Revista Brasiliense de Engenharia e Física Aplicada

Guanabara Bay

Proposals for a Territory of Exclusion Born from Paradise — Part II, For a Macro-Engineering Covenant

Nilo Serpa, *Centro Universitário ICESP, Brasília, Brasil;* Richard B. Cathcart, *GEOGRAPHOS,* California, USA.

Received: _08 Oct 2019_ / Accepted: _25 Nov 2019_ / Published: _27 Dec 2019_.

Abstract: Previously, we discussed the prevailing regional eco-cultural situation of Guanabara Bay (GB), characterizing it as a true Exclusion Territory under the action of obviously stressful degenerative anthropogenic phenomena, which have dramatically affected all persons living in its vicinity. Having suggested actions that could mitigate the damages already caused to the environment and the population, this detailed article completes the general proposal presented in PART I of our research on the possible creation of a pipeline system transferring pressurized oceanic seawater extracted from the South Atlantic Ocean to the vast shallow interior of upper GB, presenting a viable alternative that can become useful to other similarly distressed nations in Earth's biosphere. In summary, because of our confidence in the effectiveness of geographically large-scale ambitious megaproject plans for the orderly and sustainably use and enjoyment of both public and private urban spaces, our strongly suggestive study constitutes an aspirational Macro-Imagineering prospect for the recovery of the remaining mangrove forests, famed beaches and fishing activity within GB, rescuing and enhancing a potential quality of life for GB's permanent bayfront human population.

Key words: Guanabara Bay, human quality of life, seawater pipeline system.

Resumo: Anteriormente, discutimos a situação ecocultural vigente na Baía de Guanabara (BG), caracterizando-a como um verdadeiro Território de Exclusão sob a ação de fenômenos antrópicos degenerativos que afetam dramaticamente todas as pessoas que vivem em sua vizinhança. Tendo sugerido ações que poderiam mitigar os danos já causados ao meio ambiente e à população, este artigo detalha e completa a proposta geral apresentada na PARTE I de nossa pesquisa sobre a possível criação de um sistema de dutos transferindo água de mar aberto pressurizada, extraída do Atlântico Sul, para o interior raso da BG, apresentando uma alternativa viável que pode se tornar útil a outras nações igualmente afetadas pela degradação ambiental de suas regiões costeiras. Em suma, devido à nossa crença na eficácia de megaprojetos para o uso e o aproveitamento sustentável de espaços urbanos públicos e privados, o presente estudo, altamente sugestivo, constitui uma perspectiva macro-imaginativa para a recuperação dos manguezais, das praias famosas e das atividades de pesca na BG, resgatando e aumentando a qualidade de vida da população do seu entorno.

Palavras-chave: Baía de Guanabara, qualidade de vida, sistema de transferência de águas oceânicas.

1. Introduction

One of the most surprising and inexplicable facts is the absence of wise and timely investments in necessary environmental recovery, when it is known that classical physics offers sufficient theoretical and experimental evidence to account for most of the environmental problems [1-4], and that humanity's survival for a little more Geologic Time in Earth will depend on such investments. More than that, people go hungry by millions, suffering from diseases caused by disgustingly poor water quality; despite this, it seems few anywhere are thinking seriously of large-scale application of technically simple and low-cost fluid pumping devices that hold the possibility to extinguish the daily existential agonies of bayfront-sited people worldwide. Our Earth is a marine habitat, especially for residents of its Southern Hemisphere [5]! In fact, on the basis of the ratio of maximum length of the major bay axis (~30 km) to the entrance width (~1.5 km) — in this particular instance, about 20 — GB qualifies oceanographically as an **enclosed sea** characterized by markedly inhibited tidal flushing, a non-oceanic

Corresponding Author: Richard Brook Cathcart, *GEOGRAPHOS*, rbcathcart@gmail.com.

This work was sponsored by

UNIDESC Centro Universitário

sea-wave climate, variable seawater salinity and temperature vertical and horizontal structure, a marginal sedimentary basin as well as a pollutant trap, with a unique and distinctive aquatic ecosystem different from the South Atlantic Ocean adjacent. This enclosed sea is a relatively quiescent seascape, the external seawater flow is micro-tidal and the exchange between GB and the ocean is the most important hydrodynamical mechanism for the transport and dispersion of pollutants as well as substances such as nutrients and deposited sediments. Wherever pollutants are retained in the GB for some time, entrapment of the effluvial of GB's urban syndrome streams is the essential cause [6]. The bay-bottom is festooned with macroscopic trash. Tidal measurements done by Sanches Dorta during AD 1781 commenced near the entrance to GB close to Rio de Janeiro. Interfering modern landfills such as Fundão Island and the nearby International Airport have already slowed the normal seawater circulation of the western part of the GB. Because of the intentionally designed dimensions of its present-day main navigation channel, dug to accommodate the largest passing ocean-going vessels, the intensity of shipping and the maneuverability of the various types of vessels, it may be that alterations of the central navigation channel amplified the tide somewhat in the farthest reaches of uppermost GB. Certainly, rapid settlement of the steep slopes of the suburb of Niteroi City after the construction of the 8.8 km-long over-water section of the Rio-Niteroi Bridge intensified GB sedimentation after its completion during 1974 AD. Possibly the installed submarine sewage outfall situated in Jurujuba Sound deflects currents. In any case, we have foreseen that GB seawater movements post-device emplacement, may cause circulatory reactions as yet undiscerned by macro-imagineers. However, it was L.M. Mayr who anticipated the true possibility that very shallow areas of the GB can be flushed by a cleansing tide-induced seawter circulation [7]; we are first to appreciate that simple seawater pumping devices may in future improve on Nature's extant tidal regime at GB.

Guanabara Bay (GB) and its landscape surround—Nature's physiographic artwork already hugely modified by industrious and ecologically thoughtless humans—is hereby characterized a real-world territory of social exclusion, "aquacide" [8] as proposed by Roger H. Charlier (1921-2018) and even a possible 21st Century future place for "disaster tourism" [9] due to the increasingly visible pollution of its shallowest, most inland seawater mass. As a coastal body of seawater body belonging to a country with severe eco-social disfunctions, nowadays GB is a watery cast-off aquatic waste-bin of unwanted and unneeded anthropogenic exogenous substances. Since even Petrobras and others [10] may not care much about the actual poisoning of the Bay by petrochemical emissions, spills and dumped infrastructure castoffs, nevertheless we still maintain the hope that, as a foreign researcher as well as a proud citizen, we can together establish and disseminate to the immediate region's despoliation-beset human community a doable mechanical means to rehabilitate that coastal landform whose current state of near-term social abandonment affects, at different levels, about ten million human beings, both Brazilians and visitors.

Film-makers in Hollywood have "…been largely responsible for 'inventing' a specific image of Rio de Janeiro for world consumption" (11, page 52). 2017's ***Geostorm***, at time 1.06.23 shows Rio de Janeiro beachgoers dressed as 1962's "The Girl from Ipanema" (AKA, Helo Pinheiro) instantly frozen to death because of errant beamed-energy operations of a sabotaged world weather control satellite command-post. If instead we presume that GB is truly a reflection of prevailing local human consciousness [12], set to a modern-day song music superseding the still popular *bossa nova* jazz, then some substitute must please the cariocas and others; it cannot be virtual hang-gliding over Rio de Janeiro backgrounded by a nearly 60 year-old enjoyable tune [13]! Claude Levi-Strauss

(1908-2009) unkindly epitomized the narrow GB entrance/exit channel as an ugly toothless human mouth; shamefully, today in the 21st Century period of our world's ocean losing "breath" due to basin-scale hypoxia, he might perhaps have added that the GB has aquatic halitosis [bad-breath] in the form of polluted and contaminated seawater during its ebb-tide "exhalations" (14)!

Whilst there is always curative hopes, certainly there is no single technological GB recovery solution solving all eco-social ills at once. Political will, education and waste management in a broad context of environmental governance are among the main promoters of a sustainable project for the recovery of coastal or inland seawater bodies with effectiveness on the long term. It is high time to understand that we need to tenderly modify our Earth-world's beloved regions such as GB .

2. The SIBEO Perspective

In the PART I of our work, we discussed the possibility of a macroproject comprised of pipelines transporting oceanic water, under pressure, to the stagnant shallow northernmost areas of the GB, creating a suitably piped artificial non-tidal seawater current capable of massive renewal of bay waters, thus promoting a more immediate bubbled oxygenation for the rehabilitation of fisheries. In search of similar experiences, fortuitously we have been offered an interesting proposal: the SIBEO initiative originating in Mexico.

The Wave Energy-Driven Seawater Pump (SIBEO in Spanish language) developed at the National University of Mexico (UNAM) may be an viable alternative to cleanse and improve the level of oxygenation in stagnated areas of GB by injecting open-ocean seawater abstracted from the surf-zone of the South Atlantic Ocean coastline, from Maricá to Itaipuaçú municipalities, allowing the unmolested passage of living marine organisms and reinvigorating the fisheries of bay-bordering municipalities (see Figure 2). Since SIBEO uses the available ever-renewing kinetic-energy of sea-waves, the operational monetary costs are thus very low. Certainly, financial affordability is a key requisite for any GB macro-project! Enhancing the hydrodynamics of GB seawater circulation, treating ghastly in-tributary organic sewage sent into GB with UV and heated carbon dioxide bubbles [15-16] and utilizing physical boom barriers/racking filters to preclude debris carelessly thrown into the contributory degraded rivers from entering an contaminating the GB might induce the once truly glorious mangrove forests to recover, a fostered rehabilitation result. Only ~30% of GB's pre-Columbian mangrove forest still exists [17], only 0.00694226% of the Earth-biosphere's estimated 1,152,361 km^2 total [18]. In face of similarities among the developing countries with respect to their environmental problems arising exclusively from overall inadequate water-seawater management, we think that efforts towards a Brazil-Mexico R&D technological co-operation would bring great benefits to both nations, as well as important gains in empirical Science advancement. A covenant on coastal waters governance for the countries of Latin-America could emerge from this international cooperation.

3. Physical Principles

The formalism for hydrodynamical modeling given by Czitrom *et al*. [19-20] came from Daniel Bernoulli's theorem, according to which, throughout any current line, the sum of the kinetic, piezometric and pressure energies is constant. In fact, this theorem is an extension of the principle of energy conservation. Czitrom and his co-workers begin with two non-linear time-differential equations coupled by an air-compression term (the forth term of both equations) to be submitted to numerical integration:

$$\left(\chi_1 + L_1\left(1+\varepsilon_1\right) + \frac{T}{\cos\theta}\right)\ddot{\chi}_1 + \frac{\dot{\chi}_1^2}{2} + \left(\frac{K_1}{2} + f_1\right)\dot{\chi}_1\left|\dot{\chi}_1\right|$$

$$+\frac{P_A-\rho gH}{\rho}\left[\left(1-\frac{A_1\chi_1-A_c\chi_2}{Vo}\right)^{-\gamma}-1\right] \quad (1)$$
$$+g\cos\theta\chi_1=W;$$

$$\left(\chi_2+L_2\left[\frac{A_c}{A_2}(1+\varepsilon_1)+\frac{L_c}{L_2}\right]\right)\ddot{\chi}_2+\frac{\dot{\chi}_2^2}{2}+\left(\frac{K_2}{2}+f_2\right)\dot{\chi}_2|\dot{\chi}_2|$$
$$+\frac{P_A-\rho gH}{\rho}\left[\left(1-\frac{A_1\chi_1-A_c\chi_2}{Vo}\right)^{-\gamma}-1\right] \quad (2)$$
$$+g\chi_2=0,$$

where:

1)- χ is the surface displacement in either duct with respect to the equilibrium level in compression chamber;
2)- Subscripts 1, 2 and *c* correspond, respectively, to resonant duct, exhaust duct and compression chamber;
3)- L_1 and L_2 are the resonant and exhaust lengths;
4)- Vo is the compression chamber volume;
5)- γ is the air compressibility;
6)- ρ is the seawater density;
7)- $g\cos\theta$ is the reduced gravity due to the inclination of resonant duct at compression chamber;
8)- W is the wave forcing computed by the resonant duct equation (1).
9)- A is the surface area.

Coupled, equations (1) and (2) incorporate Bernoulli’s theorem by the second and fifth terms. Simulations were well performed by Czitrom *et al*. [1], with a model seawater pump driven by sea-waves of various spectra imitating the real world-ocean surface and testing the response of the system to each frequency component, so that there is no need to summarize this point. It is enough to note that, since in practice Bernoulli's theorem is not rigorously verified because of the presence of viscosity (friction) and formation of vortexes along the ducts, the coupling includes a non-linear third term that are not in Bernoulli’s equation in order to account for friction and vortex losses, and radiation damping. This damping term includes the factor

$$\left(\frac{K_1}{2}+f_1\right)$$

also to allow energy extraction from the system. Lastly, the first term accounts for the inertia, and the restoring force on the oscillating system is assigned by the compression of the air-chamber combined to the gravitational force.

A brief refresher on Daniel Bernoulli’s Theorem

To induce a certain current in a known and mapped stagnant area of the GB we must play by the rules established with Bernoulli's theorem. There is a tangential acceleration caused by a pressure difference in the direction of motion. Contrary to what one may mistakenly intuit, a lower pressure causes a higher velocity. A simple, reasoned deduction of Bernoulli’s equation from Newton’s law is sufficient to

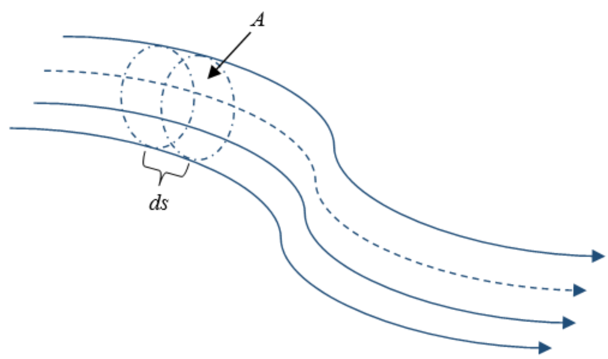

Figure 1 – A small segment of seawater flux.

clarify this fact. Now, let us take a very little Salami-slice piece of seawater held within an impermeable walled duct (Figure 1). This infinitely small mass element moves as a full conduit to which any mass variation is given by

$$dm=\rho Ads.$$

According to Newton's law, we may write

$$F = dma = \rho A ds \frac{dv}{dt}.$$

But, $F = AdP$, where P is the pressure, so that

$$A \frac{dP}{ds} \delta s = \rho A \delta s \frac{dv}{dt}.$$

Simplifying, we gain

$$\frac{dP}{ds} = \rho \frac{dv}{dt} = \rho \frac{dv}{ds} \frac{ds}{dt} = \rho v \frac{dv}{ds}.$$

Then,

$$dP = \rho v dv.$$

We can integrate this expression along the path z in the flux trajectory, such as

$$\int_z dP = \rho \int_z v dv,$$

so reaching the formal result of Daniel Bernoulli's theorem

$$P_{z_1} - P_{z_2} = \frac{\rho}{2}\left(v_{z_2}^2 - v_{z_1}^2\right),$$

an equality that clearly shows the relationship between increasing pressure and decreasing velocity. So, the GB SIBEO device must govern this relationship to gauge the seawater current mainly to refresh the internationally notorious most northern parts of Brazil's polluted upper GB. In fact, as described in Czitrom et al., the experimental pump implemented was just fully instrumented with seawater height-sensors and piezoelectric pressure sensors. Also, the device was prepared to measure the fluid's flow rate through the pump.

5. The *Organum Hydraulicum* in a Preliminary Approach

Organum Hydraulicum is the name we gave to the set of ducts that make up our macro-version of the SIBEO system, because the configuration of the discharge of sea water resembles the tubes of a church organ. The system was conceived for an average tidal volume of 268,000,000 cubic meters (m^3). The hourly flow needed to induce the anthropogenic tide, assuming 20% of the total value, would be 53,600,000 cubic meters per hour (m^3/h), which provides approximately 14,889 cubic meters per second (m^3/s).

The Bresse-Forchheimmer equation relates the diameter of the water duct in *m* (*D*) to the flow in m^3/s (*Q*) and the operating period of the system in hours per 24 hours (*x*), so that

$$D = C\sqrt{Q}\sqrt[4]{x},$$

where *C* is a constant[1]. Applying this formula for the calculation of the total pipe diameter[2], considering a realistic value of the constant *C* (= 0.75) and an operating period of 8 hours for every 24 hours, we obtain

$$D = 0.75\sqrt{14{,}889}\sqrt[4]{0.3333} \simeq 69.535m.$$

This is equivalent to 12 ducts of 5.8 *m* in diameter. Although the resonance compensation system directly influences the efficiency control, it is important to have a notion of the loss of charge per duct. Williams-Hazen's formula,

[1] The constant *C* is still controversial, seeking to reflect the relationship between investment cost and operating cost.

[2] Strictly speaking, the Bresse-Forchheimmer formula calculates the diameter of the rebound pipe in everyday cases of hydraulic projects. However, since in the project discussed there is no conventional suction pumping system and taking into account there will always be an elevation of the water from the sea level, we extrapolate the application of the formula, not ruling out possible further adjustments.

$$J = 10.641 \times c^{-1.852} \times D^{-4.87} \times Q^{1.852},$$

allows estimating the loss of load J in meters per meter (m/m), c being a constant that expresses characteristics of the internal surface of the duct (for concrete with a good finish, c = 130). Thus,

$$J = 10.641 \times 130^{-1.852} \times 5.8^{-4.87} \times 1,241^{1.852} \simeq$$

$$\simeq 0,133 m/m.$$

This would result in a loss of approximately 4 kilometers to be regulated by the compression chambers.

6. Technical Features

The most efficient geodetic trajectory for the resonant pipeline would cover approximately 30 kilometers, coming from the South Atlantic over the lagoon of Maricá, passing through the locality of Jardim Catarina and arriving at the northeast border of the GB in the immediate vicinity of the present ecological station (Figure 3). It is a place dominated by lowlands, interspersed by reliefs of low altitude. Except for some odd geological obstacle, most of the path chosen crosses a relatively free region. The route was designed taking into account the least possible urban impact and the lowest load losses. Also, the choice of the pipeline entrance zone was guided by the large supply of ocean waves in the area; it is well known the force of waves in the municipality of Maricá, which suffers occasional damage caused by the invasion of the sea. Thus, the great exposure of the coast of Maricá to the storm waves (swelling) of the southern quadrant makes this locale ideal for exploitation of the sea oscillation mechanical energy. An automatic system of floodgates in the vicinity of the lagoon of Maricá, comprising all 12 ducts, will allow the control of the influx of sea water according to the periods of tide. As in former SIBEO project, since the wave frequency changes in time, large variable volume compression chambers will be installed to adjust resonance.

Compared to the so-called "Great Man-made River", the ambitious Libyan irrigation network with more than 3,700 kilometers of pipelines, the *Organum Hydraulicum* will require a much smaller amount of prestressed concrete pipes, something around 360 kilometers, weighing between 70 and 90 tons each pipe unit. We expect that cranes of about 450 tons will be needed for the installation of concrete cylinders.

7. Final Remarks

It is not a question of sweeping the waste into the open sea. All measures to control dumping in GB should be concomitant with the implementation of the proposed anthropogenic sea dynamics. Environmental education certainly underlies these measures, in addition to a major effort to oversee the companies that currently pollute GB. The cost of implementing the project, although certainly high, is justified by the non-measurable social gain, as well as the medium-to long-term economic return of tourism and fishing activities**,** reminding that sanitation measures drastically reduce public health costs**.**

The beach system of the locality of Maricá is very dynamic, causing extreme events of storm and arrival of sea water beyond the coastline. All Maricá beaches are classified as exposed, which is why this project may include protection devices mainly on a critical point of the coast, the beach of Barra de Maricá, providing even the stabilization of waves for surfing. As can be seen, the gains are many, not only for the municipalities on the edge of GB, but for a whole region rich in tourism potential. It remains to be seen whether, behind the insidious corruption that punishes us for so many decades, there is true will and manhood for this important step towards social development.

8- Acknowledgements

This article was elaborated within the Postgraduate Program in Inclusion and Social Development of UNIDESC - University Center. The authors thank Tânia Rossi from UNIDESC for the support and encouragement of this research.

References

[1] Costa, L.A. *et al*. (July 2018). "Chemical and biological indicators of sewage river input to an urban tropical estuary (Guanabara Bay, Brazil)" *Ecological Indicators* 90: 513-518.

[2] Aguiar, V.M *et al*. (August 2018) "Environmental assessment concerning trace elements and ecological risks at Guanabara Bay, RJ, Brazil" *Environmental Monitoring and Assessment* 190: 448.

[3] Olivatto, G.P. *et al.* (February 2019) "Microplastic contamination in surface waters in Guanabara Bay, Rio de Janeiro, Brazil" *Marine Pollution Bulletin* 139: 157-162.

[4] Silva, M.M. *et al*. (April 2019) "Dispersal of potentially pathogenic bacteria by plastic debris in Guanabara Bay, RJ, Brazil" *Marine Pollution Bulletin* 141: 561-568.

[5] Hessler, S. (Ed.) (2018) *Tidalectics: Imagining an Oceanic Worldview through Art and Science.* The MIT Press. 240 pages.

[6] Fonseca, E.M. *et al.* (20 September 2013) "Stormwater impact in Guanabara Bay (Rio de Janeiro): Evidences of seasonal variability in the dynamic of the sediment heavy metals" *Estuarine, Coastal and Shelf Science* 130: 161-168.

[7] Mayr, L.M. *et al.* (1989) *"Hydrobiological characterization of Guanabara Bay"* pages 124-138 IN Magoon, O. and Neves, C. (Eds.) *Coastlines of Brazil*. New York: American Society of Civil Engineers.

[8] Charlier, R.H. (1999) "Aquacide—an urgent need to legislate to protect: viewpoint and review" *International Journal of Environmental Studies* 56: 325-343.

[9] Frank, T..O. (November 2014) "Neologisms in the Language of Tourism as Indicators of Innovativeness in Tourism" *Academica Turistica* Year 7: 73.

[10] Gomes, O.V.O. *et al.* (2019) "Origin of salinity and hydrogeochemical features of porous aquifers from northeastern Guanabara Bay, Rio de Janeiro, SE-Brazil" *Journal of Hydrology: Regional Studies* 22: 1-15.

[11] Freire-Medeiros, B. (Summer 2002) "Hollywood Musicals and the Invention of Rio de Janeiro, 1933-1953" *Cinema Journal* 41: 52-66.

[12] Nasar, J.L. and Li, M. (2004) "Landscape mirror: the attractiveness of reflecting water" *Landscape and Urban Planning* 66: 233-238. SEE also: Filho, E.P.M. *et al* (June 2016) "Global, diffuse and direct solar radiation at the surface of the city of Rio de Janeiro: Observational characterization and empirical modeling" *Renewable Energy* 91: 64-74 and Lee, Z. *et al*. (March 2019) "Estimating the transmittance of visible solar radiation in the upper ocean using Secchi disk observations" *Journal of Geophysical Research: Oceans* 124: 1434-1444.

[13] Soares, L.P. *et al.* (4 August 2005) "Virtual Hang-gliding over Rio de Janeiro" SIGGRAPH '05 ACM SIGGRAPHY 2005 Article No. 29.

[14] Iwata, N. and Rio, V. del (1 December 2004) "The Image of the Waterfront in Rio de Janeiro: Urbanism and Social Representation of Reality" *Journal of Planning Education and Research* 24: 171-183.

[15] Kelly, C.B. (November 1961) "Disinfection of sea water by ultraviolet radiation" *A.J.P.H.* 51: 1670-1680.

[16] Sanchis, A.G. *et al.* (2019) "Virus and bacteria inactivation by CO_2 bubbles in solution" *Clean Water* 2: 5.

[17] Santi, L. *et al.* (2006) “Patterns of Species Richness and Species Density of Sublittoral Soft-bottom Polychaettes in a Grossly Polluted Urban Bay: Guanabara Bay, Rio de Janeiro, Brazil” *Journal of Coastal Research* SI39: 1127-1131.

[18] Doughty, C.L. *et al.* (2016) “Mangrove Range Expansion Rapidly Increases Coastal Wetland Carbon Storage” *Estuaries and Coasts* 39: 385-396.

[19] Czitrom, S.P. (1997) “Wave Energy-Driven Resonant Sea-Water Pump” *Journal of Offshore Mechanics and Arctic Engineering* 119(3): 191-195.

[20] Czitrom, S.P. ; Coronado, C. ; “Nunez, I. Flushing of the port of Ensenada using a SIBEO wave-driven seawater.” in 9th Pan American Congress of Applied Mechanics (PACAM 9), 2006. Merida, MEXICO: *Mathematical Science Publ*.

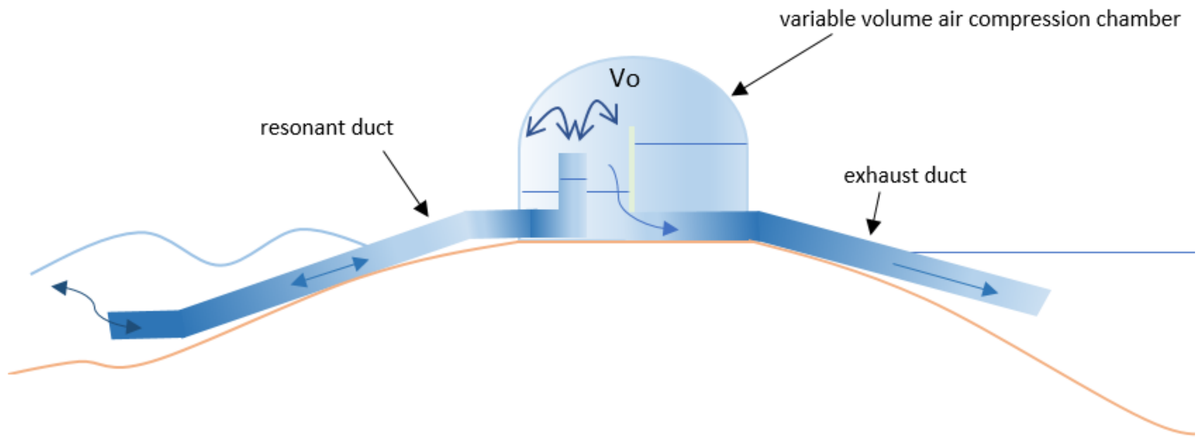

Figure 2 – The scheme of SIBEO engine.

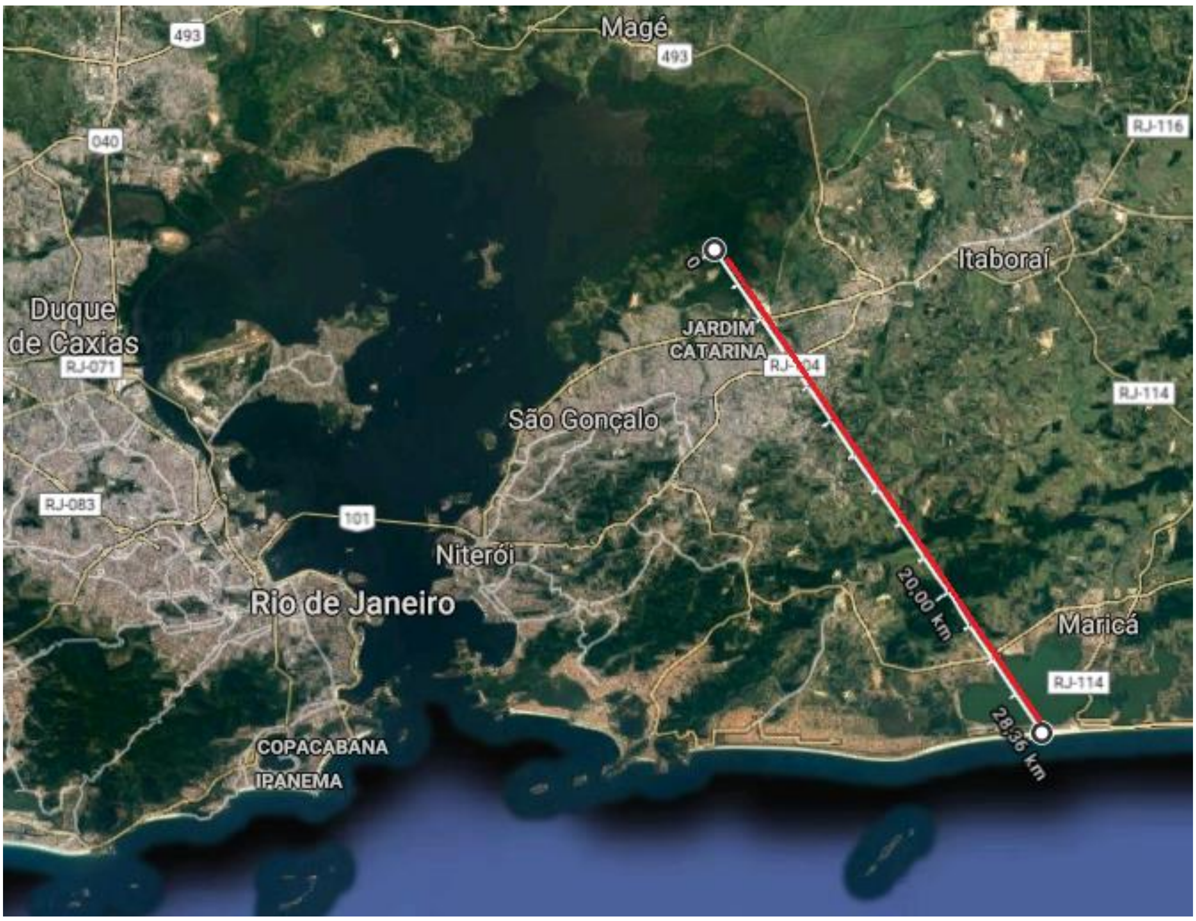

Figure 3 – The most efficient geodetic path.