF). This type of analysis can be carried out, typically, in a restricted model, that is, with boundary conditions or totally free, without boundary conditions, the latter also presenting rigid body vibration modes. At first, the modal analysis of the structure of mesh 2 with and without freedom restriction was carried out, which was done using single point constraints, in order to obtain 10 vibration modes between 0 and 50 Hz.

Finally, it is important to emphasize that the piezoelectric transducers present in the plates were not included in the modeling, and that the material (steel) considered in the model is purely structural. The objective of the study is to analyze the behavior of the structure subjected to vibration, preferably at natural frequencies (Charette, et al. 2006), in order to complement the physical analysis. With that, the form of vibration generation is irrelevant, as well as the associated energy expenditure. In short, piezoelectrics were disregarded for the sake of simplicity and because they are unnecessary for understanding the physical phenomenon of structure vibration. Therefore, only the normal modes of the mechanical system obtained by software were observed, not limited to the type of vibration source, intensity of energy supplied and position of the source.

4 RESULTS

The comparison of results is shown in Table 1 and frequencies associated with rigid body vibration (< 1 Hz and occurring throughout the model structure) were disregarded.

Table 1 - Frequencies of the main vibration modes obtained

Mode	Without restriction	With restriction
1	3,365311E+01	2,970205E+01
2	3,003663E+01	3,218460E+01

The two modes of vibration in each case are related to the oscillatory response in each of the rotating plates. Then, in order to verify eventual discrepancies in the results between different types of meshes and to observe the behavior of the structure of the model in a more simplified approach, the modal analysis was redone for a model of mesh 1 without restriction.

The results obtained for this model were non-rigid vibration modes at 38.24 Hz, 41.45 Hz and 43.70 Hz, shown in Figures 5, 6 and 7, respectively. It can be seen that these frequencies are relatively close to those obtained for the three-dimensional model, with a difference of about 10 Hz and one more mode. It is possible to see that the deformations arising from the vibration are symmetrical in the system, as predicted.

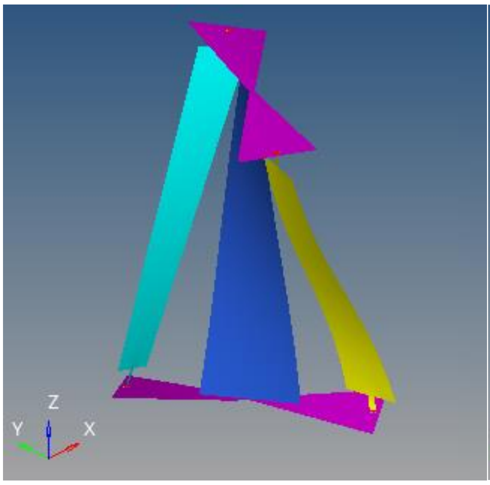


Figure 5 - Deformation at 38.24 Hz

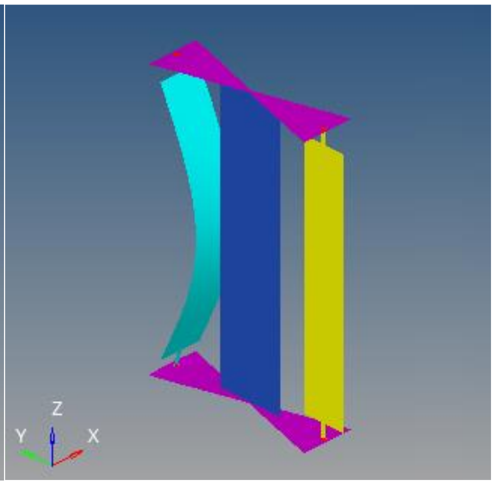


Figure 6 - Deformation at 41.45 Hz

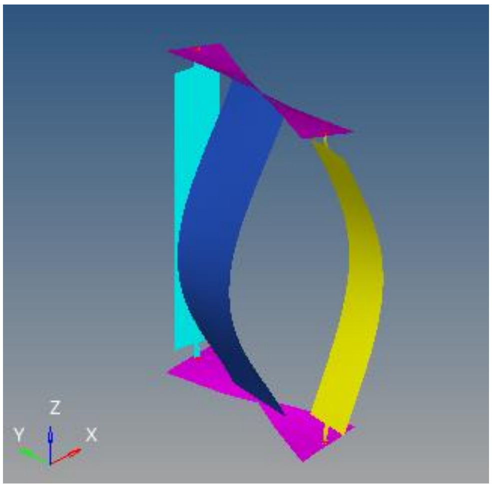
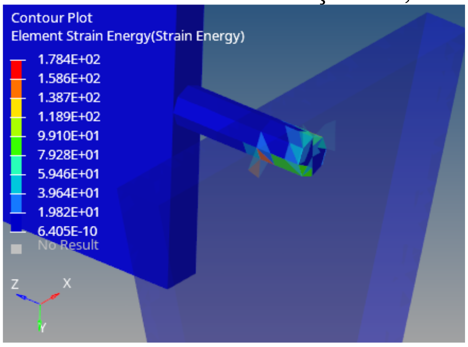


Figure 7 - Deformation at 43.70 Hz
Source: Prepared by the author.

Bearing in mind the hypothesis of the creation of internal tensions between the components caused by the increase of energy in the system, a certain deepening of the subject is justified. The analysis of the finite element strain energy (ESE) allows identifying the regions of the model that tend to suffer greater strain stress when subjected to vibration at a natural frequency.

Since the strain energy of the components can be more easily visualized in the contact between them, the analysis was performed on the mesh model 1 without restrictions. Again, a qualitative understanding of the results is most valuable for understanding the phenomenon. The results obtained are shown in Figure 8.

Figura 8 – Concentração de *ESE* em um mancal com vibração a 30,0 Hz. Fonte: Elaborada pelo autor.



5 DISCUSSION OF RESULTS

A variety of results were presented from finite element analysis in different models used. For the two-dimensional mesh, normal vibration modes close to those of the three-dimensional mesh were obtained. Taking into account the size and objective of the present study, the discrepancies obtained from the two approaches can be considered acceptable. Still, the proximity between the frequency values guarantees a certain level of reliability, which is fully sufficient to provide qualitative results that support the argument presented here. The differences between the mesh elements and between the boundary conditions of the models can be pointed out as sources of this divergence.

The two-dimensional modal analysis and the three-dimensional element strain energy stand out, whose presented data complement each other. With the modal analysis, in turn, it was possible to observe the elastic behavior of the structure of the device and its relationship with conservation of momentum, as previously mentioned. Thus, any deformation or translation of part of the system generated a symmetrical reaction in another part, thus maintaining the total amount of momentum of the system. Once based on this principle, the center of mass of the system is not expected to move in space, as a consequence of the absence of pulling forces.

The dependence or independence of the mesh has a great impact on the result. It was possible to observe that DOF restrictions placed on the models generate, mainly, rigid body vibration modes (at low frequencies, and that apply homogeneously throughout the system). Another effect is the elimination of the internal reaction to deformation through the translation of another component, which is the case in Figure 6.

The high concentration of deformation energy in the contacts of the device parts shows that the oscillatory energy supplied to the system does not leave its interior, converting itself into stresses. In reality, these tensions, deformations and translations of part of the system are different manifestations of the same reaction forces that will always be present with the oscillation, regardless of the existing linear or angular momentum and its orientation in that space. In short, when considering the whole device as a closed system, as proposed, there is no alteration of its initial moment and neither does true displacement occur.

It is important to make it clear that this study aims to qualitatively analyze the behavior of the proposed mechanical system when subjected to vibration in order to complement the physical formulation made. In this sense, the meshes, with and without independence, three-dimensional and two-dimensional, provided discrepant results, but which still make it possible to observe very similar behaviors, expected and sufficient for this case.

6 CONCLUSIONS

In the present study, a bibliographic review and formulation of the physical phenomenon about the propulsion obtained through the vibration of structures was carried out, as proposed by Charette (2006) in his patent. Through this research, it was possible to frame the proposal under analysis in a category of reactionless engines, which have been presented in different configurations and with more or less complex operating principles by several inventors in the last decades. Essentially, the whole idea of reactionless engines is based on converting forces internal to forces external to the system to generate motion, but that violates the fundamental principle of conservation of momentum, so as to doom any such inventions to failure.

Like attempts to obtain perpetual motion, attempts to circumvent Newton's Third Law result from ignorance or misunderstanding of physics on the part of its authors. Nevertheless, these attempts still appear sporadically in articles and patents, gaining media attention and even attracting funding from renowned institutions such as NASA. With this in mind, it is essential to test such proposals in order to demonstrate, whenever necessary, their unfeasibility. This study intends to fulfill this function by analyzing the driving principle by oscillation that was proposed. To this end, a computational modeling and analysis of the studied engine was also carried out, which validated the already expected results for the theme, in line with the review of other authors.

Given the above, it is essential to clearly state that the propulsion generated by the vibratory response of structures proved to be unfeasible, especially for application in space vehicles. It can also be assumed that even with interaction with a medium in such a way that the device could propel itself, such an energy expenditure would make its application in other contexts unfeasible.

However, oscillatory propulsion is not entirely unfeasible, nor is it bound to be less efficient in open systems. It is notorious that oscillations combined with the variation of drag produced as a function of direction are widely used in the animal kingdom as a form of unidirectional propulsion in a physical environment and being the product of a long process of evolutionary refinement. Examples include the movement of fish fins, the wings of birds and insects, and the bodies of caterpillars and earthworms. It is possible that, eventually, some form of similar displacement will prove preferable to current forms of land, sea or air displacement. Therefore, research on this topic is encouraged.

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REFERENCES

Apostolyuk, V. (2002), “Coriolis vibratory gyroscopes: Theory and design”, 1ª ed, *Spirnger*, Cham.

Charette, F., Croteau, L. (2006), *Propulsion force produced by vibrational response of structures*, US Patent Application Publication nº 2006/0169073, Canton.

Dean, N. L. (1959), *System for converting rotary motion into unidirectional motion*, US Patent Application Publication nº 1959/2886976, Washington.

Fitzpatrick, R. (2011), *Rotational Stability*, University of Texas. Disponível em <https://farside.ph.utexas.edu/teaching/336k/Newtonhtml/node71.html> . Acesso em 30 jun. 2022.

Loukanov, I. (2015), “Vibration propulsion of a mobile robot”, *IOSR Journal of Mechanical and Civil Engineering*, Botswana, vol. 12, 23-33.

Millis, M. (2004), “Prospects for breakthrough propulsion from physics”, *NASA Conference on Evolvable Hardware*, Seattle.

Millis, M. (2005), “Assessing potential propulsion breakthroughs”, *New Trends in Astrodynamics and Applications II*, Princeton.

dos Santos, M.T. (2022), “*Hierarchical Models for Aircraft Joint Analyses*”, Tese de Doutorado, UFMG, Belo Horizonte.

Shames, I. (2003), “Dinâmica mecânica para engenharia”, 4ª ed, *Pearson*, New Jersey.

Siegel, E. (2019), *For the last time, no, a NASA engineer has not broken physics with an impossible engine*, Forbes. Disponível em <https://www.forbes.com/sites/startswithabang/2019/10/17/for-the-last-time-no-a-nasa-engineer-has-not-broken-physics-with-an-impossible-engine/?sh=2cd3628727bf> . Acesso em 20 jul. 2022.

Sutton, G., Biblarz, O. (2010), “Rocket propulsion elements”, 8ª ed, *John Wiley & Sons*, New Jersey.

Tajmar, M. et al. (2021), “Thrust measurements of microwave-superconducting and laser-type EmDrives”, *72nd International Astronautical Congress*, Dubai.