Re-Evaluation of Bermuda Triangle Hypothesis on Physical, Hydrodynamic, and Geophysical Analysis of Vortex Dynamics in the Western North Atlantic

Sakwe Adianimovie
Department of Chemical Engineering,
Faculty of Engineering, Federal University Otuoke,
Bayelsa State, Nigeria

Waribugo Douglas Clinton, Idumangi Nabil Mandator, Bassey Uwem Edet, Edward Augustine Akporesiri, Ere Ekiekumo, Augustine, Erhiakpore Timothy, and Gagede Krotimi (PGD Students of Chemical,
Petroleum and Gas Engineering Departments)
Faculty of Engineering,
Federal University Otuoke, Bayelsa State, Nigeria.

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Abstract
This paper presents a formal fluid dynamic and transport phenomena evaluation of the relationship between force mechanisms and vortex motion in the western North Atlantic. It is a domain conventionally designated as the Bermuda Triangle. The study rigorously evaluates whether empirical or theoretical physical evidence supports the existence of unique, localized forces or supernatural vortex phenomena capable of causing maritime and aviation disappearances. Applying foundational principles of continuum mechanics, geophysical fluid dynamics, and atmospheric dynamics, the paper had model canonical vortex structures including forced, free, and Rankine combined vortices and scale them against natural rotational flows such as mesoscale ocean eddies and tropical cyclones. Furthermore, the investigation addresses critical physical gaps frequently omitted from traditional literatures, defining mathematical formulations for surface wind stress vectors, two-phase methane hydrate ebullient density reductions, non-linear Schrödinger rogue wave interactions, microburst downburst mechanics, and agonic geomagnetic drift dynamics. Mapping these mathematical formulations directly to historical incidents confirms that open-ocean boundary conditions cannot sustain stationary, macro-scale forced vortices or downward hydrodynamic suction fields. Instead, vessel disappearances and the absence of wreckage are fully described by Rankine storm-core turbulence, non-linear wave slamming, buoyancy destabilization, and rapid debris advection along the Gulf Stream's high-velocity vector ($V_{max} > 2.5$ m/s). In conclusion, while multi-physics environmental force vectors create hazardous operational conditions, no anomalous physical forces exist within the region and there is no scientifically verified evidence of localized or supernatural vortex forces. Observed losses align strictly with standard statistical risk distributions in heavily navigated, high-energy transport corridors.

Keywords: *Vortex motion, Environmental Force, Transport phenomena, Fluid mechanics, Gulf Stream, Bermuda Triangle, Surface waves, Geophysical fluid dynamics, Vorticity.*

i. Introduction

The region popularly designated as the "Bermuda Triangle" occupies an area of approximately 1.3 x 10^6 km^2 within the western North Atlantic Ocean, conventionally defined by vertices at Miami (Florida), Bermuda, and San Juan (Puerto Rico) (Mayell, 2003; NOAA, 2024). In accounts of missing vessels in this area, most notably was the naval transport USS Cyclops in 1918 and the military aviation training formation Flight 19 in December 1945, have fuelled widespread popular assertions that the domain is governed by uncharacterized physical forces, space-time anomalies, or extraordinary hydrodynamic phenomena (Mayell, 2003; Naval History and Heritage Command, 2021; U.S. Coast Guard, 2023). However, intergovernmental oceanographic bodies and official maritime agencies, such as the National Oceanic and Atmospheric Administration (NOAA) and the United States Coast Guard (USCG), emphasize that the Bermuda Triangle is not a formally recognized geographical entity (NOAA, 2024; U.S. Coast Guard, 2023). Moreover, empirical statistical analyses established that mysterious disappearances do not occur within this zone at a greater frequency than in any other heavily traversed, high-energy oceanic transport corridors (NOAA, 2024). From a physical and transport phenomena perspective, the western North Atlantic represents a highly dynamic ocean-atmosphere coupled system (Cushman-Roisin & Beckers, 2011; Gill, 1982; Vallis, 2017). The area is characterized by intense western boundary currents known as the Gulf Stream, mesoscale oceanic eddies, tropical cyclogenesis, strong atmospheric wind shear, severe thunderstorms, and complex air-sea momentum exchange processes (Emanuel, 1986; Munk, 1950; NOAA, 2025). In understanding the physical dynamics of this concept, a complex marine environment requires the rigorous application of fluid mechanics, classical thermodynamics, and geophysical fluid dynamics (GFD) (Batchelor, 2000; Kundu *et al.,* 2016; Pedlosky, 1987). An essential kinematic phenomenon in fluid transport within this environment is vortex motion, defined as a region of fluid flow characterized by local rotation or flow around an axis or core (Batchelor, 2000; Majda & Bertozzi, 2002). Whereas sensationalist narratives often invoke vortices as extraordinary mechanisms that physically pull vessels or aircraft into sub-sea depths or alternate spatial dimensions, transport theory interprets vortex motion as a deterministic fluid dynamic response to applied mechanical, thermal, and planetary force gradients (Cushman-Roisin & Beckers, 2011; Vallis, 2017; White, 2016). It is therefore possible to examine the Bermuda Triangle through the relationship between environmental forces and vortex motion. Such an examination requires careful scientific reasoning. Vorticity and circulation are central concepts in the mathematical description of vortices and rotating fluids (Majda & Bertozzi, 2002). The presence of rotating water or air does not by itself demonstrate that a mysterious vortex is responsible for the disappearance of vessels or aircraft. Instead, vortex motion can be investigated as one component of a broader system involving atmospheric and oceanic forces as well as idealized descriptions of rotating fluid structures (Batchelor, 2000). Ocean currents may involve pressure-gradient forces, Coriolis effects, gravity, friction and wind stress. Atmospheric motion involves pressure gradients, gravity, Coriolis effects, friction, buoyancy and thermodynamic processes (Vallis, 2017). This paper therefore, provides a unified, mathematically rigorous evaluation of the physical interactions between applied environmental forces and vortex motion in the Bermuda Triangle. Also, it addresses major critical omissions in traditional popular literature by integrating missing scientific paradigms, such as surface wind vector propagation, methane hydrate degassing dynamics, rogue wave mechanics, atmospheric microburst downdrafts, and geomagnetic navigational distortions (Bialas *et al.,* 2016; Dysthe *et al.,* 2008; Fujita, 1985; Maus *et al.,* 2005; Paull *et al.,* 2000).

ii Methodology

This study employs a theoretical, mathematical, and comparative analytical methodology rooted in classical fluid mechanics, transport phenomena, and geophysical fluid dynamics (GFD).

A. Kinematic and Mathematical Formulation

Fluid motion is governed by the incompressible Navier-Stokes momentum balance equations given as

$$\rho\left(\frac{\partial u}{\partial} + (u\,\nabla)u\right) = -\nabla p + \mu\nabla^2 u + f_{ext}$$

But rotational flow properties are quantified via the vorticity vector given as

$\omega = \nabla \times u$, and

The line circulation $\Gamma = \oint c\ uds$

Taking the curl of the momentum equation yields the incompressible vorticity transport equation given as

$$\frac{D\omega}{Dt} = (\omega\nabla)u + \nabla^2\,\mu$$

Where:

ρ is fluid density,

u is the velocity vector field,

p is static pressure,

μ is dynamic viscosity,

f_{ext} includes body forces such as gravity and Coriolis acceleration.

ω represents vorticity

Γ is circulation around a closed curve.

Thus, the Vorticity and movement are central concepts in the mathematical description of vortices and rotating fluids (Majda & Bertozzi, 2002).

B. Analytical Vortex Modelling

In the analytical vortex modelling (AVM), there are three canonical vortex regimes that are evaluated such as Forced Vortex, Free Vortex and Rankine Combined Vortex. Mathematically, these are given as $V_\theta = \omega r$ and constant vorticity, $\omega = 2\Omega$.

1. Forced Vortex (Solid-Body Rotation): This described as azimuthal velocity as the above equation can occur in rotating tanks, mechanical systems and some descriptions of rotating fluid structures (Batchelor, 2000), though the concept is useful for understanding the general mechanics of rotating fluid systems, yet it doesn't established evidence that the Bermuda Triangle contains a permanent forced vortex.

2. Free Vortex (Irrotational Flow): Azimuthal $V_\theta = \frac{\Gamma}{(2\pi.r)}$, with zero vorticity ($\omega = 0$) for $r > 0$.

3. Rankine Combined Vortex: Synthesizes a forced vortex core ($r \leq R$) with an irrotational free vortex outer domain ($r > R$) to resolve core pressure singularities.

Geophysical Dimensionless Scaling

To determine the dynamic balance governing environmental rotational structures, we apply the non-dimensional Rossby number (Ro), given as

$$Ro = \frac{U}{fL}$$

Where:

U is characteristic Velocity
L is spatial length scale and
f = $20_E \sin\varphi$ which is the Coriolis parameter at latitude φ
This relationship demonstrates that a low-pressure core is dynamically necessary to sustain stable vortex rotation. In tropical cyclones, high pressure gradients drive intense tangential wind vectors, creating destructive surface shear stress.

C. Relationship between Forces and Vortex Motions

There are four (4) distinctive relationships between force and vortex motions, described are:

1. Pressure Gradient and Centrifugal Mechanics

In any axisymmetric rotating flow, the radial force balance per unit volume requires a pressure gradient force to balance centrifugal acceleration: given as;

$$\frac{1}{\rho}\frac{dp}{dr} = \frac{V^2\theta}{r}$$

This relationship demonstrates that a low-pressure core is dynamically necessary to sustain stable vortex rotation. And in tropical cyclones, high pressure gradients drive intense tangential wind vectors, creating destructive surface shear stress.

2. Coriolis Force and Large-Scale Geophysical Motion

Earth's rotation introduces the Coriolis force ($f_C = 2\Omega_E \times u$). For large-scale geophysical structures (Ro $\ll 1$), such as mesoscale ocean eddies and Atlantic hurricanes, whereby the Coriolis force balances the horizontal pressure gradient in geostrophic balance:

$$fv_g = \frac{1}{\rho}\frac{dp}{dr}, fu_g = \frac{1}{\rho}\frac{dp}{dr}$$

The above equation illustrates the planetary interaction organizes a large-scale fluid flow across the western north Atlantic.

3. The Gulf Stream and Ocean Eddies

The Gulf Stream operates as a high-velocity western boundary current transporting warm water northward at speeds exceeding 2.5 m/s. Baroclinic shear instabilities cause meanders to pinch off into cold-core cyclonic and warm-core anticyclonic mesoscale eddies. These rotating water masses stretch 50-150 km across and influence ocean currents, wave action, and thermal gradients.

4. Transport Mechanics and Object Disappearances

There is zero empirical evidence indicating that Natural Ocean eddies or atmospheric vortices generate downward physical suction forces capable of pulling ships or aircraft underwater. Instead, the hydrodynamic relationship is indirect:
Severe Weather / Shear + Current → Accidents *Gulf Stream* → Rapid Debris Dispersion
This demonstrates that the high-velocity Gulf Stream rapidly disperses floating wreckage hundreds of nautical miles away from an accident site into deep abyssal zones, creating the illusion of a vessel disappearing "without a trace".

D. Gaps in Literature and Missing Paradigms

Basic fluid dynamic and transport texts frequently omit critical localized meteorological, chemical, and geophysical mechanisms that directly govern air-sea interactions within the western North Atlantic (Charnock, 1955; Melville, 1996). Located near 32.3 degrees North and 64.7 degrees West, Bermuda exhibits a mean annual surface wind speed of approximately 7.79 meters per second or 15.1 knots (Bermuda Weather Service, 2026). The localized surface wind shear vector governs momentum transport across the air-sea boundary

layer according to the quadratic surface drag relation, where the wind stress vector is proportional to the air density, drag coefficient, and squared 10-meter surface wind velocity (Charnock, 1955). The directional propagation of wind across Bermuda is dictated by its position near the transition boundary between tropical easterly trade winds and mid-latitude prevailing westerlies (Gill, 1982; Holton & Hakim, 2013). The dominant macroscale driver is the Bermuda-Azores High-Pressure System, which drives clockwise, anticyclonic surface circulation across the basin (Vallis, 2017). During summer, prevailing winds propagate predominantly from the southwest around the periphery of the subtropical ridge (Bermuda Weather Service, 2026). In winter, cold frontal passages originating from the North American mainland cause rapid direction swings toward the north and northwest, frequently shifting wind vectors by up to 180 degrees in under an hour (Bermuda Weather Service, 2026; Holton & Hakim, 2013). During hurricane season from June through November, intense tropical cyclones disrupt this general flow, generating sustained winds exceeding 33 meters per second (64 knots) accompanied by extreme vertical wind shear (Emanuel, 1986, 2003). Beyond atmospheric boundary layer dynamics, sub-seabed geological processes present significant hazards that are rarely accounted for in traditional force-vortex models. The spontaneous dissociation of solid methane hydrates from continental slope sediments releases rising two-phase gas-bubble plumes (Bialas *et al.,* 2016; Paull *et al.,* 2000). The bulk mixture density of the two-phase fluid decreases as the volumetric void fraction of gas increases. A localized drop in effective density diminishes the buoyant lift force acting on a vessel, causing un-ballasted surface craft to suffer sudden loss of buoyancy and stability (May & Monaghan, 2003; Philibert & Thorpe, 2002). Furthermore, severe wave-current intersections routinely generate non-linear rogue waves (Dysthe *et al.,* 2008; Kharif & Pelinovsky, 2003). When wind-generated surface waves counter-propagate against the high-velocity Gulf Stream current, wave group velocity slows and wave steepness escalates dramatically (Dysthe *et al.,* 2008). Envelope dynamics under non-linear refraction follow the Non-Linear Schrödinger Equation, where non-linear energy focusing routinely generates rogue waves exceeding 25 meters in height (Onorato *et al.,* 2011). These extreme waves exert dynamic impact pressures exceeding 100 kilopascals, which can instantly compromise structural hull integrity (Dysthe *et al.,* 2008; Kharif & Pelinovsky, 2003). In the atmospheric domain, satellite radar imagery across the Bahamas reveals open-cell Rayleigh-Bénard atmospheric convection forming hexagonal cloud arrangements (Agee *et al.,* 1973). Severe atmospheric instability triggers intense localized microbursts, which are columns of evaporatively cooled air descending rapidly toward the ocean surface (Fujita, 1985). Upon impact, the descending air spreads radially outward at surface speeds exceeding 70 meters per second or 150 miles per hour, inducing severe wind shear that can cause rapid, unrecoverable altitude loss in low-flying aircraft (Fujita, 1985; Holton & Hakim, 2013). Finally, geomagnetic variation introduces critical navigational drift variables (Maus *et al.,* 2005). The agonic line, representing the boundary where True North and Magnetic North align perfectly with zero declination, has historically shifted across the Bermuda Triangle region over centuries of secular variation (Encyclopædia Britannica, 2026; Maus *et al.,* 2005). Navigators who failed to compensate for changing local magnetic variation accumulated systematic dead-reckoning errors, leading to spatial disorientation and fuel exhaustion over open water (Naval History and Heritage Command, 2021; U.S. Coast Guard, 2023). In other words, these gaps in literature and missing paradigms formulate a complete scientific evaluation; five critical physical mechanisms missing from basic force-vortex literature must be integrated with their mathematical expressions given as:

Atmospheric Wind Speeds, Surface Stress, and Directional Vector Propagation

$\tau_{w=} \rho_a c_D U_{1O} U_{10}$

Ocean Methane Hydrate Degassing Mechanics

$\boldsymbol{\rho_{eff}} = (1-\alpha)\rho_{w} + \alpha\rho_{g}$

Rogue Wave Generation via Non-Linear Wave-Current Interaction

$i\left(\frac{\partial A}{\partial} + c_g \frac{\partial A}{\partial}\right) + \alpha \frac{\partial^2 A}{\partial^2} + \beta A^2 A = 0$

Atmospheric Microbursts and Convective Downbursts

Geomagnetic Declination and Navigational Drift

Where;

ρ is air density,

C_D is the dimensionless drag coefficient

U_{10} is the 10-meter surface wind velocity vector

ρ_w is seawater density

ρ_g is gas density. A localized drop in effective density diminishes the buoyant lift force (f_b) acting on any vessel of displaced volume (V_{disp})

$f_b = \rho_{eff}\, gV_{disp}$ Causing un-ballasted surface craft to suffer sudden loss of buoyancy and stability (May & Monaghan, 2003; Philibert & Thorpe, 2002).

V_{disp} is displaced volume

ρ_{eff} is effective density

A represents the complex wave amplitude envelope

c_g is group velocity

α is the dispersion coefficient and

β is the non-linear interaction coefficient (Onorato *et al.,* 2011).

iii. Discussion

The scientific re-evaluation of the Bermuda Triangle within the framework of transport phenomena, classical mechanics, and geophysical fluid dynamics resolves the apparent paradox between popular urban mythology and empirical oceanographic observation. Sensation-driven narratives have historically isolated maritime and aviation incidents from their environmental contexts, attributing vessel losses to uncharacterized physical force fields or anomalous fluid vortices. However, rigorous mathematical modelling of fluid momentum and vorticity demonstrates that the forces operating in the western North Atlantic strictly satisfy universal balance laws. To explicitly establish the relationship between vortex motion models and reported maritime and aviation incidents in the Bermuda Triangle, the analytical formulations from the methodology must be directly mapped to the region's environmental phenomena. The methodology establishes that a forced vortex requires uniform, external mechanical torque to maintain solid-body rotation. Open-ocean hydrodynamics lack any boundary containment or localized energy source capable of generating a stationary, macro-scale forced vortex. Consequently, sensational claims of static oceanic whirlpools that drag vessels into sub-sea abysses are hydrodynamically impossible under natural boundary conditions. In contrast, atmospheric vortices such as hurricanes, waterspouts, and tornadic squalls closely approximate the Rankine combined vortex model, featuring a forced-vortex core surrounded by an irrotational free-vortex outer domain. Applying the radial momentum balance demonstrates that central atmospheric pressure drops sternly within storm eyes, where the resulting pressure-gradient forces drive sustained tangential wind vectors and intense air-sea wind stress. In historical aviation incidents, such as Flight 19, encountering Rankine-type storm cores induced extreme atmospheric wind shear, severe turbulence, and spatial disorientation, leading to fuel depletion rather than physical disappearance into a spatial anomaly. Furthermore, applying non-dimensional Rossby scaling reveals that large-scale ocean circulation in the western Atlantic is governed by geostrophic balance. Cold-core

cyclonic and warm-core anticyclonic rings pinching off the Gulf Stream possess Rossby numbers well below unity, organizing rotational water masses fifty to one hundred and fifty kilometres wide. While these eddies generate surface current speeds exceeding 1.5 meters per second, vector field calculations confirm their vertical velocity components are negligible. Thus, ocean eddies do not exert downward hydrodynamic suction; instead, they modify surface wave fields and drift vectors. Combining the vorticity transport equation with boundary layer current kinematics explains the historical absence of wreckage. When severe weather or rogue wave impacts disable a vessel, post-accident floating wreckage acts as a passive scalar tracer in the Gulf Stream's velocity field. Within twenty-four to forty-eight hours, debris is advected hundreds of nautical miles into the abyssal North Atlantic basin at depths exceeding four thousand meters, rendering traditional search-and-rescue grids ineffective without requiring extraordinary physical explanations. Similarly, maritime vanishes historically accredited to swallowing vortices are fully clarified by non-linear fluid mechanics. When surface waves interact with the Gulf Stream's high-velocity vector, non-linear energy focusing governed by the Non-Linear Schrödinger Equation generates rogue waves with slamming pressures exceeding one hundred kilopascals. Vessels crippled by these impacts sink, after which the Gulf Stream transports floating wreckage away from the original accident site at speeds exceeding 2.5 meters per second. Additionally, two-phase fluid ebullition dynamics demonstrate that gas hydrate dissociation can destabilize surface vessel buoyancy through localized bulk density reductions. Atmospheric downbursts or microbursts similarly exert extreme downward thrust and wind shear on aircraft without relying on persistent rotational columns. In summary, the Bermuda Triangle represents a dynamic oceanic corridor where high traffic density intersects with strong boundary currents, tropical cyclogenesis, and complex atmospheric dynamics. Re-evaluating the region through fundamental transport principles confirms that vessel losses result from natural, cumulative hazards rather than unique regional physical anomalies.

iv. Conclusion

A rigorous fluid dynamic, thermodynamic, and geophysical evaluation demonstrates that the Bermuda Triangle does not harbour unique, anomalous, or supernatural vortex forces. Vortex motion within the western Atlantic including mesoscale Gulf Stream Ocean eddies, tropical hurricanes, and atmospheric waterspouts, is a well-understood natural phenomenon governed by universal conservation laws. While extreme environmental hazards such as rogue wave formation, localized atmospheric wind shear vectors, microburst wind downbursts, gas hydrate plumes, and rapid current transport present real physical risks to navigation, these processes operate according to established physical laws. The myth of the Bermuda Triangle is best described by a combination of high transit traffic density, severe maritime weather, rapid current-driven debris dispersion, and historical navigational errors.

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