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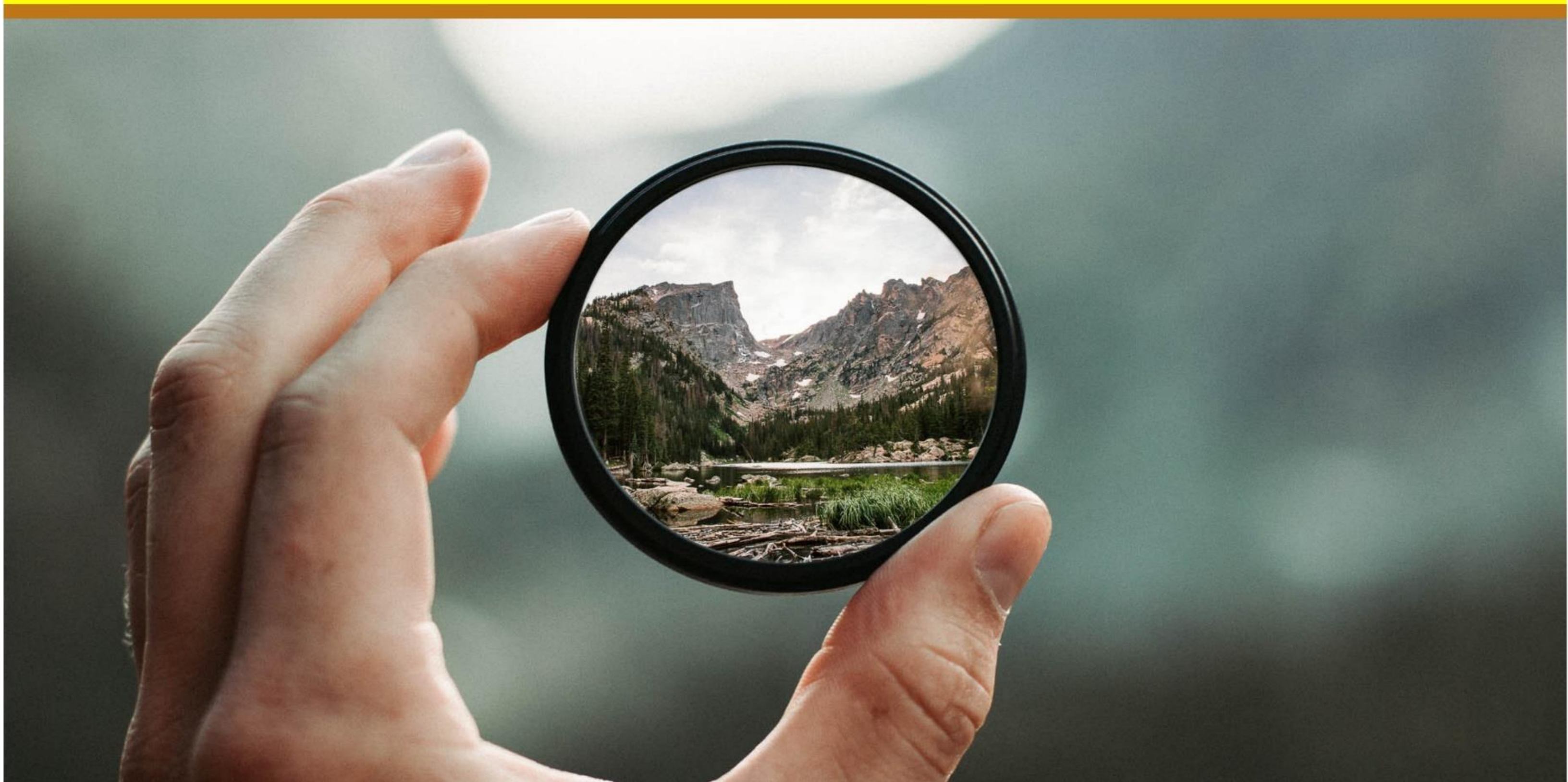

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Contenido

Editorial

Por: M.Sc. Ing. Jhonatan Paolo Tovar Soto

La investigación es parte fundamental de la formación y preparación de un profesional y es un eslabón que se debe construir con el aporte multidisciplinario de diversas ramas del saber. La colectividad y la socialización del conocimiento es un reto que debe desafiar el mundo académico, ya sea por las adversidades al momento de hacer investigación, o por el bajo interés por promover un pensamiento crítico y que explore en su complejidad el mundo.

Escribir como parte inherente del proceso de investigación no es tan sólo desplegar palabras, tablas e imágenes para plasmar una idea, sino que, es un espacio en donde el investigador puede darse libertad para exponer su punto de vista de manera rigurosa, estructurada y por supuesto, con un método adecuado que explora una idea. Sin embargo, la academia nos ha maniatado a comercializar las ideas de la investigación, promoviendo así una idea falsa de socialización y circulación de conocimiento, en donde quien tenga más citaciones es mejor investigador, o quien tenga más artículos merece más reconocimiento.

No se puede negar que las métricas de medición de la calidad investigativa tienden a volverse una competencia feroz por obtener un mejor puesto, por obtener mejor remuneración y por tener un reconocimiento como una figura "pop", explotando el conocimiento como si fuera un producto sin sentido alguno y que sólo se realiza para generar un ambiente de mejora y falso bienestar. En ese camino se ve envuelto el investigador, experimental o teórico, y se estrella con un laberinto en donde el que mejor posibilidad de mercado tenga sale más rápido al otro costado (Luchilo, 2019).

Sin embargo, las revistas intentan mejorar sus estándares verificando de manera plausible los procesos de selección y garantizan en cierta medida que no exista un monopolio de publicaciones, pero, el fenómeno actual es que el investigador muchas veces escribe sólo por producir, herencia propia del sistema capitalista que monetiza cada acción de la naturaleza y, por tanto, el negocio no se mueve si no se tiene los mejores productos. Así mismo, se tiene un comportamiento similar en las publicaciones científicas y en las editoriales, que tergiversan la verdadera tarea de la socialización del conocimiento a su concepto personal, banal y ambiguo, en el cual lo que más prima es tener un conjunto de productos para el mejor postor, y así ser más visible, como si se tratase de un mercado de gran superficie que compite con sus adversarios para ver quien da el producto con menor precio y una supuesta "mejor calidad" (Puentes-Cala, 2019).

Por ello, la intención de un artículo no debería ser para generar un reconocimiento personal, o para validar de manera ególatra el conocimiento, sino que, por el contrario, debería ser la apertura para que ese conocimiento se socialice de manera real y no por métricas de calidad que muchas veces están sesgadas, y no contempla a la otredad como algo valioso para la sociedad, sino que lo desecha porque no piensa como el común.

Si la validez de una investigación se mide por reconocimiento y no por resultados, el sistema de investigación universal va a colapsar, pero si, por el contrario, generamos una verdadera socialización de conocimiento multidisciplinario, no importa si se publica o no los resultados, lo que realmente vale la pena es dar soluciones y dar posibilidades para que, aplicando ciertos fundamentos o experimentos, no quede en simple papel nuestras ideas.

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Hidroituango: How to Reach Adaptive Management to Recover Part of the Ecosystem Connectivity in the Cauca River Basin in Colombia

Julián Camilo Bocanegra Gutiérrez[1]

Abstract

With the worldwide rapid population increase seen in the past century, the electric energy demand increased also dramatically. In Colombia this led to a boom in the construction of hydroelectric plants in the late 60ies. Today, some accidents while the construction of the biggest plant in the country, Hidroituango, revealed a series of errors made through all those years and opened up a discussion on how to address management focused on the environmental protection of riverine systems in this and similar projects in the Country. Adaptive management has proven to be an effective alternative when giving solutions to this kind of problems. Successful implementation cases have been found in the Colorado and Columbia rivers (In the U.S.A) among others. Similar adaptive management processes can be applied in Colombia. However, there must be considered many local variables as well as political, social, economic and some others interests and complications.

Key Words: Cauca river, ecosystem service, electrical energy, energetic project, environmental remediation, upstream and downstream flow.

Hidroituango: Cómo alcanzar el manejo adaptativo para recuperar parte de la conectividad ecosistémica en la cuenca del río Cauca en Colombia

Resumen

Tras el rápido aumento de la población mundial observado en el último siglo, se vio también un aumento dramático en la demanda de energía eléctrica. En Colombia, particularmente, esto llevó a un auge en la construcción de plantas y represas hidroeléctricas a finales de la década de los 60. Hoy en día, algunos accidentes durante la construcción de la planta más grande del país, Hidroituango, revelaron una serie de errores cometidos a lo largo de todos esos años y abrieron un debate sobre cómo abordar la gestión con un enfoque en la conservación ambiental de los sistemas fluviales en este y otros proyectos similares en el país. La gestión adaptativa ha demostrado ser una alternativa eficaz a la hora de dar soluciones a este tipo de problemas. Al respecto, se han encontrado casos exitosos de implementación en los ríos Colorado y Columbia (en los EE. UU.) entre otros, que podrían llegar a ser aplicados en Colombia de manera similar. Sin embargo, es necesario considerar muchas variables locales, así como intereses personales e implicaciones políticas, sociales y económicas, entre otras.

Palabras clave: Río Cauca, servicios ecosistémicos, energía eléctrica, proyecto energético, remediación ambiental, flujo aguas arriba y aguas abajo.

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Introduction

In April and May 2018, the biggest hydropower project in the Colombian history, "Hidroituango", went through a series of problems after constructive errors and extreme rainfall events. The failure of the dam put the entire structural integrity at risk, which could cause a flood releasing more than 2 billion cubic meters of water and soil. This would trigger an immense environmental and social catastrophe which some experts even compare to the Chernobyl disaster (Portafolio, 2018).

Furthermore, following the events described, between January and February 2019, the gates had to be closed to check the structural integrity of the dam. This entailed an extreme reduction of the river flow and the occurrence of the lowest level ever measured. Consequently, it also caused an incalculable mortality of various fish species, and affected thousands of people living downstream (Miranda, 2019).

In recent years, many countries around the world have been working on finding solutions to deal with similar problems in riverine systems. One approach to identify the equilibrium between the necessary use and management of water resources is called "adaptive management" and it is described as a learning by doing process. The main objective of adaptive management is to address river restauration by using different approaches and management techniques overtime and to ensure the essential ecosystem services of riverine systems.

The different instances surrounding Hidroituango project opened up a broad discussion about hydropower projects management in Colombia. The central question asked is then: How can Colombia address an adaptive management strategy for barrages soon?

The objective of the present document is to analyze the selected study case, and the problems surrounding it. Moreover, similar cases and possible solutions around the world are considered, considering the local implications and applicability difficulties. The Section 1 is an introduction, it describes the problem and justifies the necessity to find an urgent solution. Section 2 presents the pools of literature, where most of the information for this research was obtained from. The 3rd presents a description of the study area, focusing on the river basin, the riverine system and the availability, accessibility, and water quality. The 4th section shows some literature research on the environmental implications of hydroelectric projects and mainly large dams. Whereas the section 5 presents similar cases around the world, and how the adaptive management was successfully applied in some of them. Finally, the conclusion section discusses the possibility of implementing similar adaptive management strategies and which kind of problems can be found in the country.

Pools of literature

The debate around Hidroituango project attracted not only the attention of experts and researchers, but also the one of public and media. For this reason, a large amount of journalistic, academic, social, political, scientific, and environmental reports has been written. Although this project is the case of study for the present research, the main objective of this is to find techniques of how to improve the management of dammed river basins, based on analyzing the errors made in the past when constructing hydropower plants in Colombia. Possible new solutions are proposed based on existent research done by international academic institutions. Additionally, local governmental institutions, such as the National Agency for Environmental Licenses (ANLA), and the National Institute of Hydrology and Meteorology (IDEAM) provide enough information regarding technical considerations and legal framework.

Description of the River Basin

Colombia is located in the Northwest of South America and is the only country in the subcontinent with coasts in two oceans, the Pacific, and the Atlantic. Additionally, the relatively high precipitation (1000 mm/year in the Atlantic, more than 7000 mm/year in the Pacific and 3000 mm/year in average) and mountainous relief makes the country one of the most privileged in matter of water resources. In 2014 Colombia was positioned by the FAO (Food and Agriculture Organization of the United Nations) as the sixth country with most availability of renewal water resources, with around 2300x10^9 m³/yr (FAO Water, 2015). Regarding this, the IDEAM, in its 2014 ENA (National Water Report) reported that 271x10^9 m³/yr (approx. 12% of the country total), correspond to the Cauca-Magdalena basin (IDEAM, 2015). This, added to that the biggest urban agglomerations in the country lie in the watershed influence area, makes this basin the most appropriate to build large hydropower plants.

The Cauca river is the second most important one in the country and it flows across 1350 Km from the southern Colombian Andes to the North, where it discharges in average 3000 m³/s in the Magdalena river. Along its course, part of its water is used for agricultural purposes, water supply and gold mining. These activities cause the discharge of unknown amounts of mercury into the waters, what constitutes it as one of the most pollutant activities in the river. Furthermore, it receives the wastewater discharges from more than 10 million people, 20% of Colombia population (Espinel & Valencia, 2007) and four big dams are constructed in it (See figure 1).

Figure 1. Main dams in Colombia in 2017.
Source: Modified, from Ríos Vivos (2018).

Until 2007, 80% of the energy in Colombia was generated by hydropower plants, most of these plants were conceived, designed and built in the 70ies. Hidroituango was part of this plan, however, due to its technical complexity, the plant did not start its construction until 2010 (Mariño, 2007; El Espectador, 2018). It plans to generate 2400 MW of energy, damming $2.2x10^9$ m³ of water, with a 220 m height and 560 m long barrier. It is built in the lower part of the Cauca river basin, where the average flow is around 2000 m³/s and the ecological flow is 450 m³/s and the main economic activity in the influence zone is fishery. The ecological flow is defined as the minimum discharge a stream must have to ensure the preservation of the species that depend on it (Vásquez, 2019).

Impacts of dams in riverine Ecosystems

The environmental and social impacts of hydropower projects have been largely discussed in the last half century, and from this discussion many different impacts have been addressed. Most of the researchers agree when saying the most important negative impact is in the river connectivity. Rivers are complex corridors for all kind of components of the environment. When a dam is constructed it not only cuts this corridor for animal and vegetal species, but also affects more complex dynamics between ecosystems.

Among these can be mentioned the water and energy cycles, the sediment and the nutrients transport (McCartney & King, 2001). If more than one dam is built in the same river, as in the Cauca river case, this problem becomes even more serious. Regarding this, McCartney and King present a pyramidal model where the impacts are presented into three different hierarchies, showing the main environmental issues that must be considered when planning a hydropower project (see Figure 2). The authors also remark that the interacting processes increase from first to third order impacts and as they increase, they are more difficult to predict due to the complexity of the relations.

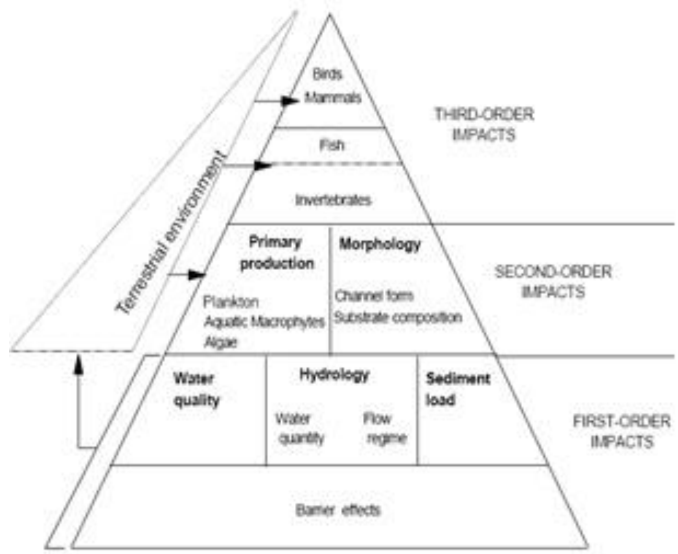

Figure 2. Impact of dams in river ecosystems.
Source: Adapted from McCartney & King (2001).

In Colombia, every hydropower project is involved in producing each of the mentioned environmental impacts. Additionally, most of them are surrounded by social problems such as illegal occupation of protected areas, ancient areas occupied by indigenous communities or conflict of interests. Furthermore, there has never been an approximation, from part of the plant owners (government) to manage such issues, and when the projects reach their useful life, they are just abandoned without any kind of management. Therefore, it is imperative to come up with ideas on how to manage the plants to, at least, recover part of the ecosystems in the Cauca river basin.

Similar cases and feasible solutions

Determine the best management practice, is never an easy task. While some can state that restoring riverine systems to their natural conditions is always the best alternative (renaturation), others hold that it is impossible to revoke the ecological damage induced by this kind of projects and propose to simply avoid any intervention in the zone (benign neglect). Finally, some other perspectives stay in a point in between. Furthermore, there can be management measures supporting each of these perspectives. Therefore, some authors agree to say adaptive management is an iterative process, further than one (or more) single alternative of management. This means that a compendium of ideas from different points of view are discussed and, some of them, tested, in order to come up with alternatives which are re-evaluated in a cycle.

Wieringa and Morton (1996) indicate that an "Adaptive Management Work Group" should be created with representatives of all parties involved in a project. It is expected that in every project, each of these parties has a different interest, either economic, political, ecological or other, therefore it is so important to analyze and consider all the variables surrounding them (see Figure 3).

Another crucial part of the work group is the technical, composed by the scientific community (scientists, universities, institutes, etc.), which is the one in charge of presenting the best alternatives of solution considering the interests of the parties, and the main objective of the whole group. Experts agree that this main objective is the core of the adaptive management process, since all the ideas and decision are taken in order to accomplish this achievement. When selecting management practices, many objectives can be considered, such as, for example, the recovery of sand in the riverbanks downstream a dam, or the protection of certain species affected by the loss of connectivity, but just one of those should be selected as the priority. The proposed alternatives will all point to this direction, while also trying to reach the secondary goals selected after the trade of agreements between the parties and the scientific recommendations.

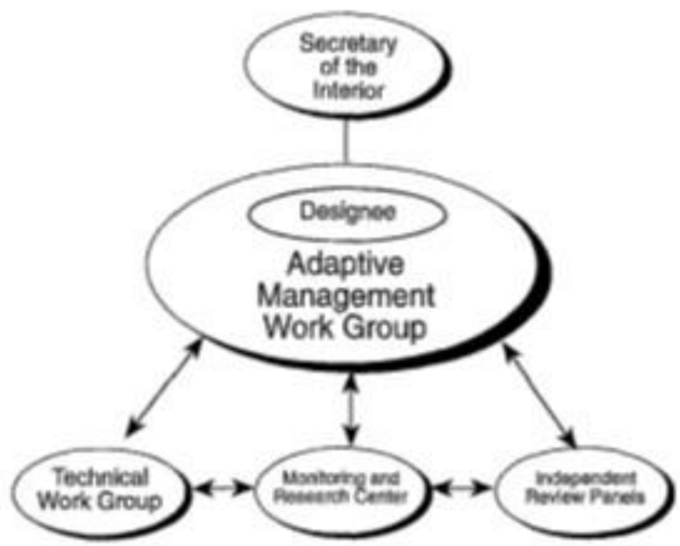

Figure 3. Organizational estructure of the adaptive management program.
Source: Adapted from Wieringa & Morton (1996).

Finally, the whole group should be regulated by an entity which ensures the taking of the best decisions. Particularly, in hydropower projects it is important to understand that the most significant changes in the riverine system appear due to existence of the dam rather than how it is operated. Modifying the operation can certainly change the characteristics of the effect, but never will it be eliminated while the dam still exists.

In the other hand, in most of the cases, the dam itself creates new environmental conditions downstream, like the change on the riparian zone vegetation, or the species distribution, among others. In these cases, the elimination of the dam might not be either the best management solution. For these reasons, a successful adaptive management program must recognize the presence of a dam and the changes it entails and work towards managing the downstream ecological community for mutually established objectives (Wieringa & Morton, 1996).

One of the pioneers and most widely known cases of adaptive management program applied to hydropower, is the one in the Glen Canyon dam in the Colorado river in United States. It is specially considered in this research because it shares similar characteristics with Hidroituango (Table 1).

Table 1. Characteristics of Glen Canyon Dam and Hidroituango.

	Glen Canyon Dam	Hidroituango
Installed Capacity (MW)	1320	2400
Height (m)	220	220
Length (m)	480	560
Volume (m^2)	33×10^9	2.2×10^9

Source: Adapted from U.S. Bureau of Reclamation (2009).

The dam was completed in 1963, and through decades many public and private stated that the dam was hardly affecting the environment downstream. A series of environmental impact states (EIS) and a public law to protect the Grand Canyon created in 1992, lead to the origin of the Glen Canyon Adaptive Management Work Group (AMWG) focused on protecting and mitigating adverse impacts to improve the values of Grand Canyon and Glen Canyon. The group is, among others, constituted by representatives US Fish and Wildlife Service, Secretary of Energy, State governors, National Parks, and Native American tribes (US Bureau of Reclamation, 2019).

In its first years the Glen Canyon AMWG found that one of the biggest effects of the dam on the river, was the change in sediment charge, which used to be 57 million tons/year before 1963. This, added to the seasonal temperature variations, kept a constant renewed amount of sediments as well as natural beaches. With the construction of the dam the sediment amount changed drastically, and the beaches were practically lost. Scientists found that this lost affected the amount of a native fish (the humpback chub) by more than 70%. This because the sandbars and beaches used to provide sheltered backwaters for the humpback chub fry. After this finding, the protection of this native fish, by restoring the sediment flow, became the main objective of the work group (Powell, 2002).

The first management decision made by the AMWG was tested on March 1996, when the bypass tubes were opened to let 1290 m^3 of water flow and flood the downstream area for seven days. Although the initial idea was to mobilize the sediments deposited upstream the dam and restore the eroded beaches, the results were not as expected. While at first sight, the experiment seemed to be successful, after two months the new beaches started to be eroded again and, after one year the condition downstream was the same as before.

This "unsuccessful" experiment was interpreted as a big fail by most of the project parties, mainly by the Power Administration, which lost lots of money by stopping the energy production to allow the experiment realization. However, the technical group got an important understanding on how the sediments behave in this part of the river, and how further experiments should be carried out (Powell, 2002). In fact, nowadays, this experiment is considered as the most important step to improve the management practices applied afterwards in successful experiments (Figure 4) (National Park Service, 2018).

In 2016, 20 years after the first experiment, a Long Term Experimental and Management Plan (LTEMP) was created. It provides framework and an operation procedure to perform high flow experiments (HFE) from 2016 to 2036, based on the knowledge gained from the experiments and analysis done in 1996, 2004, 2008, 2012, 2013, 2014 and 2016 (National Park Service, 2018).

After the successful results obtained in the Glen Canyon dam, some other adaptive management groups were created. One of this was applied by the Columbia River Basin Fish and Wildlife Program, in general terms, the objective in this case differed widely from the one in the Glen Canyon dam. Since in the Columbia River case, the focus of the program is to restore paths for the salmon and some other fish species, without considering the sediment dynamics or another environmental issues. Moreover, the interested parties and the conflicts of interest act in a different manner as in the first example. However, the adaptive management model was applied in a similar way and proved the possibility to address valid and feasible management techniques (Wieringa & Morton, 1996).

(a)

(b)

Figure 4. 4. 56 Km downstream situation (a) before and (b) after 2008 High flow experiment.
Source: Adapted from National Park Service (2018).

Following this tendency, an adaptive management group was created in the Morelos Dam, in the same Colorado river, downstream the Glen Canyon. The selected management practice was, also flooding the area downstream and it was applied in March 2014. The main objective in this case was recover previous habitats to attract different species of birds which were diminished after the construction of the dam. Although the results of this experiment still in analysis and discussion, this case is an example of a functional adaptive management program in areas with high political and social difficulties as in the Colombian cases. In addition, the Morelos dam represents an example for a group made between different countries representatives, since it is a transboundary issue between United States and Mexico (Witze, 2014).

Conclusion

Adaptive management can be recognized as one feasible alternative when trying to find management practices to solve environmental problems in riverine systems affected by dams. In addition, Hidroituango, other hydropower projects in Colombia, and the Cauca river basin, meet the requirements to be considered in such projects, since the environmental and social problems related to them are proven, and need prompt solutions.

However, as shown in this research, adaptive management programs, need of some guidelines to be followed. At first, the involved parties should have the disposition to discuss and "negotiate" the terms to address the best management solutions. Nevertheless, most of the parties in the country (Society, electricity companies, politicians, etc.) are not willing to give in to their own interests and trade agreements that may bring economical loses. In addition, corruption has always been a limitation since political decisions are historically been directly affected by interests of private companies, ignoring the environmental organizations or civil population.

The financial problem represents another limitation to the Colombian case, since the government may not count with the resources to carry out such a program, considering the can extend even to decades. The governmental entities should understand the urgency to apply management technics in the riverine systems in the country, so it can be possible to find alternative economic sources.

Although many other difficulties can be found in the way, it is widely known that no project is free of risks and difficulties. The scientific, academic, and journalistic communities in the country should take advantage of this study case to impulse the government on giving the first step to adaptive management. So, in the medium term, Colombia can have riverine systems more adequate to benefit both the ecosystems and the different groups of people who take advantage of their resources.

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A review of the current state of Pico and Nanosatellites: some applications in Latin America and other regions of the world

Jhonatan P. Tovar Soto[1], Carlos F. Pareja Figueredo[2], Jonathan S. Vargas Cañón[3] y Luis C. Gutiérrez Martínez[4].

Abstract

Small satellites have been a fundamental factor in the constant growth of space technologies from 60 years ago. Since the space war began during the Cold War, thousands of satellites have been put into low orbit to carry out radio frequency applications, analysis and sending satellite images of the earth, joint research tasks for space exploration on artificial satellites, as well as missions in other astronomical bodies. By 2019, more than 50 countries around the world have put into orbit at least 1 small satellite, which accounts for the persistent work to increase the applications of these devices and the need make known the potential of these elements for research and for technological applications. Due to this, the present article was based on the documentary search to carry out a review of the current state of small satellites, and especially of nano and pico satellites. The research defined 3 phases for the writing of this document: choice of databases and search engines according to the research area, use of selection algorithms using logical discrimination chains and, finally, extensive analysis of the chosen documents for the writing of the article. All the information was presented through statistical graphs with detailed information from years of publication, language, region, terms, and areas the greatest research of small satellites. It was found that CubeSat and CanSat are the types of nano and pico satellite with the greatest predilection for research by universities and technological institutions, given its low cost and in most cases its easy implementation.

Keywords: Artificial satellites, low earth orbit satellites, space technology, small satellites.

Una revisión al estado actual de Pico y Nano satélites: algunas aplicaciones en América Latina y otras regiones del mundo

Resumen

Los pequeños satélites han sido un factor fundamental para el constante crecimiento de las tecnologías espaciales durante los últimos 60 años. Desde que se inició la guerra espacial durante la guerra fría, miles de satélites han sido puestos en órbita baja para realizar tareas de radiofrecuencia, análisis y envío de imágenes satelitales de la tierra, tareas conjuntas de investigación para la exploración espacial en satélites artificiales, así como misiones en otros cuerpos del espacio exterior. Para el año 2019 más de 50 países en todo el mundo han puesto en órbita al menos 1 pequeño satélite, lo que da cuenta del trabajo persistente por incrementar las aplicaciones de estos dispositivos y la necesidad dar a conocer el potencial de estos elementos para la investigación y para aplicaciones tecnológicas. A partir de esto, el presente artículo se fundamentó en la búsqueda documental para realizar una revisión del estado actual de los pequeños satélites, y en especial de los nano y pico satélites. La investigación definió 3 fases para la escritura de este documento: elección de bases de datos y motores de búsqueda acorde al área de investigación,

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uso de algoritmos de selección mediante cadenas lógicas de discriminación y, por último, el análisis en extenso de los documentos elegidos para la escritura del artículo. Toda la información es presentada mediante gráficos estadísticos con información puntualizada de años de publicación, idioma, región, términos y áreas de mayor investigación de pequeños satélites. Se encontró que los CubeSat y CanSat son los tipos de nano y pico satélites de mayor predilección para realizar investigación desde las universidades e instituciones tecnológicas, dado su bajo costo y en la mayoría de los casos su fácil implementación.

Palabras clave: Satélite artificial, satélites de órbita baja terrestre, tecnología espacial, pequeños satélites.

Introduction

Modern society is going through an in-flection point in its history where information technologies and the new digital age are important for their daily activities. The conception of a society where there is a transversely of the new technological trends to solve personal and collective needs is a reality (Xu & Feng, 2017).

The potential found in communication technologies has conceived a new way of relationship between different people and has shown that over the years, the fusion between technology and society is something that could not be stopped. Thus, we find applications dedicated to the analysis of information from our environment, to the study of the variables involved in the management of metropolitan areas, to the collection of data that involves personal interaction on social networks and the performance of statis-tics from Geo referenced images (Li et al., 2017). This all information in the present it was not had possible without the help of a device that has been present for many decades but, despite its great im-portance in history, it is something particularly unknown. This is the case of satellites that are widely used for communications applications, and that are not only focused on an exclusive use of space science.

One of the main trends in recent years has been the interest in small satellites and especially CubeSat [3]. Its implementation has allowed obtaining specific data and transmitting information like other larger satellites [4]. In particular, small satellites have always been present throughout the development of technologies associated with space, however, there is another group of small satellites additionally nanosatellites (where CubeSat is classified), which in the last 15 years have given an opening to a greater implementation of space technologies: the Pico Satellites [5].

This research is a review of the current state of small satellites and their applications. A systematic search for information was carried out, identifying the most relevant contributions of the projects in Latin America and other regions of the world. Finally, this article is intended to be a fundamental input for researchers and people interested in the application of this type of technology, to address the issue with greater timeliness and with a differential approach, in order to promote the use of small satellites from different areas of knowledge.

Methodology

The research methodology of this article is of type exploratory, which was done through recognized databases. The systematic review was divided into 3 criteria: (1) identification of search engines and databases, (2) synthesis and selection of key terms to discriminate documents, and (3) analysis of information and preparation of the document.

In the first part, the relevant documents from the scientific databases are listed, present in Google Scholar, IEEE Xplore, Springer, Scopus and SciELO. The articles found were analyze with the grouping technique, and they were identified the terms with the highest repetition and validity related to pico and nanosatellite applications. The selection of journals within these databases was made through the SCImago Journal Rank, identifying those that provide contributions in aeronautical engineering and those contain specific topics of space applications, especially the technologies applied to space design and production of nano and pico satellites. To determine the articles with the greatest contribution to the re-search, concepts and keywords were related in the search strings of the data-bases, thus evidencing the following relevant terms: spatial applications, Pico satellites, Nano satellites, CanSat technology, CubeSat technology and small satellites.

The discrimination of the documentation for its selection was made from the following considerations:

- Was the publication written between 2014 and 2019?
- Is the document part of a scientific journal, is it a conference paper, is it a research paper in undergraduate or post-graduate, or is it a publication on space technology and small satellites?

Once the documents are identified, their inclusion and rejection were made based on the following questions:

- Does the document identify technologies applied to space tasks and within its content mention the methodology applied to carry out this development?
- Does the document validate information from previous years and show adequate state of the art information in applications of small satellites focused mainly on Pico and nano satellites?

Based on the above, a total of 370 differentiated documents that meet the initial requirements were identified and, using the rejection criteria, the 50 most relevant for this review were chosen.

Finally, an analysis of the most recent applications of small satellites was carried out in a discriminatory way, to subsequently identify the advances in recent years of Pico and Nano satellites with special emphasis on Latin America and lastly to mention some possible future contributions.

Information gathering

To identify the relevance of the selected works, within the investigation a distribution of these was proposed based on general subthemes, recognized by the fundamental terms found in the documentary search and the reading of the documents. Due to this, the distribution showed a total of 7 specific areas where elements common to these topics are grouped, and an eighth sub-theme where very general and diverse concepts are distributed that are not necessarily or explicitly related to the subject of review, this last subdivision was named “others”. The Fig. 1 show the distribution of inclusion of the 50 documents in each group, thus formulating that 100% of the documents are related to the topic of satellites, and that the generic group “others" have with 59.6% inclusion. Likewise, it is evident that the design topic is included at 53.2% of the articles and the topic of applications and tests have an inclusion percentage of 40.4% and 38.3% respectively. On the other hand, 23.4% of the articles mention works related to measurement systems and environmental variables obtainment. The 18% of the articles mention the development of software technologies and hardware for the elaboration of the projects that be found there.

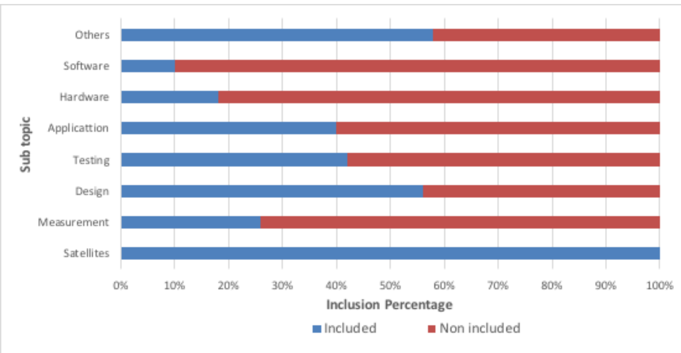

Figure 1. Inclusion of papers in the subtopics identified in the documentary search.
Source: Authors.

The articles differentiated by subtheme can be found in a discriminated way in Table 1, where some documents from each identified area are suggested so that they can be consulted later in future research. Another of the relevant characteristics in the documentary search has been the type of publication, since it is important to know the source of the research and in what percentage the re-search is concentrated in papers (including conferences and congresses) and in degree works.

Consequently, Fig. 2 allows identify that 63.8% of the documents are classified as articles, 19.15% as conference proceedings and 17.02% as theses resulting from graduate works or dissertations. Likewise, the amount in Spanish, English and Portuguese can be observed for each type of document.

Table 1. Papers included in each subtopic.

Subtopic	Reference documents
Satellites	(Sweeting, 2018), (Miyazaki, 2018), (Nambu et al., 2019), (Bedington et al., 2016), (Parco et al., 2013), (Herrera Arroyave et al., 2015), (Burgos González, 2016), (Mozombite Frisancho, 2012), (Islam et al., 2019), (Ramadhan et al., 2019)
Measurement	(Pető, 2013), (Bulut et al., 2013), (Colin, 2015), (Madry & Pelton, 2019), (Mendieta Daza et al., 2017), (Buitrago et al., 2019)
Design	(Kizilkaya et al., 2017), (Colín et al., 2016), (González-Llorente et al., 2012), (Santiago Flores et al., 2016), (Mancilla Cerezo et al., 2019), (Mafra de Carvalho et al., 2013), (Herrera et al., 2015)
Testing	(Ostaszewski Michałand Dzierzek & Magnuszewski, 2018), (Colin, 2016), (Krejci & Lozano, 2018), (Friend et al., 2016), (Hernandez, 2012), (Mendoza et al., 2015)
Applications	(Çabuloglu et al., 2011), (Lee et al., 2017), (Pelton & Madry, 2019), (Anchino et al., 2019), (Alen Space, n.d.), (Ramos Yáñez, 2019)
Hardware	(Angel Rojas et al., 2017), (Salamanca Céspedes, 2013), (Bohorquez Garzón, 2019), (Báez Suarez & Rodríguez Moncayo, 2013)
Software	(Lim et al., 2016), (Pineda Ramirez & Salas Valderrama, 2018), (González-Llorente et al., 2012), (De Martino, 2013), (Pablo et al., 2014)
Others	(Davoli et al., 2019), (Madry et al., 2018), (González Llorente et al., 2016), (Gómez Roa et al., 2018), (Prado-Morales et al., 2017), (Buzarquis & Barán, 2019)

Source: Authors.

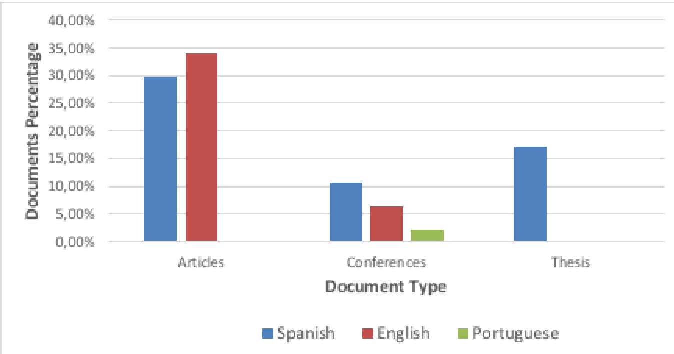

Figure 2. Classification of documents found by type of publication and language.
Source: Authors.

A characteristic that cannot be omit-ted to carry out the review of small satellites is the year of publication of the documents, with the purpose of differentiating the increasing research in this field. Therefore, the documents were discriminated by year of publication, in order to differentiate the largest number of documents in the last 5 years.

Fig. 3 shows the division of documents from 2008 to 2019, thus allowing to infer that 74% of documents have been published from 2015 to 2019, with which it can be argued that the research on the topic of small satellites has been on the rise in the past five years.

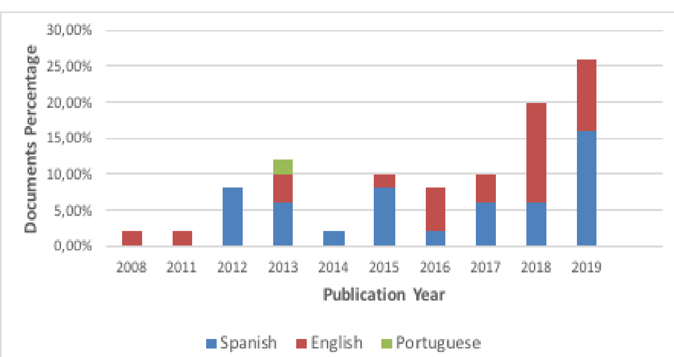

Figure 3. Classification of papers by year of publication and language.
Source: Authors.

In Fig. 4 distinguishes the number of documents made in America and found that 68.1% are researches or works done in the United States. The same figure shows the discrimination by language of writing of the document.

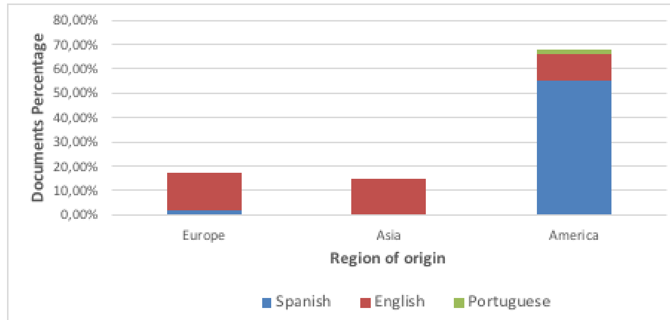

Figure 4. Classification of documents by publication continent and language.
Source: Authors.

Finally, Fig. 5 details the distribution of documents in America by country of origin of the work, thus finding that Mexico and Colombia have a total of 28.13% of documents each, and that the country with the nearest number of articles is USA with 12.5% of documents found.

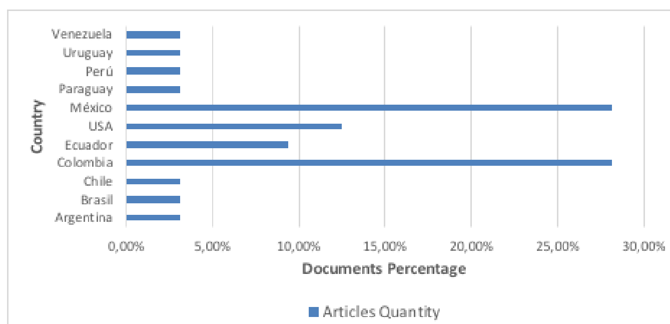

Figure 5. Classification of documents by country of origin of the research in America.
Source: Authors.

The following sections present in de-tail the state of the art and the discriminated review of nano and picot satellites, first in their generalities as small satellites and then identifying the advances in Latin America and other regions of the world.

Small satellites

In the history of satellites, many developments of these devices have been evidenced; the main characteristics of its design are its size and the associated mass. Its classification is: large satellites (more than 1000 kg) and small satellites (less than 1000 kg) (Sweeting, 2018).

In the decade between 1950 and 1960, the first into orbit satellites launches were executed , the main characteristic of which was their size and associated mass, most of which were small satellites of reduced dimensions and low mass, compared to satellites that were used for communications purposes (Pelton & Madry, 2019).

Satellites have had a great reception in different areas of application since the 1960s, and in the following 60 years the development of space technologies was mainly permeated by communications applications and military uses, and for the most part, the devices designed and developed began to increase in size due to the needs of signal transmission, which has been called "technology inversion" (J. N. Pelton and Madry, 2019). As a result, the research centers have contemplated since 1990, the need to make a turn to this type of designs, and the possibility of beginning the massification of smaller satellites, emerging a new concept called "space 2.0" (J. N. Pelton and Madry, 2019).

The interest for these technologies has increased due to new discussions which have emerged from different fields of knowledge, such as commercial development, scientific development, governmental and military applications where satellites are a component of their organizations (Friend et al., 2016). Likewise, software and hardware technologies contribute to the development of smaller devices, with faster information processing speeds and lighter applications that have multiple associated tasks (Friend et al., 2016).

A reason why small satellites have been increasing their design and application is due to the LEO constellations (low orbit) that have several advantages over other methods of positioning satellites in orbit, such as GEO and MEO constellations. Among the main advantages of the LEO constellation are the lower associated cost, low communication latency, low power consumption, and high fault tolerance (Davoli et al., 2019). Because of that the new space age in 2000 started with modern projects for small satellites and with a mainly educational, training and capacity building approach to these devices (Sweeting, 2018). This new space age contemplates the combination of the usual satellite construction techniques, emerging technologies, and rapid development skills in people, such as STEM skills. Thus, from 1980 to 2018, the countries that have developed, implemented and positioning small satellites into orbit have gone from being only 3 to a total of 64 (see Fig. 6), showing that new space technologies have increased their participation with new challenges and applications (Sweeting, 2018).

Another important topic of the new space technologies focuses on the sustainble development objectives promoted by the United Nations. Since the beginning of the space race in the cold war, this entity has raised the possibility of having international cooperation, with the intention of obtaining targeted solutions to humanitarian aid and defense of the environment. Consequently, since

1970 agreements are established to hold events and workshops around the development of projects to solve needs associated with remote monitoring, geographic information systems, meteorological and climate stations and the generation of space laws (Madry et al., 2018).

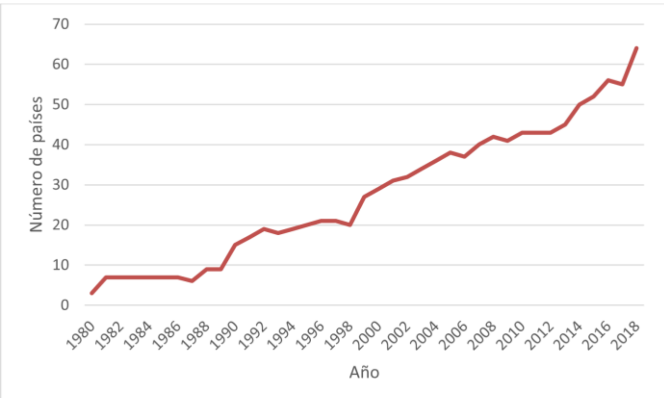

Figure 6. Number of countries that have placed small satellites in orbit since 1980.
Source: Adapted from Sweeting (2018).

The aforementioned has promoted, that different organizations and university institutions teaching the use of these technologies from the classroom, thus making young people and children interested in this area of study. Therefore, this type of experiment differentiates some basic concepts that must be taken into account for the design and development of these devices, and attempts are made to have clarity in concepts such as Femto satellites, Pico satellites, nano satellites, earth station and space missions (Madry & Pelton, 2019).

It should be noted that there are two main types of design in the application of these strategies, and they are found in the classification of small satellites, such as CubeSat and CanSat. The CubeSat program had its beginnings in 1999 at Stanford University in order to have a low-cost and low-mass satellite, whose structural analysis and design would take place between 1 and 2 years (Davoli et al., 2019). This device is a cube with dimensions approximately 10x10x10 cm and its mass does not exceed 1.3kg. These devices can work in constellations and have functionalities such as control system, propulsion system, power source, communication protocol and display (Davoli et al., 2019). For the other hand, CanSat technology is defined as a development that can simulate the functions of a real satellite and whose size limit is defined by the dimensions of a soda can, where some elements such as sensors are integrated , batteries, microcontrollers and recovery system (Mendoza et al., 2015). This type of device is widely used in competitions for students to reinforce the design and construction skills of small satellites, making use of highly economic elements that can be easily programmed and implemented.

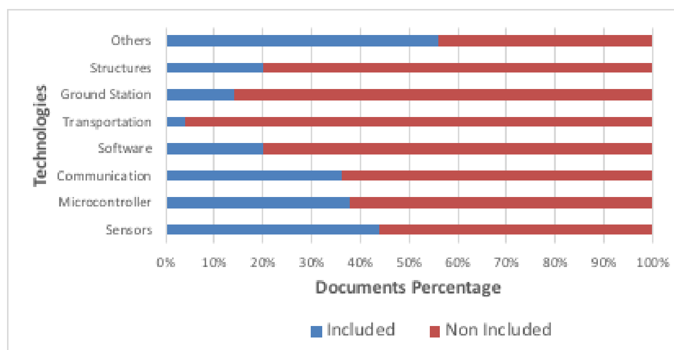

Figure 7. Classification of technologies in the documents found.
Source: Authors.

Among the different technologies in the application of this type of development are those mentioned in Fig. 7, whose discrimination has been carried out according to state-of-the-art documents. The percentage of inclusion in all documents is identified, thus allowing inferring those of greatest use in the de-sign and application of small satellites. In the following sections, the information found will be broken down into two specific topics: nano satellites and pico satellites.

Applications and projects of nano satellites

A Nanosatellite is a type of small satellite that is characterized by having a mass of 1 to 10 kg, its dimensions are almost always not greater than a 10x10x10 cm cube and are widely used in low-orbit constellations for shipping and transmission data through UHF communications (Ultra High frequency) (Sweeting, 2018). One of the great ad-vantages of these devices is their modularity and distributed functionality, due to the fact that their architecture is mainly aimed at reducing the costs associated with each unit and their specific functions and interfaces are based on devices of small size and weight, and in a additionally these devices are very simple to program and operate from a unified electronic unit (Friend et al., 2016).

Outside Latin America contributions

Nanosatellites have made it possible to carry out projects not only focused on teaching purposes, else have extrapolated their applicability to very specific tasks such as military applications or communications. The document presented by Lee et al. (Lee et al., 2017) provides a brief overview of the development trends of small satellites in military applications, with a special focus on nanosatellites. The authors present relevant information in 3 specific countries: United States, Japan, and North Korea. In the case of the United States, it details two successful cases of putting nanosatellites into orbit, The first case is PhoneSat 1.0 in 2013, demonstrating the ability to produce a communications satellite at a very low cost, and whose validations led to the determination in 2014 that it was possible to share communication between eight CubeSat positioned in the space (Lee et al., 2017). The second project is TechEdSat-5 whose device was launched in 2016 from the International Space Station (ISS), subsequently deploying an aerodynamic brake. Japan, for its part, experienced 60 launches from its "Kibo" module between 2012 and 2015, obtaining information and positioning its small satellites into orbit with the least amount of vibrations possible (Lee et al., 2017). Finally, North Korea has made some space contributions with small satellites since 1992, and they have put together a CubeSat competition since 2012 to pro-mote space technology, but the results of their workshops still fails to compare with technologies that of other countries like the United States (Lee et al., 2017).

It should be noted that the development of CubeSat as a strategy to expand knowledge and teaching of space technologies has been fundamental, and in that order of ideas it has allowed different applications to emerge from academic spaces. In the article that Nambu et al. (2019) an open collaboration methodology based on models is established through the use of BALUS software, which allows for collective collaborations and the provision of ideas through diagrams, in order to elaborate the final model of the nanosatellite project called OPUSAT- KIT. This initiative was developed in Japan with a group of students, and the document gives insights to carry out this type of strategy in the framework of projects applied to space technologies, thus being a useful tool to develop projects in environments university and with few resources.

In addition to the above, it is necessary to add some contributions that are presented for the structural design and commissioning of these satellites. On the one hand, the authors in (Miyazaki, 2018) mention some deployment structures in orbit for small satellites, addressing the most widely used, among which are: deployable antenna, deployable telescope, deployable solar panel, deorbit device, starshade, solar sail. Besides, the authors refer to the techniques most used in deployment identifying the following: deployment actuator and damper, deployable boom, membrane structure and hold-release mechanism (Miyazaki, 2018).

Latin America contributions

The inclusion of CubeSat technology in Latin America has been a significant advance in space science of the region. In this way, the different universities and institutes have made efforts to promote different events and workshops around this type of developments, which has led to many designs and projects that have been positioning into orbit. Next, some projects that have emerged from this academic and research work that have brought to the realization of nanosatellites or elements for their efficient operation in orbit will be detailed.

The work carried out by Herrera et al. (2015) exposes the process to carry out the design of the structure of a CubeSat from a prescriptive model. They developed a launch vehicle taking into account the vision of internal and external users to the project, in order to proceed to an optimal design of the physical and mechanical properties of the structure for to obtain a device robust and according to needs. Among the main features defined are the protection of the internal devices that comprise it; the maximum mass of 1.33kg whose center of gravity could not be exceeded by 2 cm measured on the XY plane and defined at the geometric center of the Z direction; an access hatch on a lateral face to access the interior of the satellite and make possible changes; have the ability to withstand static launch acceleration and finally be able to function seamlessly without damage in the internal and external structure (Herrera Arroyave et al., 2015). The modeling was carried out through computeraided design using a mathematical analysis of the structure, whose performance was due to fluctuations naturally given by random vibrations, shock vibrations, static acceleration, and sinusoidal vibrations. The choice prototype was analyzed from finite models in order to simplify the real problem and thus obtain the preliminary arrangement for the final solution of the design proposed by Herrera Arroyave et al. (2015). The document finally allows to detail the design analysis process and it include the development of a Cubesat based on elements of mathematical modeling that it allows simplify design tasks.

Another of the works found in Latin America is the one developed by Mozombite (2012) in which the design of a nanosatellite is proposed in order to use it for atmospheric study in Peru. The proposed solution is based on the modular structure of the CubeSat, which having a cube shaped structure, makes it possible to locate the internal devices in a simpler way. The structure was made of alodized aluminum, to avoid corrosion by abrasion of the structure and allowed it to protect itself from radiation. Among its internal components for data collection was used a microprocessor from the company Texas Instruments, whose power consumption performance is low. For data communication a PicPacket Terminal Control Node and the Yaesu VX-3R transceiver were used, allowing the operation of the VHF and UHF bands. The choice of these elements, as mentioned by the author, is mainly due to their use in previous projects whose benefits were feasible and gave positive results in the tests (Mozombite Frisancho, 2012). Finally, the CubeSat obtains its energy source from a system integrated of photovoltaic cells, a DC/DC converter, a battery charging system, and a battery arrangement.

One of the main challenges to put a nanosatellite into orbit is the power performance. Special attention has been given to this topic. The Sergio Arboleda University in Colombia has developed an analysis and design of an energy conditioning system for a nanosatellite unit. In the document of Rojas et al. (Angel Rojas et al., 2017) it is noted a design methodology for an architecture for power conditioning, in order to obtain the CubeSat energy source from solar cells. However, the main analysis is not only focused on the energy collection capacity, but a detailed analysis of the energy consumption of each device that may be present in a satellite of this type has been carried out, allowing to give to know the reader what are the limitations, the benefits of the presented system and the possible architecture developed in the research. The final system that they deliver has electronic protection that demonstrates the importance of having safe systems that do not exceed the desired performance, in order not to obtain physical damage to the components and damage to the satellite and its tasks specific (Angel Rojas et al., 2017).

Lastly, two projects applied to launching nanosatellites into orbit should be highlighted. First, the document by Parco et al. (Parco et al., 2013) mentions the development of the positioning of nano satellites through the use of probe ULA rockets in Venezuela, whose conditioning tests were carried out from 2006 to 2011, and resulted in two prototypes of a rocket with a payload launch: The first model probe rocket used solid fuel based on ammonium perchlorate, and the second model used hybrid fuel based on hydrogen peroxide and paraffin (Parco et al., 2013). The second project was carried out in Brazil and was titled CONASAT. In the document by Mafra et al. (2013), the development of the LEO constellation with 8U size nanosatellites with a maximum fall time of approximately 25 years is shown. A mission time of 24 months with a maxi-mum height of 625 km was established, and it was determined that the conditions for operation were only met with constellations of 8 satellites for which the use of 6 distributed satellites was defined in one, two, three or six orbital levels. Additionally, they present with statistics of the maximum review time in each of the scenarios, in order to obtain the best relationship to define the number of satellites, the orbital maps and the precision of the information that could arriving from the constellation (Mafra de Carvalho et al., 2013).

Applications and projects of pico satellites

Within the classification of artificial satellites, one of them is the Pico satellites, these devices have a mass of 0.1 to 1 kg, fulfilling the dimensions of a drink can (approximately 120 mm high and 70 mm high diameter), a fundamental characteristic for them to take the name of CanSat (satellite of can). These satellites have varied designs and configurations that depend on the mission to be accomplished and it should be taken into con-sideration that one of the peculiarities of these devices is that they are not put into orbit, however, they can be to be launched with different devices (rockets, balloons, drones, flying model, etc.) to be placed in the stratosphere, where they are normally used in the measurement of variables in the atmosphere and the prediction of it changes and behaviors. This information is usually obtained by means of telemetry tools, either from the provision of a ground station to display the information in real time or by means of storage in a memory for later downloading and analyzed. It should be noted that its main objective is educational, allowing young university students and high school students to use these tools to learn more about the work being done from space science and robotics (Colin, 2016).

Outside Latin America contributions

At the Pakistan Institute of Space Technology (Islam et al., 2019) they designed a Pico satellite for meteorological monitoring using real time telemetry of the data obtained by temperature, pressure, and humidity sensors. Additionally, the second mission also took images and store them for future analysis. This design has a particularity because its launching system was made by means of a helium balloon, which allowed the CanSat to collect data during the ascent and descent and, finally, to be able to compare the atmospheric changes in these two movements. In Indonesia, according to document (Ramadhan et al., 2019) a CanSat was designed whose mission was to collect atmospheric data; different materials such as aluminum and carbon fiber were used in its structural design, making its structure lighter than conventional Cansat. This design features al-lowed the structure to be more resistant to withstand strong shocks when the downward movement was performed. Likewise, another feature of this design is its recovery system that used airscrews, thus allowing its descent to be more controlled and slower than when using a parachute. Finally in Poland according to the document (Ostaszewski Michałand Dzierzek & Magnuszewski, 2018) a CanSat was designed for atmospheric studies, taking data from a height of 400 meters; these datum were interpreted and analyzed to make computerized atmospheric predictions in the measurement collection area. This satellite was driven by a solid fuel propelled rocket, obtaining a height of 400 meters where the pico satellite mission has been started.

Latin America contributions

Latin American countries in recent years have increased satellite research either for educational or exploratory purposes, thus reaching new prototypes of pico satellites and devices for simulating them.

The document presented in (Santiago Flores et al., 2016) shows the construction of the CanSat called CAPTEUR-

SAT, whose objective is the construction of a pico satellite to collect atmospheric data. The variables of interest that were considered in this project were: the number of chemical compounds and their identification in the atmosphere; essential data such as temperature, global positioning, atmospheric pressure, orientation and height. The device was able to generate statistics to determine the meteorological conditions in which the atmosphere was at the time of making the measurements and subsequently, by telemetry send that information for analysis.

On the other hand, in the document presented at (Gómez Roa et al., 2018) the school of science and technology in Tijuana, Mexico, it details a structural dynamic analysis that presents a pico satellite applying finite element theories using ANSYS (modeling and analysis platform) for its study, this tools allowed them to observe the performance of the structure of the pico satellite in each of the phases of the mission such as its launch, descent and recovery. The research considered specific variables such as an acceleration force of 30g (gravities) in the vertical direction due to its natural physical movement; thus, these analyzes resulted in the concentration of sheer stresses and deformations of the material of the pico satellite (Gómez Roa et al., 2018).

Another of the projects found is presented in (Mancilla Cerezo et al., 2019), which proposes the design and construction of a pico satellite called WashiSat V1.0, which was presented in the fourth national competition for educational satellites CanSat of the Mexican Space Agency. The mission to be fulfilled had two purposes, the first was to transport an egg as payload and maintain good conditions during takeoff, descent and landing; the second purpose was to collect data on the internal and external temperature of the pico satellite, measurement of variables such as the atmospheric pressure, the relative humidity of the environment, the altitude of the pico satellite, the coordinates of latitude and longitude; additionally the design included a battery level indicator. This together allowed to identify the attitude behavior of the satellite peak. All the mentioned information was sent by telemetry to a ground station for analysis. These three documents show the great contribution that Mexico has had in the application of these educational strategies in order to socialize the new space technologies and their scope to the community.

Similarly, there are other countries that have encouraged the implementation of these tools, such as Colombia. For example, the document written by Pineda and Salas (2018), show the developed prototype to simulate the attitude and a mechanical interface model for a pico satellite, using a cardan-type suspension model. On the other hand, in the document presented in (Buitrago et al., 2019), the design of a pico satellite was detailed, whose mission is to take environmental measurements, integrating low-cost technology, such as a hardware plate with a Tensilica L106 microprocessor 32 Bit, allowing communication with different sensors to fulfill its mission and obtain the measurement of atmospheric variables such as ambient temperature and barometric pressure. The use of attitudinal sensors such as the accelerometer, gyroscope and GPS were also implemented, and all these data were transmitted by telemetry to a ground station for analysis.

Another of the projects found is in Argentina; according to the document written by Anchino et al. (2019), the implementation of a Pico satellite with different missions or purposes is described. Here, the technical aspects and process for the construction of these non-orbital satellites have been detailed, integrating low-cost mechanical and electronic components developed by themselves, extending their research to promote scientific and technological dissemination to awaken in young students of different educational levels your interest for the space sciences.

Finally, is important that different educational institutions participate with research group or jointly research projects in the development of new projects and technologies focused on space science and its applications, at their different educational levels. These meetings have become visible as competitions that allow this type of development and research to be carried out, just as the National Institute for Space Research in Brazil does (INPE), where they annually hold a com-petition called "Cube Design", which from different Categories promote the participation of students interested in space research, allowing them to compete by creating prototypes of Pico satellites, nanosatellites and propulsion devices such as rockets.

Future contributions

In the context of the digital age and new technological trends, there is the need to start integrating different areas of study in order to mitigate some needs and deficiencies that are present in society and as mentioned by the United Nations, efforts must be made to make new technologies aimed at solving these social, cultural, economic, environmental and technological problems. Through the documentary search that has been carried out in this article, could be determined that the applications of small satellites can be extrapolated to applications such as agriculture, meteorology, internet networks, data analysis, sustainable environments and equity of individuals in the society. Therefore, it is expected that this review will be a contribution to establish a starting point for researchers and developers of new applications, so that they encourage the use of these technologies in different areas of knowledge, and that it is a basis for different institutions and universities promote this type of development to a greater extent.

Conclusions

Small satellites have been the instrument that since the beginning of the space race, have allowed important advances in the space sciences, and in the last 3 decades, the development and launch of these devices has made more countries can enter into competition with the great powers that have historically led these advances. Within this set, the pico satellites that are widely used to teach young people the step-by-step of the construction of a real satellite stand out, leading to contemplate from the phase of design and selection of components to its implementation and testing. The CanSat in this sense, are the essential tool so that from the academy the learning of space sciences is encouraged and therefore, there is an increase of people interested in studying these disciplines and who are capable of applying these ideas in multiple fields of society.

The Nanosatellites have been a formula for position small projects into orbit, encouraged by institutions and universities, in order to promote communications in constellations and the management of information through signals high frequency, but at low costs and with smaller devices; thus, CubeSat has categorized as one of the essential elements in the generation of new projects in order to implement cutting edge technology in low orbit. These devices like the CanSat are of great potential, since not requiring a high cost in economic fact, they provide fast and innovative solutions that can be extended to various applications, and even more so in the new digital age which requires very specific solutions to the equitable access of technologies in the society.

In this way, the use of small satellites can be a possible way out of the discussions that are currently being addressed about climate change, sustainability, equity, participation and collaboration by different countries of the world, with the reason of generating prompt solutions and in accordance with the improvement plans around social problems.

With the above it is possible that, in the regional and local context, and specifically in Colombia, the developments based on this technology allow identifying new ways of facing problems in fields such as agriculture, access to communication networks in rural areas, the analysis of atmospheric data through the collection of information in constellations, as well as the other challenges facing all nations in the world and which are a fundamental commitment of the United Nations.

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Diseño conceptual de una tobera convergente divergente de área variable para un túnel de choque

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Resumen

Un túnel de choque supersónico es una herramienta utilizada para realizar pruebas a velocidades supersónicas de nuevos modelos y tecnologías en el campo de la ingeniería aeronáutica. Los túneles de choque están compuestos por diferentes partes que cumplen funciones indispensables para el desarrollo de una prueba. Uno de los componentes fundamentales de un túnel de choque es la tobera convergente divergente la cual se encarga de controlar la velocidad de un flujo según sea necesario para realizar la prueba. Al realizar una investigación de antecedentes de los túneles de choque se pudo encontrar que para el 2020 con relación al campo de investigación en Colombia la existencia de estas herramientas es nula, por lo cual, la finalidad de este proyecto de grado está en diseñar conceptualmente una tobera convergente divergente de área variable que pueda proveer una mejor manipulación con relación a las demás toberas convergentes divergentes que se encuentran en los túneles de choque comerciales.

Palabras clave: Aerodinámica supersónica, Tobera convergente divergente, Área variable, Túnel de choque supersónico.

Conceptual design of a variable area divergent converging nozzle for a shock tunnel

Abstract

A supersonic shock tunnel is a tool used to test new models and technologies at supersonic speeds in the field of aeronautical engineering. The shock tunnels are made up of different parts that fulfill essential functions for the development of a test. One of the fundamental components of a shock tunnel is the divergent converging nozzle which is responsible for controlling the speed of a flow as necessary to perform the test. Conducting background research of shock tunnels was made, determining that in Colombia the existence of these tools is null, therefore the aim of this document is to describe the conceptual design of a variable area convergent-divergent nozzle, which provides higher handling on the specimen in a test.

Key words: Supersonic aerodynamic, Convergent- divergent nozzle, Variable area, Supersonic shock tunnel.

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Introducción

Esta investigación se centra en el desarrollo de túneles de choque supersónicos para el análisis del comportamiento aerotermodinámico del fluido a través de sistemas supersónicos. Para lograr el avance de nuevas tecnologías en la industria aeroespacial se deben cumplir con varios ciclos de diseño, en los cuales se evalúan análisis teóricos-analíticos, computacionales y experimentales antes de ser puestos en operación.

Para el desarrollo de nuevas tecnologías en la Ingeniería Aeroespacial (Aeronáutica y Astronáutica) es necesario someter los diseños propuestos a análisis teórico-analíticos, computacionales y experimentales antes de realizar pruebas de vuelo con los prototipos. Como una opción de evaluar el rendimiento aerodinámico experimentalmente en instalaciones en tierra, se implementan herramientas como los túneles de viento, que tienen como finalidad acelerar un fluido a lo largo de una sección de prueba en donde se encuentra el objeto de estudio para visualizar su comportamiento aerodinámico, con el fin de recrear el comportamiento del fluido a diferentes condiciones de operación. La existencia en Colombia de estos túneles de viento se reduce a unas pocas universidades y centros de investigación, pero con la evolución de la aviación en usos militares y civiles el rango de velocidades que se desean explorar es mayor, por lo cual las velocidades requeridas superan la velocidad del sonido (velocidades supersónicas).

Por otro lado, para la prueba de vehículos que operan a velocidades supersónicas, es necesario la implementación de túneles de choque supersónicos, los cuales aceleran el fluido por medio de una tobera convergente-divergente, que son capaces de convertir la energía térmica y la presión de un fluido, en energía cinética. Las toberas convergentes-divergentes son ampliamente usadas tanto en equipos de pruebas en tierra, en cohetes y aeronaves de alta velocidad.

Metodología

El desarrollo de este diseño conceptual se llevó a cabo con un método globalizador cuyo objetivo principal es mezclar diferentes métodos de estudio, para así llegar a un desarrollo de un producto o servicio que se acople a las diferentes necesidades y requerimientos del interesado (Riba, C. 2002). El diseño metodológico fue implementado en cuatro fases: la primera fase tuvo en cuenta la metodología descriptiva con el fin de realizar una conceptualización de antecedentes de túneles de choque supersónicos. La segunda fase se realizó por medio de la metodología analítica generando el diseño preliminar de una tobera convergente divergente de área variable. Para la tercera fase, se realizó el diseño CAD del mecanismo de área variable de la tobera, y finalmente, en la cuarta fase, por medio de la metodología analítica reflexiva, se analizaron los resultados obtenidos en las diferentes pruebas generando una discusión.

Desarrollo

La investigación fue divida en dos partes principales. La primera parte consiste en un análisis aerotermodinámico del flujo a través de una tobera convergente divergente para de esa forma conocer e interpretar el comportamiento de un fluido en el sistema, ya en la segunda parte, se realizó un modelo CAD (diseño asistido por computador) apropiado para las características de operación de esta tobera.

Para realizar el análisis del flujo de la tobera se realizaron consideraciones pertinentes para simplificar los cálculos matemáticos. Se considera un fluido isentrópico a lo largo de la tobera, se considera un fluido no viscoso y una relación de calores específicos a presión y volumen constante a lo largo de todo el sistema. El modelo matemático se obtuvo a partir de Anderson (2003).

En la Fig. 1 se puede ver el análisis aerotermodinamico del flujo a través de la tobera, y el comportamiento del número Mach con relación al área de la tobera, mientras que en la Fig. 1b, 1c y 1d se puede ver la relación de densidad, presión y temperatura en donde el valor máximo de la gráfica representa a la garganta de la tobera en donde el área es menor en la geometría y un número Mach igual a 1.

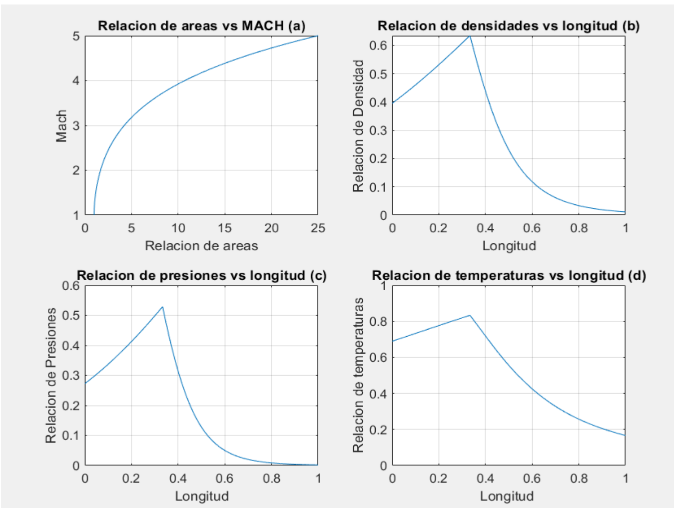

Figura 1. Comportamiento aerotermodinamico del flujo a través de una tobera convergente-divergente.

Fuente: Autores.

La Fig. 1a presenta la gráfica correspondiente a el número de Mach contra la relación de área de una tobera, en donde se puede observar que la velocidad tiene un comportamiento parabólico lo cual indica que para una mayor relación de área en una tobera se obtiene un numero de mach mayor a la salida de esta. Por otro lado, la relación de densidad tiene un comportamiento diferente a lo largo de la tobera, como se puede ver en la Fig. 1b, la densidad tiende a aumentar la zona convergente de la tobera y hasta llegar a un punto máximo al terminar la reducción de área lo largo de toda la geometría el cual recibe el nombre de punto crítico, después de este punto la densidad disminuye con la expansión del fluido.

Las presiones a lo largo de la tobera están modeladas por la Fig. 1c en donde se observa que la energía en el flujo tiene un comportamiento similar a la densidad ya que en la zona convérgete la presión en el fujo aumenta hasta llegar al punto crítico en donde el fluido tiene una pérdida de energía potencial mientras aumenta la velocidad del flujo por la descompresión hasta llegar a la presión atmosférica inicial.

La temperatura es otra característica del comportamiento importante a tener en cuenta en el diseño de este sistema, ya que este puede afectar el funcionamiento de los diferentes materiales a la hora de su construcción, como se puede ver en la Fig. 1d, el comportamiento de la temperatura es similar al comportamiento de la densidad y la presión, teniendo en cuenta este comportamiento, se puede afirmar que el punto crítico de una tobera es donde al tener menor área, el flujo tiene una mayor energía que se ve representada en las altas presiones, temperaturas y densidades, sin embargo, a su vez, en este punto la velocidad es menor que en cualquier otro punto del sistema, lo que indica que el flujo tiene un aumento de energía potencial y una reducción de su energía cinética para después ser descomprimido y acelerado según sea requerido para el experimento.

Para realizar el análisis del sistema se seleccionaron tres puntos importantes de estudio, el primer punto de análisis es la entrada de la tobera que corresponde a las condiciones del lugar de operación del túnel, el segundo punto de análisis corresponde a el punto crítico el cual tiene el valor mínimo de área en el sistema y por último se tiene la salida de la tobera en donde fueron realizados tres diferentes análisis que corresponden a las diferentes velocidades de diseño.

Resultados

Para el modelo matemático las condiciones iniciales fueron tomadas de las tablas de la atmosfera estándar (Engineering ToolBox, 2003) para 2600 metros sobre el nivel del mar que corresponde al lugar de diseño del sistema los cuales se encuentran en la Tabla 1.

En la Tabla 2 se puede ver la relación de área en el segundo punto de análisis en donde se presenta la relación del área de entrada y el área de la garganta del sistema, así mismo se encuentran las relaciones de las condiciones del fluido en este punto respecto a las condiciones de entrada del sistema. En este punto crítico del sistema se presenta un aumento de la energía reduciéndola velocidad a un número Mach igual a 1.

Tabla 1. Características del flujo a la entrada de la tobera.

Propiedades	Magnitud	Unidades
Área	4.418e-03	m2
Densidad	9.475e-01	Kg/m3
Presión	7.3759e+04	N/m2
Temperatura	271.27	K
Velocidad	1.5	Mach

Fuente: Autores.

Tabla 2. Comportamiento del Flujo en el punto crítico.

Propiedades	Relación
Área	0.66
Densidad	0.6339
Presión	0.5283
Temperatura	0.8333
Velocidad	X

Fuente: Autores.

En el tercer punto de análisis del sistema se pueden encontrar las mismas relaciones de área densidad y temperatura para las tres diferentes velocidades de diseño del sistema que se pueden ver en las Tablas 3, 4 y 5, correspondiendo a 2.5, 3.5 y 4.5 Mach de salida.

Tabla 3. Características del flujo a 2.5 Mach.

Propiedad	Relación
Área	2.63
Densidad	0.131
Presión	0.0585
Temperatura	0.444

Fuente: Autores.

Tabla 4. Características del flujo a 3.5 Mach.

Propiedad	Relación
Área	6.78
Densidad	0.0452
Presión	0.0131
Temperatura	0.2899

Fuente: Autores.

Tabla 5. Características del flujo a 4.5 Mach.

Propiedad	Relación
Área	16.56
Densidad	0.0174
Presión	0.0035
Temperatura	0.1980

Fuente: Autores.

Discusión

La tobera convergente-divergente se diseñó con base a los motores que utilizan los aviones de combate que son capaces de alcanzar altas velocidades gracias a su tobera de área variable.

El mecanismo de ampliación y reducción de área es aplicado en la sección de salida (o sección convergente de la tobera), ya que la sección de entrada (o sección divergente) de la tobera tiene una relación fija con respecto al tubo de choque acoplada a ella y la garganta debe tener una relación fija con respecto a esta sección, para aproximar la velocidad en este punto a Mach=1.

A continuación, se realiza una descripción de las piezas del mecanismo:

1. Armadura móvil Inferior (ver Fi. 2) se encarga de proveer y mantener la geometría en la zona convergente del sistema, mientras que a su vez está unida en la parte superior de la Base soporte (ver Fig. 10) con una unión de bisagra (ver Fig. 13) la cual permite el cambio de posición si se requiere en el sistema.

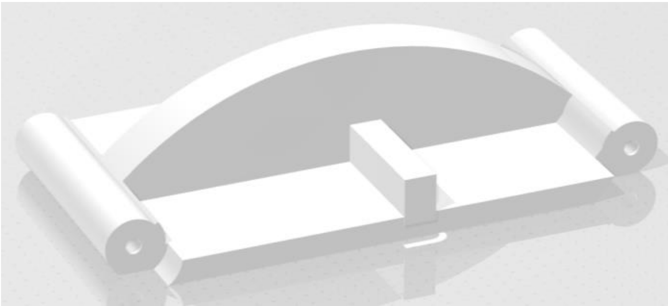

Figura 1. Armadura móvil Inferior.

Fuente: Autores.

2. Armadura móvil superior (ver Fig. 3) se encarga de mantener la geometría en la zona divergente del sistema que a su vez está acoplada al Brazo Actuador (ver Fig. 12) que modifica la posición de este componente. Está ubicado en la parte superior de la armadura móvil superior y en su parte frontal posee dos acoples para el Brazo con Rodamiento como se muestra en la Fig. 13.

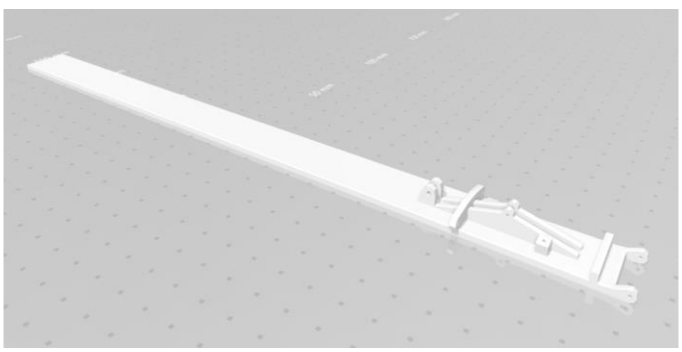

Figura 2. Armadura móvil superior.

Fuente: Autores.

3. Armadura Fija Inferior (ver Fig. 4) es la encargada al igual que mantener la geometría en la zona convergente del sistema con la particularidad de que el movimiento de este componente está únicamente guiado por la Armadura Móvil inferior, este componente va acoplado a la Base (ver Fig. 10) y tiene un acople de bisagra con un pasador (ver Fig. 13), este componente sirve de acople en su parte frontal a una Guía de Armadura (ver Fig. 6).

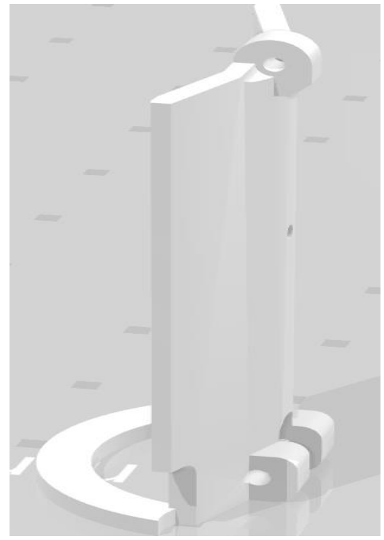

Figura 3. Armadura Fija Inferior.

Fuente: Autores.

4. Armadura Fija Superior (ver Fig. 5) se encarga de complementar la geometría en la zona divergente del sistema, al igual que la Armadura Fija Inferior (ver Fig. 4), el movimiento de este componente depende de otro, correspondiente a la Armadura Móvil Superior (ver Fig. 3). Este componente está ensamblado en la parte superior de la Armadura Fija Inferior. En la parte frontal de este componente se pueden encontrar los componentes con el fin de modelar y asegurar el movimiento de este, Guía de Armadura (ver Fig. 6) y Soporte de brazo (ver Fig. 7).

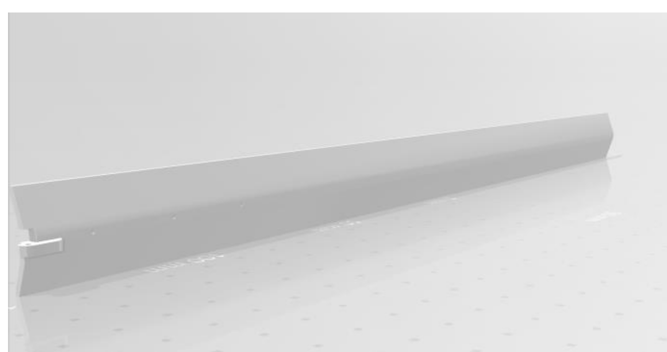

Figura 4. Armadura fija superior.

Fuente: Autores.

5. Guía de Armadura (ver Fig. 6) es la encargada de mantener la Armadura Fija superior (ver Fig. 4 y 5) e inferior acopladas a la Armadura Móvil (ver Fig. 2 y 3) superior e inferior y también tiene como función principal guiar el movimiento de las Armaduras móviles a las fijas a la hora de modificar la geometría, va acoplada como se aprecia en la Fig. 13 en la parte posterior de la Armadura Fija superior e inferior.

Figura 5. Guía de Armadura.

Fuente: Autores.

6. Soporte de Brazo (ver Fig. 7) es el encargado de dar movimiento circular al Brazo con rodamiento para mantener los componentes fijos en una sola posición y se puede encontrar acoplado en la parte posterior de la Armadura Fija superior (ver Fig. 5).

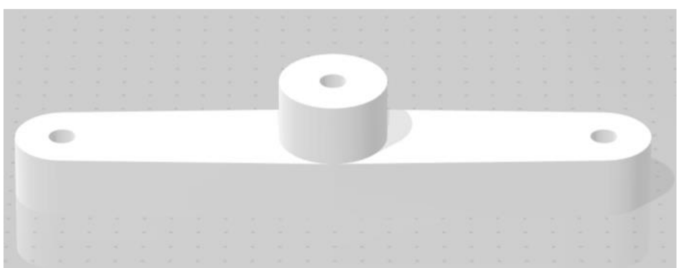

Figura 6. Soporte de Brazo.

Fuente: Autores.

7. Brazo con Rodamiento (ver Fig. 8) es el encargado de dar un límite al movimiento de la zona divergente del sistema, así mismo, este componente se encarga de mantener la distancia entre las armaduras móviles y fijas, se puede encontrar con la parte del rodamiento sobre el soporte de Brazo (ver Fig. 7) y unida con un pasador a la Armadura Móvil superior (ver Fig. 3).

Figura 7. Brazo con Rodamiento.

Fuente: Autores.

8. Guía superior (ver Fig. 9) es la encargada de mantener una posición uniforme entre las armaduras móviles y fijas sin permitir que tengan un movimiento al largo del eje Z, se puede encontrar acoplada en la parte posterior de la Armadura Fija Superior como se puede ver en la Fig. 13.

9. Base soporte (ver Fig. 10) es la encargada de servir como soporte para las armaduras y demás componentes del sistema, mientras que su vez es la encargada de acoplar el sistema con el túnel y demás componentes. Se encuentra acoplada en el sistema como se presenta en la Fig. 13.

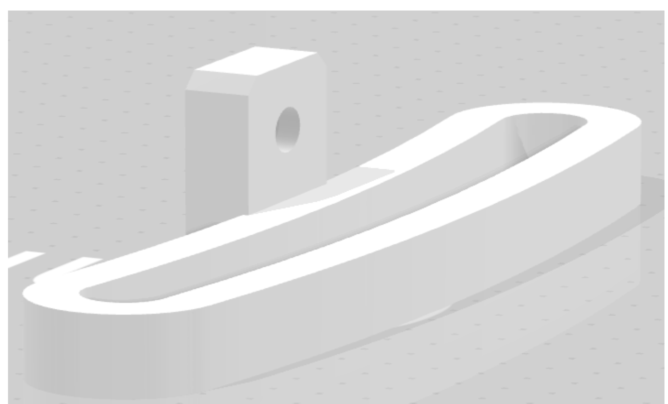

Figura 8. Guía superior.

Fuente: Autores.

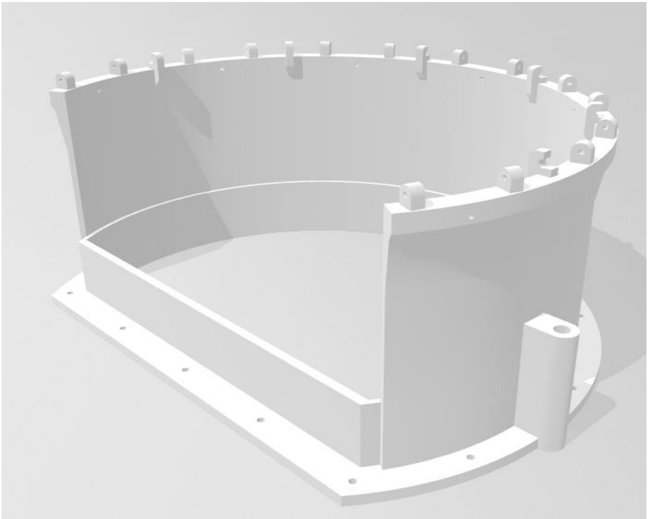

Figura 9. Base soporte.

Fuente: Autores.

10. Anillo Actuador (ver Fig. 11) es el encargado de proporcionar las dimensiones del sistema con un movimiento sobre el eje longitudinal del sistema acoplado a los Brazos (ver Fig. 12), mientras que mantiene las posiciones alrededor de la Base soporte (ver Fig. 10).

11. Brazo Actuador (Fig. 12), este componente tiene la función de guiar el movimiento de la Armadura móvil superior (ver Fig. 3) dependiendo de la magnitud del movimiento proporcionada por el usuario al anillo actuador. Este componente se encuentra acoplado al Anillo Actuador (ver Fig. 11) como se puede apreciar en la Fig. 14.

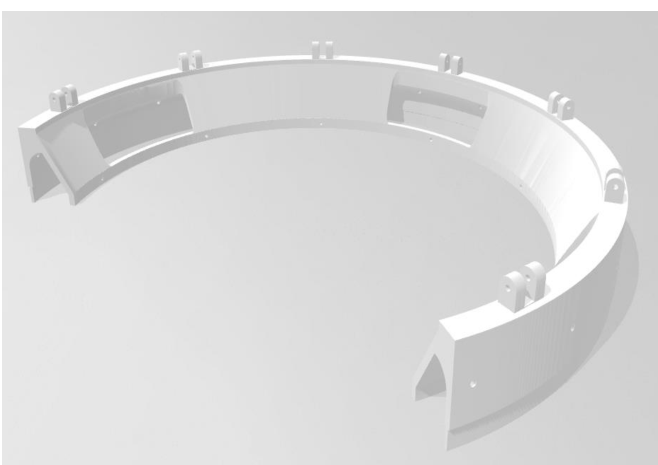

Figura 10. Anillo Actuador.

Fuente: Autores.

Figura 11. Brazo Actuador.

Fuente: Autores.

En la Fig. 13 se puede visualizar el ensamble de todos los componentes mencionados, en donde es posible visualizar la forma en que la guía de armadura mantiene la forma entre las armaduras fijas y las móviles mientras que el brazo con rodamiento unido a la armadura móvil superior por un extremo está anclado a la armadura fija superior.

En la Fig. 14 se puede observar el ensamble final de todo el sistema con el anillo actuador, al cambiar la posición del anillo actuador sobre el eje longitudinal de la base se modifica el área de la geometría a la salida. Así mismo las Fig. 14, 15 y 16 muestran las tres diferentes áreas de salidas del sistema 2.5, 3.5 y 4.5 Mach respectivamente.

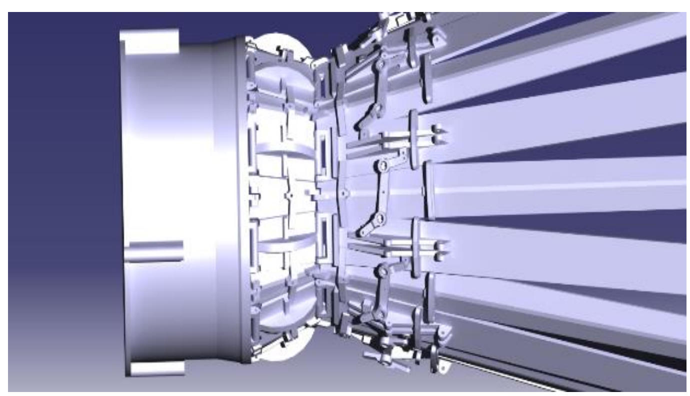

Figura 12. Ensamble del Mecanismo.

Fuente: Autores.

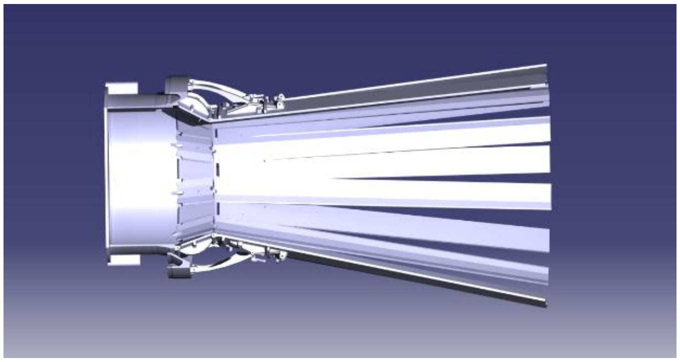

Figura 13. Ensamble para 2.5 Mach.

Fuente: Autores.

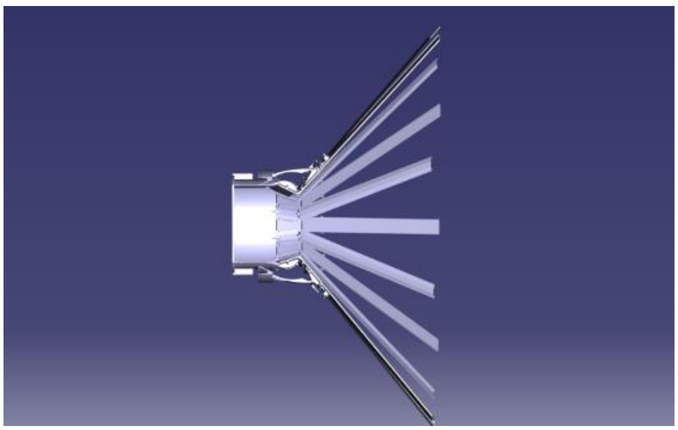

Figura 14. Ensamble para 3.5 Mach.

Fuente: Autores.

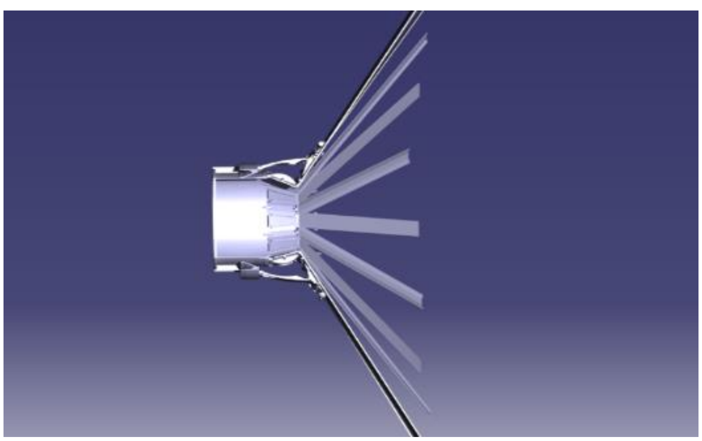

Figura 15. Ensamble para 4.5 Mach.

Fuente: Autores.

Conclusiones

En este proyecto de investigación es propuesto el diseño conceptual de una tobera convergente-divergente de área variable en la sección divergente, la cual es la encargada de dirigir el fluido a la velocidad deseada a la sección de prueba de un túnel de choque supersónico.

Realizando comparaciones sobre otros diseños, se puede concluir que los datos obtenidos en el diseño de la tobera convergente-divergente de área variable son congruentes con el comportamiento aerotermodinámico del fluido en toberas convergentes-divergentes convencionales, analizadas por CFD.

El mecanismo determinado que permite realizar la expansión o retracción de la sección divergente de la tobera fue abordado con base al mecanismo encontrado en toberas de propulsión vectorial usado en aeronaves de combate. En este caso fueron necesarios 86 componentes, los cuales fueron ensamblados de forma tal que, por medio de su trabajo sinérgico, permita la variación de área deseada, adicionalmente fue aumentada la longitud de los componentes de la sección convergente para alcanzar la relación de áreas deseada según el ángulo medio escogido para cada una de las velocidades esperadas en la sección de pruebas.

A partir del diseño presentado se hace necesario el diseño de una membrana interior que evite el escape del fluido y al mismo tiempo la formación de fenómenos aerodinámicos supersónicos tales como ondas de choque y sus derivaciones a través de la tobera.

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