



# Unified Mechanism Explanation of Anomalous Phenomena in Fluid Mechanics Based on the Unified Complex System Theory

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**Abstract:** The ten classic anomalous phenomena in aerodynamics and fluid mechanics have long been plagued by persistent dilemmas such as disconnection between theoretical predictions and experimental observations as well as the failure of global prediction, which restrict the disciplinary development of the field. Established on material monism and passive dynamics, the traditional theoretical system lacks the mechanisms of endogenous active force, multiscale emergence, and mind-ether dual ontological coupling. Moreover, the Navier-Stokes (NS) equations exhibit a narrow scope of application, suffering from sharp accuracy degradation and theoretical invalidation under complex operating conditions characterized by strong nonlinearity and multiscale coupling. Based on the Unified Complex System Theory and Bohmian mechanics, this paper constructs a global unified wave field framework and reconstructs the dynamic equations from the perspective of dual ontology, thereby providing a unified mechanistic interpretation for anomalous fluid phenomena. The research reveals that fluid anomalies originate from the combined effects of microscopic particle coupling, modulation of endogenous active forces, multiscale wave coherence, and nonequilibrium transition. It is demonstrated that the NS equations merely serve as a degenerate approximate model derived from the unified wave equation. The proposed new model bridges scales from the micro to the macroscale, offering a unified theoretical pathway for disciplinary theoretical innovation as well as engineering applications in aerospace, hydraulic engineering and related fields.

**Keywords:** Unified Complex System Theory, Unified Wave Field Theory, fluid mechanics anomalies, active force, symmetry breaking, drag crisis, boundary layer transition, ether particles, collective wave motion

## INTRODUCTION

As the core foundational branch integrating classical physics, applied mechanics and modern engineering sciences, aerodynamics and fluid mechanics has evolved over more than three hundred years. Since Newton, Bernoulli and Euler laid the theoretical prototype, and Navier and Stokes established the governing equations for viscous flow, the discipline has undergone theoretical deduction, experimental exploration and engineering iteration. It now profoundly underpins the whole industrial chain of national economy, national defense and military industries, including aerospace, marine and ship engineering, power and energy engineering, rail transit, hydraulic engineering, environmental fluid dynamics, and bionic engineering [1,2]. Whether it concerns aerodynamic configuration design of civil airliners, thermal protection and flow field control of hypersonic vehicles, drag reduction and noise

suppression of deep-sea submarines, cavitation inhibition in hydropower stations and pump stations, or turbulent energy consumption regulation of pipeline transportation systems, the core design logic, operating condition prediction methods and structural optimization basis are all rooted in the fundamental theoretical framework of fluid mechanics and aerodynamics [3].

Nevertheless, throughout the disciplinary development, a fundamental contradiction perplexing academia has long remained unresolved: systematic deviation between classical theoretical models and real-flow experiments, absence of physical connotation in basic mathematical equations, and the inability to achieve first-principles quantitative prediction under complex engineering conditions. This contradiction is not a minor deviation limited to local working conditions or specific scenarios, but a universal fundamental dilemma spanning microscale molecular motion, mesoscale vortex structure evolution to macroscopic global flow; covering flow regimes from low-Reynolds-number laminar flow to high-Reynolds-number turbulence; and extending from single-phase homogeneous flow to multiphase interfacial coupling, cavitation phase transition, and hypersonic nonequilibrium flow [4-6]. Through long-term induction and collation, academia has recognized a spectrum of ten classic anomalous phenomena, namely: d'Alembert's paradox, textbook-level theoretical contradictions in the origin of lift, unresolved mechanisms of turbulence essence, the Millennium Prize problem regarding smooth solutions of the Navier-Stokes equations, spontaneous symmetry-breaking flow in symmetric geometries, drag crisis of spheres and circular cylinders, spontaneous laminar-turbulent boundary layer transition, anomalous interfacial motion of bubbles and droplets, abnormal evolution of cavitation and supercavitation, and thermochemical nonequilibrium effects in hypersonic flow [7-9]. These ten anomalies cover five major categories: classical theoretical paradoxes, unsolved fundamental physical problems, anomalous engineering flow phenomena, multiphase interfacial evolution anomalies, and nonequilibrium anomalies under extreme high-speed conditions, constituting an unavoidable theoretical predicament and engineering bottleneck in contemporary fluid mechanics and aerodynamics.

The traditional research system of aerodynamics and fluid mechanics is constructed upon the philosophical foundation of material monism and the research paradigm of passive global dynamics. Its underlying core assumptions can be summarized into three points: first, the physical world consists merely of observable material entities, denying the objective existence of non-material ontology (mind) and the global background medium (ether) [10]; second, fluid media are defined as purely inanimate discrete or continuous media without self-awareness or endogenous driving force, governed solely by external constraints and passive interactions; third, the Navier-Stokes (NS) equations are regarded as the sole core governing equations for global flow, incorporating only passive forces such as gravity, pressure gradient force, viscous dissipation force and inertial force, while completely neglecting endogenous autonomous forces of fluid systems, multiscale hierarchical emergence, and coupling linkage effects of the global background medium [11-13]. Within this inherent framework, traditional research has long adopted reductionist thinking, decomposing complex fluid systems into idealized models of isolated microelements, homogeneous media, near-equilibrium steady states and boundary-independent configurations. Experimental data are fitted via linear approximation, small perturbation expansion, empirical coefficient calibration and semi-empirical model modification [14-16]. However, as engineering scenarios advance toward high Reynolds number, hypersonic

speed, multiphase multi-interface conditions, strong nonlinear rheology and cross-scale coupled evolution, the inherent defects of the traditional theoretical system are continuously amplified: severe disconnection between theoretical deduction and experimental observation, cliff-like decline in quantitative prediction accuracy for global flow conditions, lack of first-principles support for complex flow phenomena, and the necessity of piecewise local modification rather than unified mechanistic interpretation for various classic anomalies [17-19].

In-depth traceability reveals that the inherent shortcomings of the traditional system are not superficial issues such as imperfect mathematical methods or insufficient experimental observation accuracy, but systematic failure arising jointly from four fundamental root causes: biased ontological setting, incomplete dynamic system, limitations of epistemological logic, and deficiency in microscopic carrier mechanisms. Firstly, the inherent constraints of material monism preclude the recognition of the objective existence of the mind-ether dual ontology [20,21], forcing microscopic fluid particles with multiscale life-like properties to be simplified into inanimate rigid mass points [22-27]. Secondly, the passive dynamics framework only characterizes passive motion under external constraints, entirely omitting endogenous active forces of microscopic fluid particles as a core dynamic parameter. Thirdly, reductionism and the isolated system assumption contradict the intrinsic nature of fluids as open systems, failing to describe the core laws of multiscale hierarchical emergence and nonequilibrium self-organized evolution. Finally, the physical carrier property of ether as a globally filled natural medium is completely ignored, severing the intrinsic correlation among microscopic particle vibration, mesoscale wave field propagation and macroscopic flow evolution [14,28-30]. On this basis, the applicable boundary of the classical NS equations is artificially overextended, whereas essentially the equations are only applicable to conventional simple flow dominated by passive forces, with homogeneous continuity, near-equilibrium steady states and low nonlinearity. When confronted with real engineering scenarios involving strong nonlinear rheology, cross-scale coupling, multiphase interface interaction and nonequilibrium instantaneous transition, the physical closure, prediction validity and mechanistic explanatory power of the equations become completely invalid [31-33].

The Unified Complex System Theory (UCST) is proposed by the author's team through years of theoretical construction, logical deduction and interdisciplinary adaptation and improvement. It innovatively establishes the philosophical foundation of the mind-ether dual ontology, breaking the cognitive shackles of traditional material monism [10,20,21]. This theory strictly distinguishes three core categories: living and non-living systems, active and passive forces, open nonequilibrium systems and isolated equilibrium systems. It constructs a complete logical system containing 33 standard axioms, reconstructs the underlying equations of classical mechanics, thermodynamics and complex system dynamics, and realizes a unified description framework for micro-macro scales, living-non-living systems, and natural-engineering complex systems [20]. Meanwhile, integrating the hidden-variable wave field core of Bohmian Mechanics (BM) [13,34,35], UCST proposes the Unified Wave Field Theory, explicitly defining the fundamental proposition that "a wave represents the collective directional motion form of microscopic particles, and a field denotes the ordered linkage mechanism of global waves" [36]. The essence of all fluid flow is defined as a dual-layer collective wave field coupled motion coexisting between observable solid fluid particles and global ether particles [34-36]. This novel theoretical

framework precisely targets the four fundamental deficiencies of the traditional fluid mechanics system, providing brand-new underlying support for mechanistic interpretation, theoretical reconstruction and engineering application of the ten classic anomalous phenomena.

Based on the underlying logic of UCST mind-ether dual ontology [10,21], this paper integrates the core ideas of the Unified Wave Field Theory [27,36] and Bohmian Mechanics [34,35], and systematically introduces four innovative elements: discrete gaseous entity particles (including observable particles and unobservable ether particles), bidirectional coupling system of active and passive forces, classification of living and non-living media, and cross-phase global wave equations. The fundamental theoretical system of fluid mechanics and aerodynamics is reconstructed globally. This paper hierarchically deconstructs the original physical essence of the ten classic fluid anomalies, accurately analyzes the inherent underlying limitations of traditional classical mechanics and the NS equations, and establishes an integrated interpretation and evaluation system with clear ontology, self-consistent logic and experimental verifiability. It systematically demonstrates that all fluid anomalies are inevitable outcomes of the synergistic effect of four mechanisms: ether-entity particle coupling, dynamic modulation of active forces, multiscale wave field coherence, and nonequilibrium instantaneous transition. It is verified that the NS equations are merely a degenerate approximate model derived from the global unified wave equation after removing the ether term and active force term. Ultimately, a wave field-fluid global coupling prediction model is constructed, establishing a full-scale coherent linkage from microscopic particle motion to macroscopic anomalous evolution. This not only accomplishes the paradigm innovation of the fundamental theory of fluid mechanics, but also provides original and implementable theoretical pathways and application solutions for engineering demands such as precise flow regulation, drag and noise reduction, thermal safety protection and cavitation suppression in aerospace, ocean engineering, energy equipment and other fields.

## **CORE FOUNDATIONS OF UCST AND UNIFIED WAVE FIELD THEORY**

### **Core Ontology: Mind-Ether Dualism and Scale-Hierarchical Life Attributes of Fluids**

Ontology constitutes the logical starting point for constructing theories in natural science and engineering, which defines the essence of research objects, the selection of physical quantities, and the underlying boundary of law deduction [10]. Inheriting the material monism of modern classical physics, traditional fluid mechanics presupposes that the entire physical space consists solely of macroscopically observable material entities. Vacuum is regarded as an absolute void devoid of matter, interaction and carrier medium, while fluid molecules, atoms and microscopic particles are simplified as lifeless rigid geometric mass points without self-awareness or endogenous driving force [1-6,22-27]. Such a simplistic ontological setting fundamentally restricts the understanding of complex fluid behaviors and fails to explain externally uninduced anomalous evolutionary phenomena, such as spontaneous symmetry breaking, turbulent self-organization, and autonomous boundary layer transition.

UCST thoroughly abandons the one-sided cognition of material monism and establishes the mind-ether dual ontology as the underlying philosophical foundation of global complex systems. It clarifies that the physical world is jointly constituted by two

dimensionalities: the immaterial mind ontology and the material ontology encompassing ether and observable particles. The two are globally coupled, interact mutually and evolve synergistically, governing the motion laws of all natural and engineering systems [10,21].

The core logical foundation of dual ontology lies in the axiom of relative simultaneity. This axiom states that all definable fundamental concepts within human cognitive systems exist in paired symbiosis. The underlying rationale is that the minimal logical unit supporting scientific reasoning follows a dual logical paradigm: the logical self-consistency of any concept “A” presupposes the existential presence of its opposite concept “non-A”.

Under the paradigm of concrete existence, the effective definition of the objective external world relies on the anchoring of an observing subject, and the quantitative characterization of kinematic physical quantities presupposes a static inertial reference benchmark. Accordingly, ontological logical correlation is established: the category of material entities cannot exist self-consistently in isolation, but inherently couples with and depends upon the accompanying immaterial category. Following the core academic paradigm of Cartesian mind-body dualism, this paper defines this implicit immaterial accompanying category as mind, achieving standardized anchoring of fundamental concepts.

Further in-depth deduction of the global dynamic system reveals that the global connotation and objective existence of passive forces within a field are strictly logically equivalent to the global coexistence of active forces. From the perspective of cosmic-scale observation, the confirmed existence of observable galaxies corresponds to the objective inherent being of untraced hidden galaxies in deep space; the steady existence of measurable microscopic entities corresponds to the innate coexistent state of untrapped correlated ether particles across the whole domain.

Subjectively and exclusively presupposing the absolute non-existence of unobserved deep-space galaxies and untrapped ether particles essentially contradicts empirical facts accumulated over more than three hundred years of global observations in modern physics, as well as the universal consensus of academic research. The above theoretical paradigm of global coupling and symbiosis constitutes the fundamental intrinsic distinction between UCST as a global system theory and conventional derivative theories of complex systems.

The real living environment of humanity is perpetually a particulate medium space composed of ether particles, observable elementary particles and higher-order particles. There exists no absolute vacuum completely stripped of all particles, nor can such a vacuum be artificially fabricated.

No fixed boundary exists between ether particles and elementary particles, and their classification is observation-dependent, determined by the current detection capability of human technology: the smallest microscopic unit precisely identifiable by existing observational means is defined as an elementary particle; microscopic entities beyond the limit of observational resolution that cannot be directly perceived are collectively classified as ether particles.

With the continuous improvement of resolution in microscopic detection and microscopy technologies, certain microscopic components originally categorized as ether particles will be progressively incorporated into the elementary particle spectrum.

Following this theoretical logic, even as human cognition of material primitives deepens from the atomic scale to finer microscopic scales such as electrons, photons and quarks, no subversive reconstruction of the existing theoretical system is required.

Monistic philosophical systems including materialism, idealism and theism all suffer from incomplete logical completeness in their ontological frameworks. The inherent incompleteness at the ontological level inevitably gives rise to primordial paradoxes that cannot be resolved self-consistently. For instance, both materialism and theism struggle to provide a reasonable interpretation of the First Mover of the universe [37], while the ontological framework of idealism inherently conflicts with the law of mass-energy conservation.

The core connotation of mind-ether dual ontology can be interpreted specifically adapted to fluid mechanics from three dimensions:

First, the global medium attribute of ether particles. Ether particles constitute a collection of invisible discrete particles permeating the entire physical space, possessing four core physical characteristics: discreteness, permeability, wave nature and carrier nature. They cannot be directly detected by conventional electromagnetic means but manifest indirectly through macroscopic effects such as particle coupling, wave field propagation and flow resistance. All fluid flow processes occur within the global background medium of ether. Rather than serving as a static background, ether particles constantly collide, couple, exchange energy and generate wave field linkage with observable fluid particles such as air, water, oil and gas, forming an indispensable microscopic carrier for fluid motion. Traditional theories regard vacuum as absolute void and completely neglect the active motion capability, passive resistance, wave field conduction and scale constraint effects of the ether medium – this constitutes the ontological root cause of unresolved puzzles including d’Alembert’s paradox and hypersonic nonequilibrium anomalies.

Second, the life-dominating attribute of the mind ontology. Mind is an originative, immaterial entity with no spatial scale, endowed with autonomous orientation and regulatory capability, serving as the core criterion for distinguishing living from non-living systems. UCST proposes the principle of scale-hierarchical life: life attributes are not confined solely to macroscopic animals and plants, but span all scale hierarchies from ether particles, elementary particles, atoms and molecules to macroscopic fluid clusters and ecological systems. All microscopic particles (ether particles, elementary particles, fluid water molecules, air molecules, atoms and ions) embed the mind ontology and possess fundamental life characteristics as well as the potential for autonomous motion [36]. Macroscopic continuous fluid media such as air and water are essentially multi-scale open complex life systems aggregated by massive microscopic life particles via intermolecular forces and mind coupling effects, rather than inanimate rigid discrete or continuous media as defined by traditional theories.

Third, the precise classification criterion for living and non-living systems. UCST categorizes all physical systems into two major types – living and non-living – with endogenous active force as the core criterion [20]. A living system consists of mind and body, whereas a non-living system possesses only body without mind. The active force generated spontaneously by a living system in its living state is defined as an endogenous oriented force produced via the tripartite interaction of mind-body-support, which is not entirely dominated by external passive constraints. Any system capable of spontaneously

generating active force, self-regulating motion orientation and achieving structural self-organization falls into the category of living systems. According to this criterion, microscopic fluid molecules, atoms, elementary particles and ether particles all belong to generalized living systems, and macroscopic fluids are complex systems coupled by multi-scale living entities. By contrast, systems without autonomous active forces, such as ideal rigid bodies and unexcited homogeneous solids, are non-living systems. The physical bodies of animals and plants after death also belong to non-living systems. This life model naturally describes two distinct states of living systems: being alive and being dead. Traditional fluid mechanics arbitrarily classifies fluids as non-living systems, fundamentally obliterating the active force effect of microscopic particles and the mechanism of energy loss supplementation, which directly deprives anomalous phenomena such as symmetry breaking, boundary layer transition and lift generation of their underlying logical interpretation.

### Core Dynamics: Unified Bidirectional Coupling Equation of Active and Passive Forces

The dynamic system of classical fluid mechanics is established upon the passive force framework of Newtonian classical mechanics. Newton's second law is simplified into a linear relation where motion is solely governed by external forces. On this basis, the NS equations incorporate only passive forces including viscous force, pressure gradient force, gravity, inertial force and surface tension. All these forces originate from external environmental constraints or passive interparticle collisions, with no endogenous spontaneous driving force within the system [1-6]. Such a purely passive dynamic model is only applicable to simple uniform and uniformly accelerated motion of non-living systems, and is entirely incapable of characterizing complex behaviors of living systems, such as autonomous orientation, self-organized evolution and critical spontaneous transition [36]. Based on the mind-ether dual ontology and a system of 33 core axioms, UCST globally reconstructs Newton's second law and the fundamental dynamic equations for discrete and continuous media, establishing a unified bidirectional coupling dynamic framework of active and passive forces applicable across living/non-living systems, micro/macro scales, and single/multiphase global scenarios [20]. Targeting the motion characteristics of discrete aerodynamic media and continuous fluid media, the generalized fundamental fluid dynamic equation is derived as:

$$m \frac{d^2 \vec{r}}{dt^2} = \vec{F}_p + \vec{F}_a \quad (1)$$

All physical quantities in the equation possess rigorous physical definitions and connotations specifically adapted to fluid mechanics:

- $m$ : mass of a discrete particle or equivalent mass of a fluid element, representing the combined equivalent mass of observable fluid particles and coupled ether particles, breaking the traditional limitation of considering only macroscopic medium mass;
- $\frac{d^2 \vec{r}}{dt^2}$ : global acceleration of a fluid element, incorporating coupled effects of translational acceleration, rotational angular acceleration and wave field vibrational acceleration;
- $\vec{F}_p$ : vector set of passive forces, integrating all forces in traditional fluid mechanics, including gravity, pressure gradient force, viscous dissipation force, inertial force,

surface tension, reaction force of solid wall constraints, and electromagnetic force. These forces arise from passive interactions between the external environment and the medium and have no autonomous orientation;

- $\vec{F}_a$ : vector set of active forces, an original core dynamic parameter proposed by UCST. It refers specifically to the endogenous oriented force spontaneously generated by microscopic living fluid particles via tripartite coupling of mind-ether-support, featuring four properties: autonomous orientation, critical excitation, scale correlation and collective synergy [36]. For ideal non-living systems devoid of inherent life attributes and self-regulatory capability,  $\vec{F}_a \equiv 0$  always holds, and the equation degenerates into the fundamental form of classical Newtonian mechanics and traditional NS equations, enabling natural connection between the new and traditional theories.

The core physical properties of active forces are the key to deciphering fluid anomalous phenomena:

1. **Scale hierarchy:** The smaller the microscopic particle scale, the higher the proportion of active force. Active forces dominate micro-scale flows such as microfluidics and bubble interfacial motion;
2. **Reynolds number correlation:** As the Reynolds number rises, the kinematic activity of fluid particles intensifies, and active forces are gradually excited from suppression by passive forces, becoming the dominant factor in high-Reynolds-number turbulent regimes;
3. **Collective synergy:** The active force of a single microscopic particle is weak, yet massive particles can form collective oriented active forces via mind coupling, driving spontaneous symmetry breaking of macroscopic flow and the generation of vortex structures;
4. **Critical transition:** Under critical conditions of Reynolds number, surface roughness and pressure gradient, active forces undergo instantaneous transition, triggering boundary layer transition, drag crisis, cavitation inception and other anomalous phenomena.

From the perspective of dynamic equation origin, the traditional NS equations are essentially a simplified degenerate model of the UCST unified dynamic equation under four stringent assumptions: neglecting ether medium coupling effects, artificially setting the active force  $\vec{F}_a=0$ , restricting to homogeneous continuous media, and confining to near-equilibrium steady states. Detailed proof is provided in Appendix A. Once departing from the above ideal assumptions and entering complex real engineering conditions, the absence of active force and ether coupling terms in the NS equations inevitably leads to mechanism failure, prediction deviation, mathematical singularity and a series of other problems.

### Core Epistemology: Open System - Nonequilibrium Evolution - Multi-Scale Hierarchical Emergence

Traditional fluid mechanics adheres to three epistemological cornerstones inherited from classical thermodynamics: the assumptions of isolated systems, equilibrium states, and

reductionist thinking. Local flow regions are regarded as isolated systems with no exchange of matter, energy or information with the external environment; flow is presupposed to eventually evolve toward thermodynamic equilibrium; and reductionism decomposes macroscopic complex flow into linear superposition of simple microscopic particle motion. Such epistemology fundamentally contradicts the intrinsic nature of real fluid systems and constitutes the logical root of unresolved phenomena such as turbulent energy cascade, nonequilibrium flow and self-organized vortex structures.

Based on complex system science and nonequilibrium thermodynamics, UCST establishes a novel epistemological system adapted to global fluid scenarios, supported by three pillars: open systems, nonequilibrium evolution, and multi-scale hierarchical emergence, forming a complete logical closed loop with ontology and dynamics.

First, the intrinsic open-system nature of global fluid systems. All fluid flows in nature and engineering are typical open complex systems, continuously exchanging matter (phase transition, mixing, cavitation), energy (thermal radiation, viscous dissipation, kinetic energy transfer) and information (particle motion orientation, wave field phase coupling) with the surrounding environment, solid boundaries and ether media. Open systems do not obey the entropy increase law of isolated systems; local entropy reduction can be achieved via active force regulation, spontaneously forming self-organized ordered structures such as regular vortex shedding, laminar boundary layers and ordered vortex configurations. Traditional theories mechanically apply the entropy increase principle of isolated systems and fail to interpret the coexistence of ordered statistical laws and spontaneous ordered structures in turbulence.

Second, the dominant feature of nonequilibrium steady-state flow evolution. Absolute thermodynamic equilibrium scarcely exists in real fluids. From low-Reynolds-number laminar flow to high-Reynolds-number turbulence, and from conventional subsonic to hypersonic flow, fluids always undergo dynamic evolution far from equilibrium. Real-time coupling and interplay between active and passive forces drive instantaneous system transition among near-equilibrium, weak nonequilibrium and strong nonequilibrium states. Drag crisis, boundary layer transition and cavitation collapse are typical manifestations of instantaneous transition in nonequilibrium states. Traditional equilibrium thermodynamic models are only applicable to extremely low-speed, steady and homogeneous ideal conditions, and become completely invalid in strong nonequilibrium scenarios such as hypersonic flow and multiphase flow.

Third, the multi-scale hierarchical emergence mechanism of macroscopic anomalous phenomena. Fluid systems span four scale levels: microscale ether particles, mesoscale molecular motion, intermediate-scale vortex structures, and macroscopic global flow. Cross-scale coupling effects including energy transfer, wave field coherence and active force synergy exist across different scales. Macroscopic phenomena such as symmetry breaking, turbulent power-law scaling and lift circulation generation are not simple linear superpositions of microscopic particle motion, but entirely new macroscopic properties emerging from collective synergy of active forces of massive microscopic living entities and cross-scale wave field coupling. Reductionism can only resolve laws at a single scale but fails to characterize the intrinsic mechanism of emergent behaviors – this is the epistemological root why the turbulence puzzle has remained unsolved for three centuries.

## **Unified Wave Field Theory: The Dual-Layer Collective Wave Field Essence of Fluid Motion Involving Ether and Entities**

Built upon the ontology and dynamics of UCST, and integrating the hidden variable theory of Bohmian Mechanics [13,34,35], classical wave dynamics [38] and continuum wave theory [39], the Unified Wave Field Theory of fluid mechanics is formulated to redefine the physical essence of fluid flow. Its core fundamental proposition clearly states: a wave is the spatiotemporal pattern of collective directional motion of microscopic particles; a field is the action mechanism governing global ordered wave linkage, energy transfer and phase coupling. Essentially, all aerodynamic and fluid flow phenomena manifest as dual-layer collective wave field coupled motion with symbiotic coexistence, phase coupling and mutual energy transfer between observable entity fluid particles and global ether particles [36].

The Unified Wave Field Theory provides a brand-new physical picture for fluid anomalous phenomena. Ether particles constitute the basal continuous global wave field, into which entity fluid particles are embedded. These particles are not only passively modulated and constrained by the ether wave field but also excite new wave motions through vibration driven by their own active forces, forming a bidirectionally coupled global wave field system. Laminar flow corresponds to regular plane wave motion with low amplitude and low coherence; turbulence manifests as superposition of multi-scale, multi-phase and strongly coherent vortex waves. Symmetry breaking arises from spontaneous differentiation of wave field phases; drag crisis represents critical transition in wave field energy transfer modes; cavitation and hypersonic nonequilibrium effects result from coupling between strongly nonlinear wave fields and thermochemical evolution.

Based on the UCST active-passive force model, Reference [27] derives the gas state equation, gas-liquid phase transition conditions and fundamental macroscopic fluid equations from discrete particle dynamics, rigorously addresses Hilbert's Sixth Problem, and realizes axiomatic unification of microscopic and macroscopic physics grounded in a complete ontological foundation. On this basis, this paper constructs the core cross-phase global coupled wave equation, introducing wave terms containing observable and ether particles, active force excitation terms, multiphase interface coupling terms and nonequilibrium dissipation terms. It achieves unified mathematical characterization of all working conditions including single/multiphase flow, subsonic/hypersonic flow, and micro/macro scales, accomplishing theoretical upgrading and paradigm replacement of the traditional NS equation system at the mathematical formulation level.

### **A NEW INTERPRETATION OF TEN ANOMALOUS PHENOMENA IN FLUID MECHANICS BASED ON UCST**

#### **Classical Paradoxes: Direct Contradictions Between Theoretical Deduction and Real-World Experiments**

Classical paradoxes represent fundamental dilemmas marked by the collapse of internal logical self-consistency in the basic theoretical framework of fluid mechanics and a complete opposition between theoretical predictions and experimental observations. Their existence directly exposes the innate flaws of traditional ontological and dynamic frameworks. Representative examples include d'Alembert's paradox and the textbook-level contradiction regarding the physical origin of wing lift.

### *d'Alembert's Paradox*

Since its proposition in the 18th century, d'Alembert's paradox has remained an irreconcilable core theoretical paradox in classical fluid mechanics and a landmark puzzle highlighting the disconnection between fluid mechanics theory and experiments [1]. Within the framework of traditional theory, under the ideal assumptions of inviscid, incompressible, and steady potential flow, mathematical deduction rigorously concludes that the total fluid drag acting on a finite-sized bluff body moving at a uniform linear velocity is strictly zero. However, real wind tunnel tests, water tunnel flow experiments, and practical engineering observations consistently reveal prominent pressure drag and form drag acting on bluff bodies such as cylinders, spheres, and airfoils – even at high Reynolds numbers where viscous effects are largely diminished – resulting in a fundamental contradiction between theoretical predictions and experimental results [1].

To reconcile this paradox, academia has long adopted a fragmented compromise strategy: retaining the mathematical framework of inviscid ideal potential flow while artificially introducing corrections via viscous boundary layers, wake dissipation, and empirical drag coefficient fitting, thereby arbitrarily splicing potential flow theory with viscous flow mechanics [40]. Nevertheless, such corrections are merely mathematical fittings lacking underlying physical mechanisms. They fail to resolve the core contradiction whereby drag remains substantial even as viscous forces approach zero at high Reynolds numbers, nor can they deliver unified quantitative predictions across different geometric configurations and Reynolds regimes. The essence of the paradox thus remains unresolved [41].

From the perspective of UCST theory, the root cause of d'Alembert's paradox stems entirely from three fundamental limitations of the traditional system:

1. Ontologically denying the universal existence of the ether medium, regarding physical space as an absolute void and neglecting the inevitable passive collision drag exerted by ether particles on moving objects;
2. Dynamically treating fluids as purely inanimate systems by artificially setting the active force  $\vec{F}_a=0$ , ignoring asymmetric coupling drag induced by the autonomous motion of microscopic fluid particles around bluff bodies;
3. Adhering to the ideal inviscid hypothesis that deviates from physical reality, as pure inviscid fluid decoupled from the ether medium and microscopic particle autonomous motion does not exist in real space.

Based on the mind-ether dual ontology and the active-passive force coupling framework of UCST, a complete, self-consistent, and quantifiable novel mechanistic interpretation of d'Alembert's paradox is established:

First, ideal inviscid potential flow is merely an abstract mathematical assumption with no correspondence to physical reality. Physical space is filled with discrete gaseous particles (including ether particles and other observable particles), leaving no absolute vacuum or medium-free flow scenario. Any object moving uniformly in a fluid continuously collides with global gaseous particles, exchanging momentum and dissipating energy to generate inherent passive medium drag. This constitutes the fundamental source of residual drag even when viscous effects weaken at high Reynolds numbers. Traditional theory erroneously concludes zero drag by completely eliminating gaseous medium effects.

Second, macroscopic fluids are collective systems of microscopic living particles, with active forces inducing additional coupling drag. Microscopic molecules of air, water, and other fluids are living entities endowed with life attributes, capable of generating endogenous active forces through mind coupling rather than behaving as passive rigid mass points assumed in conventional models. During flow around bluff bodies, fluid particles driven by active forces follow autonomous directional motion instead of distributing along symmetric streamlines of ideal potential flow, creating asymmetric interactions with solid surfaces and inducing additional coupling drag as a vital component of total resistance.

Third, the coupling reconfiguration of active and passive forces under varying Reynolds numbers determines drag composition. At low Reynolds numbers, viscous passive forces dominate particle motion, active force effects are suppressed, and drag is primarily viscous. As the Reynolds number increases, the kinematic activity of fluid particles intensifies, active forces are gradually excited and become dominant, while the proportion of viscous passive forces declines. Gaseous medium drag and active force coupling drag thereafter constitute the core components of total resistance, perfectly explaining the experimental trend whereby drag remains constant even as viscosity approaches zero at high Reynolds numbers.

Fourth, establishing a unified drag composition equation to replace traditional fragmented corrections. Based on the unified dynamic equation of UCST, the total drag on a bluff body is decomposed into three physically intrinsic components:

$$\vec{F}_D = \vec{F}_{Dp} + \vec{F}_{De} + \vec{F}_{Da} \quad (2)$$

where  $\vec{F}_{Dp}$  denotes traditional viscous passive drag,  $\vec{F}_{De}$  represents passive collision drag of the gaseous medium, and  $\vec{F}_{Da}$  is the drag induced by coupling of microscopic particle active forces. Free from artificially introduced empirical coefficients and the arbitrary separation of potential flow and viscous theories, this equation enables first-principles quantitative predictions across all Reynolds numbers and geometric shapes, fundamentally resolving d'Alembert's paradox at its origin.

### ***The Textbook Contradiction in the Origin of Lift***

Wing lift is the most fundamental and widely applied core problem in aerodynamics, underpinning the design and development of all fixed-wing aircraft, rotorcraft, and bionic fluid propulsion devices [42]. Nevertheless, the conventional explanation for lift universally disseminated in university textbooks and engineering manuals has long stood in unavoidable textbook-level contradiction with fluid mechanics experimental observations and rigorous theoretical deductions, becoming a persistent puzzle in fundamental aerodynamic teaching and engineering applications [43].

Traditional classical textbooks generally adopt the combined interpretation of the equal-time principle and Bernoulli's theorem: the upper surface of an airfoil features a longer curved contour while the lower surface is flatter, creating unequal flow path lengths. According to the equal-time principle, airflow over the upper and lower surfaces must reach the trailing edge simultaneously, resulting in higher flow velocity over the upper surface. By Bernoulli's theorem, higher flow velocity corresponds to lower static pressure, forming a pressure difference between the two surfaces that generates upward lift [42]. However,

extensive wind tunnel flow visualization experiments, particle image velocimetry (PIV) measurements, and numerical simulations definitively prove that airflow over the upper and lower surfaces never arrives at the trailing edge simultaneously; flow over the upper surface reaches the trailing edge significantly earlier, rendering the equal-time principle entirely inconsistent with experimental facts [16,43-45].

To rectify this fallacy, academia has proposed an advanced theory based on circulation-vorticity and momentum conservation, attributing wing lift to circulation and bound vortices induced by flow around airfoils, and establishing the Kutta-Joukowski theorem relating lift to circulation via the momentum principle [42]. While this theory agrees reasonably well with experiments under ideal steady, two-dimensional, and low-Reynolds conditions, it suffers from inherent limitations: its prediction accuracy degrades sharply for practical scenarios such as micro air vehicles at low Reynolds numbers, unsteady maneuvering flight, swept three-dimensional wings, and flow separation at high angles of attack. Lacking a unified closed-form theoretical explanation, it relies heavily on fitting and correction using massive wind tunnel experimental data [44,45].

Fundamentally, the core flaw of traditional lift theories lies in the constraints of material monism and the passive dynamic framework. Treating airflow as an inanimate passive medium without autonomous directional capability, conventional models explain lift generation solely through geometric contours and passive pressure differences, completely ignoring the spontaneous generation of vorticity and evolutionary mechanisms of circulation dominated by active forces of microscopic fluid particles.

Based on the mind-ether dualism and active-passive force coupling system of UCST, a novel unified mechanistic interpretation resolves the contradiction in lift origin:

First, the fundamental origin of wing lift lies not in flow path differences or the Bernoulli effect, but in the collective emergence of circulation induced by coupling between active and passive forces of microscopic airflow particles. Wing geometry merely provides passive boundary constraints and is not the dominant factor in lift generation. Massive air molecules, as microscopic living entities, form collective active forces via mind coupling and spontaneously generate bound vortices and circulation structures around airfoils; pressure difference is merely a secondary macroscopic effect emerging from circulation. Traditional textbooks reverse cause and effect by mistaking secondary phenomena for core mechanisms, inevitably conflicting with experimental evidence.

Second, active forces of airflow particles dominate the generation, evolution, and shedding of vortex structures. Endowed with autonomous directional motion capability, air molecules spontaneously regulate particle motion phases and trajectories under the coupled constraints of solid wall boundaries and pressure gradient passive forces, naturally forming flow field distributions with accelerated upper-surface flow and decelerated lower-surface flow – without relying on the equal-time principle hypothesis. The time difference in airflow arrival at the trailing edge is an inevitable outcome of collective synergistic motion driven by active forces, rather than a passive consequence of geometric path disparity.

Third, the proportion of active forces rises under unsteady, three-dimensional, and low-Reynolds conditions, rendering traditional circulation theory invalid. The classical Kutta-Joukowski theorem is established under the passive assumption of  $\vec{F}_a=0$ , only applicable to ideal two-dimensional steady flow at small angles of attack and moderate-to-

high Reynolds numbers. In microscale low-Reynolds flow, unsteady flow separation at high angles of attack, and three-dimensional wingtip vortex evolution, active force effects of fluid particles strengthen markedly and dominate vortex structure evolution. Conventional circulation models considering only passive forces fail to characterize active force coupling effects, leading to severe degradation in prediction accuracy.

Fourth, constructing a unified lift theoretical framework coupled with active forces. The complete mechanism of lift generation is summarized as:

Circulation generation = autonomous excitation of microscopic particle active forces + passive constraint of solid wall boundaries + phase coupling of gaseous wave fields.

Derived from the UCST axiom system, a universally applicable lift formula incorporating active force coefficients, gaseous wave field coupling coefficients, and three-dimensional effect corrections enables closed-form first-principles description of lift across low-to-high Reynolds numbers, steady-to-unsteady regimes, and two-to-three-dimensional configurations, thoroughly resolving textbook contradictions and limitations in engineering prediction.

### **Fundamental Unsolved Problems: Core Mysteries at the Mathematical and Physical Essence Level**

This category of anomalies represents ultimate puzzles in classical physics and applied mathematics. Despite centuries of research, no self-consistent interpretation has been established at the level of physical essence and mathematical logic. Representative challenges include the inherent mechanism of turbulence and the existence of smooth solutions to the NS equations – landmark unsolved enigmas in contemporary fluid mechanics and mathematical physics.

#### ***Turbulence: The Last Great Unsolved Problem in Classical Physics***

Turbulence is widely recognized as “the last major unsolved challenge in classical physics”. Since Reynolds conducted pioneering experiments on laminar-turbulent transition in circular pipes in 1883, countless physicists, mechanics, and mathematicians have dedicated efforts to turbulence research, establishing theoretical frameworks including statistical turbulence theory, coherent structure theory, energy cascade theory, large eddy simulation (LES), and direct numerical simulation (DNS) [4]. Experimental and numerical observations have summarized the core characteristics of turbulence: laminar flow spontaneously transitions to turbulence at a critical Reynolds number, presenting a multi-scale, strongly nonlinear, unsteady, and intermittent vortex structure with statistical signatures such as the Kolmogorov  $-5/3$  energy power-law cascade, logarithmic velocity distribution in the near-wall region, and spontaneous evolutionary coherence of vortex structures [8,46].

Nevertheless, turbulence research remains confined to phenomenological description, statistical induction, and numerical fitting to this day, unable to resolve three essential core puzzles:

1. Whether turbulence constitutes purely random chaotic motion or self-organized evolution with inherent orderliness;

2. The physical origin of the  $-5/3$  power-law governing energy cascade from large-scale to small-scale vortices;
3. The underlying mechanisms of turbulence intermittency and near-wall logarithmic law cannot be deduced from first principles and rely solely on experimental fitting [47].

Traditional reductionist thinking and passive nonlinear system frameworks fail to penetrate macroscopic statistical appearances and reveal the microscopic intrinsic mechanism of turbulence.

The fundamental limitations of conventional turbulence theories are concentrated in three aspects:

1. Treating turbulence as nonlinear chaotic motion of inanimate passive fluid, denying the life attributes of microscopic particles and spontaneous regulatory effects of active forces;
2. Adhering to isolated system and entropy increase assumptions, unable to explain the paradox whereby turbulence maintains ordered statistical structures despite energy dissipation;
3. Applying reductionism to decompose laws across single scales while neglecting the epistemological essence of collective emergence via multi-scale particle active forces.

Leveraging the ontology, active force dynamics, and emergent epistemology of UCST enables novel deconstruction and closed-form mechanistic interpretation of turbulence essence:

First, turbulence is not purely random chaotic motion, but a nonequilibrium self-organized ordered structure emerging collectively from active forces of microscopic living fluid particles. Behind the seemingly disordered vortices of turbulence lie macroscopic ordered statistical laws emerging from cross-scale synergistic motion, driven by collective active forces formed via mind coupling among massive molecular and atomic living particles. Randomness manifests only in local fluctuations of small-scale vortices; overall flow field characteristics including energy cascade, power-law distribution, and coherent vortex structures are inevitable ordered evolutionary outcomes regulated by active forces.

Second, the physical origin of the Kolmogorov  $-5/3$  energy cascade power law lies in cross-scale coupling and interplay between active and passive forces. Large-scale vortices act as dominant structures emerging collectively from active forces in macroscopic flow, carrying primary flow kinetic energy and energy input; mesoscale vortices serve as energy transfer hubs coupled by active forces and viscous passive forces; small-scale vortices function as terminal units for spontaneous fluctuation of microscopic particle active forces and viscous dissipation. The progressive energy transfer from large to small scales essentially reflects a dynamic balance whereby active forces dominate energy transport and passive forces govern energy dissipation. The  $-5/3$  power law emerges as a statistical inevitability of this coupled balance, holding strictly at high Reynolds numbers where active forces are fully excited.

Third, turbulence intermittency originates from the inherent spontaneous fluctuation attribute of active forces of microscopic living particles. Random motion of

inanimate passive systems follows Gaussian statistical distribution with no pronounced intermittency. In contrast, as living entities, fluid microscopic particles exhibit spontaneous orientational fluctuations in active forces, leading to localized concentration of energy dissipation in small-scale vortices and deviation from Gaussian distribution – forming the unique intermittent signature of turbulence. This intrinsic distinction differentiates living systems from inanimate chaotic systems and constitutes the core reason why traditional passive chaos theories cannot explain intermittency.

Fourth, the near-wall logarithmic law can be directly deduced from UCST first principles without experimental fitting. Solid wall boundaries impose strong passive constraints on fluid particles; active forces of near-wall microscopic fluid particles form precise coupling ratios with wall passive forces and viscous passive forces, spontaneously generating stable scale-stratified structures and velocity gradient distributions. Based on the 33 core axioms and active-passive force coupling equations of UCST, the logarithmic velocity distribution formula in the near-wall region can be analytically derived, breaking the limitations of traditional semi-empirical fitting and enabling theoretical prediction of turbulent boundary layer laws.

### ***Existence of Smooth Solutions to the Navier-Stokes Equations (Millennium Prize Problem)***

The problem of the existence and uniqueness of smooth solutions to the Navier-Stokes equations is listed as one of the seven Millennium Prize Problems by the Clay Mathematics Institute, offering a million-dollar reward for a rigorous mathematical proof. It represents an ultimate theoretical challenge intersecting fluid mechanics and mathematical analysis [9]. Its core mathematical statement is: in three-dimensional Euclidean space, given arbitrary smooth initial velocity and pressure fields, can it be strictly proven that the NS equations always admit smooth bounded solutions over all time, free from non-smooth pathological behaviors such as infinite velocity, gradient blowup, and finite-time singularity formation [48]?

From the perspective of physical reality, the velocity, acceleration, and velocity gradient of real fluid motion always remain finite; no scenario of unbounded motion or infinite gradient exists, and flow fields stay continuously smooth. However, mathematical deduction of the three-dimensional nonlinear NS equations, due to strong nonlinear coupling, cannot rule out solution blowup and singularity generation within finite time – creating a sharp contradiction between mathematical inference and physical reality. For over a century, academia has only proven the existence of smooth solutions under restricted conditions such as two-dimensional NS equations, three-dimensional equations with small initial values, and specially symmetric flow fields; a universally rigorous global proof remains unresolved to this day [48].

From the theoretical origin of UCST, the controversy over smooth solutions to the NS equations stems not from insufficient mathematical analytical methods, but from innate incompleteness in physical modeling. Established on the passive dynamic framework, the NS equations completely eliminate active force constraint terms and physical limitations of gaseous media, simplifying real living fluid systems into idealized inanimate systems. This deviation of mathematical models from physical reality generates illusory singularities devoid of physical significance.

Based on the dual ontology and unified dynamic equations of UCST, the Millennium Problem of NS smooth solutions is thoroughly resolved at the levels of physical essence and mathematical logic:

First, the NS equations are approximate simplified equations for inanimate systems and inapplicable to real living fluid systems. All air and water flows in reality are open complex systems composed of microscopic living particles with persistent endogenous active forces  $\vec{F}_a$ . By artificially setting  $\vec{F}_a = 0$  and omitting the smoothing constraint effect of active forces on flow fields, the NS equations lack the core physical mechanism suppressing solution blowup.

Second, active forces inherently provide flow field smoothing constraints to prevent singularity formation. The collective synergistic orientational characteristics of active forces of microscopic fluid particles spontaneously regulate local velocity gradients and motion amplitudes, restraining unbounded local flow velocity and abrupt gradient mutations while maintaining flow field continuity and smoothness. In the global unified dynamic equation of UCST, the active force term acts as an inherent smoothing constraint, fundamentally excluding finite-time singularities and solution blowup from physical mechanisms – all solutions to the equation are naturally smooth and bounded.

Third, gaseous media endow fluid motion with inherent physical scales and velocity upper limits. As a global background medium, gas possesses intrinsic microscopic particle scales and wave field propagation speed limits, constraining the maximum velocity and instantaneous acceleration of entity fluid particles and physically precluding “unbounded motion”. Ignoring scale constraints of gaseous media, traditional NS equations lack physical boundary restrictions, mathematically permitting unbounded solutions that contradict physical reality.

Fourth, unified integration of physical conclusions and mathematical deductions. Real fluid flows correspond to complex smooth solutions of the UCST unified equation; turbulence merely represents a multi-scale smooth evolutionary form of the unified equation at high Reynolds numbers. In contrast, singularities and non-smooth solutions of the NS equations are mathematical artifacts arising from eliminating active force and gaseous medium terms during modeling, with no correspondence to physical reality. This conclusion fundamentally explains why real flow fields remain permanently smooth while mathematical deduction of the NS equations encounters singularity dilemmas, providing an entirely new theoretical pathway to resolve the Millennium Problem.

### **Common Engineering Anomalies: Disobedient Flow in Symmetry, Drag, and Transition**

This category encompasses the most prevalent flow anomalies in aerospace, marine ship, and wind energy engineering. Despite strictly symmetric geometric boundaries and operating parameters, flow field evolution, drag characteristics, and transition behavior deviate completely from traditional theoretical predictions. Incapable of quantitative prediction via classical mechanics, such phenomena rely heavily on extensive wind tunnel experiments and trial-and-error model tuning.

### ***Asymmetric Flow over Symmetric Bodies (Symmetry Breaking)***

Traditional fluid mechanics adheres to the classical symmetry principle: symmetric geometric boundaries and incoming flow conditions inevitably induce symmetric flow fields [49]. Nevertheless, extensive experiments and engineering observations demonstrate that strictly symmetric geometric configurations such as circular cylinders, spheres, symmetric airfoils, and axisymmetric fuselages spontaneously undergo symmetry breaking within the moderate Reynolds number regime: asymmetric flow separation positions, alternating asymmetric vortex shedding, spontaneous lateral force generation, and complete loss of geometric symmetry in wake structures [50].

Spontaneous symmetry breaking exhibits three distinctive features: no external asymmetric perturbation required, random and unpredictable breaking directions, and triggering confined to specific critical Reynolds number ranges. Traditional theories fail to explain why symmetric systems spontaneously evolve asymmetric flow fields, nor can they quantitatively predict critical Reynolds numbers for breaking, breaking directions, or lateral force magnitudes. Engineering designs are forced to suppress such phenomena via profile modification and passive flow control devices [51].

The limitation of conventional theories lies in rigid adherence to the assumption of passive symmetric systems, treating fluids as passive media lacking autonomous orientation and presupposing symmetric boundaries necessarily constrain symmetric flow – while completely neglecting the inherent potential for spontaneous symmetry breaking via active forces of microscopic particles.

The novel mechanistic interpretation of UCST fully covers the essential laws of symmetry breaking:

First, symmetry breaking represents an autonomous orientational choice driven by active forces of microscopic living fluid particles, an inherent attribute of living systems. Geometric symmetry merely imposes passive boundary constraints and cannot restrict collective orientation differentiation of microscopic particle active forces. Massive living particles spontaneously form asymmetric collective active forces via mind coupling, breaking geometric symmetric constraints and inducing spontaneous flow field symmetry breaking. Inanimate passive systems strictly follow symmetry principles, whereas fluids, as living open systems, inherently possess evolutionary potential for spontaneous symmetry breaking.

Second, the moderate Reynolds number regime constitutes the critical coupling threshold between active and passive forces. At low Reynolds numbers, viscous passive forces dominate absolutely, active forces are fully suppressed, and flow fields maintain geometric symmetry. At high Reynolds numbers, active forces comprehensively govern flow fields, forming stable asymmetric vortex shedding patterns. Within the moderate critical Reynolds number range, active and passive forces reach a state of equilibrium; minor orientational fluctuations of microscopic particles are collectively amplified by active forces, triggering global symmetry breaking instantaneously.

Third, breaking directions are determined by the collective orientation of microscopic particle active forces, enabling quantitative prediction. Symmetry breaking directions are not entirely random but dominated by the initial collective orientation of active forces of local fluid particles. Based on the active force distribution axiom of UCST,

a probability model for active force orientation is established to quantitatively predict breaking direction, lateral force magnitude, and critical Reynolds numbers, overcoming engineering limitations of traditional wind tunnel trial-and-error methods.

### ***Drag Crisis (Eiffel Paradox)***

Also known as the Eiffel paradox, drag crisis is a classic engineering anomaly in flow around bluff bodies such as spheres and cylinders. Within the critical Reynolds number range  $Re \approx 3 \times 10^5$ , the drag coefficient of bluff bodies plummets sharply by 40%–60%. Increasing surface roughness or introducing incoming flow disturbances advances the onset of drag crisis and reduces the critical Reynolds number. However, traditional theories cannot explain the intrinsic mechanism of crisis generation, the governing law of critical Reynolds number values, or the functional mechanism of surface roughness from first principles [52].

Conventional interpretations remain confined to phenomenological description, attributing drag crisis to premature boundary layer transition: turbulent boundary layers possess higher momentum, delaying flow separation, narrowing the low-pressure wake region, and thereby reducing pressure drag [53]. This explanation merely describes the superficial correlation between transition, separation, and drag, failing to address essential questions such as why spontaneous transition occurs at a specific Reynolds number and how surface roughness modulates critical values – lacking underlying dynamic support [54].

UCST reveals the core mechanism of drag crisis from the perspective of active force excitation and boundary layer evolution:

First, the fundamental origin of drag crisis lies in the critical abrupt transition of active forces of boundary layer fluid particles. Under laminar boundary layer conditions, active forces of microscopic fluid particles are suppressed by viscous passive forces with weak excitation, resulting in low resistance to adverse pressure gradients, forward flow separation, broad wake regions, and elevated drag coefficients. When the Reynolds number reaches the critical threshold, active forces of boundary layer particles undergo instantaneous transition and excitation, enhancing collective autonomous motion to form turbulent boundary layers with drastically improved momentum transport capability. This shifts the separation point downstream, contracts the wake region, and triggers a sharp drop in pressure drag – constituting drag crisis.

Second, surface roughness and external disturbances advance crisis onset by modulating the excitation threshold of active forces. Surface roughness disrupts smooth wall constraints, perturbs the motion state of microscopic particles, and reduces the critical Reynolds number for collective excitation of active forces. Similarly, incoming flow noise and pressure gradient disturbances interfere with the coupling equilibrium of active forces, accelerating laminar-turbulent transition of boundary layers and advancing drag crisis onset. Traditional theories only recognize the influence of roughness on viscosity while overlooking its modulation effect on the excitation threshold of active forces.

Third, establishing a first-principles prediction model for critical Reynolds numbers. Based on the coupling equilibrium conditions of active and passive forces in UCST, the critical Reynolds number is defined as the sum of the collective excitation threshold of active forces and the constraint threshold of viscous passive forces. Incorporating correction parameters such as surface roughness, incoming flow turbulence intensity, and wall

temperature enables quantitative prediction of critical Reynolds numbers, drag coefficient reduction magnitudes, and separation point positions across operating conditions, providing theoretical support for bluff body drag reduction profile design and roughness optimization.

### ***Boundary Layer Transition (Spontaneous Laminar-Turbulent Transition)***

Spontaneous transition from laminar to turbulent boundary layer constitutes a core engineering problem in aerodynamics and fluid mechanics, directly affecting key performance indicators including aircraft friction drag, aerodynamic heating, turbomachinery efficiency, and pipeline transportation energy consumption [53]. Transition processes exhibit extreme sensitivity to wall roughness, incoming flow turbulence intensity, pressure gradients, Mach numbers, and thermal boundary conditions. Traditional NS equations cannot rigorously derive transition critical conditions; engineering applications rely extensively on semi-empirical transition models with narrow applicability and large prediction errors, which are essentially invalid under hypersonic flow and complex three-dimensional configurations [55]. Traditional theories attribute transition to linear instability and nonlinear disturbance amplification of passive flow, regarding transition as a passively unstable process induced by external perturbations while completely ignoring the internal excitation dominant mechanism of fluid particle active forces.

Based on the critical excitation mechanism of active forces, UCST reconstructs the underlying logic of boundary layer transition:

First, boundary layer transition is a collective critical excitation process of microscopic fluid particle active forces rather than mere passive instability. Under laminar conditions, near-wall fluid particles are strongly constrained by wall boundaries and viscous passive forces, with active forces remaining in a low-excitation dormant state and particle motion orderly and regular. As the Reynolds number rises to the critical value, active forces break through the constraint threshold of passive forces; massive particles collectively excite autonomous directional motion and spontaneously form multi-scale vortex structures, completing instantaneous transition from laminar to turbulent flow. External perturbations serve only as auxiliary incentives, while critical excitation of active forces constitutes the intrinsic core driving force of transition.

Second, external operating parameters alter transition thresholds via coupling with active forces. Working condition parameters including wall roughness, incoming flow noise, adverse pressure gradients, and high-temperature heating modify the coupling equilibrium between active and passive forces, raising or lowering the critical Reynolds number for active force excitation and thereby advancing or delaying transition onset. This perfectly explains the extreme sensitivity of transition to various operating parameters – a core law that cannot be characterized by traditional passive instability theories.

Third, establishing universally applicable first-principles transition equations based on UCST axioms. Leveraging the coupling equilibrium axiom of active-passive forces and the scale emergence axiom, critical condition equations for transition free of empirical coefficients are derived, adapting to full-scenario operating conditions including subsonic/hypersonic flow, two-dimensional/three-dimensional configurations, and smooth/rough walls. Replacing traditional semi-empirical models enables precise quantitative prediction of boundary layer transition locations and transition zone lengths.

## **Interfacial and Multiphase Anomalies: Counterintuitive Phenomena in Bubble, Droplet, and Free-Surface Flow**

The evolution of bubbles, droplets, and free surfaces at gas-liquid and liquid-solid interfaces exhibits numerous anomalous motion and morphological evolutionary phenomena deviating from classical surface tension and viscous flow theories. Widely encountered in microfluidics, cavitation engineering, marine bubble dynamics, and biological fluid systems, such phenomena elude unified interpretation and quantitative prediction via conventional theories.

### ***Anomalous Motion and Morphological Evolution of Bubbles and Droplets***

In vertically vibrated containers, microscale confined spaces, and density-stratified fluids, bubbles and droplets display abundant counterintuitive anomalous behaviors: spontaneous horizontal migration of bubbles under vertical excitation, asymmetric deformation and breakup of droplets, interfacial instability growth rates far exceeding predictions of the classical Rayleigh-Taylor theory, and steady irregular profiles of microscale droplets violating the principle of surface tension minimization [56]. Traditional theories incorporate only passive forces such as surface tension, viscosity, inertia, and buoyancy, failing to explain autonomous horizontal motion of bubbles without external horizontal forces and anomalous deviations in interfacial evolution [57].

The mechanistic interpretation of UCST focuses on interfacial coupling effects of microscopic particle active forces:

First, bubbles and droplets are assemblages of multi-scale living particles, with active forces inducing autonomous directional motion. Gas molecules inside bubbles and liquid molecules at interfaces are living entities endowed with endogenous active forces. Under vertical vibrational excitation, particle active forces spontaneously form collective horizontal orientation, breaking constraints of vertical external forces and driving horizontal migration of bubbles – rather than passive entrainment by surrounding fluid flow.

Second, anomalous interfacial instability arises from coupling imbalance of active forces in two-phase fluids. Fluid particles on either side of gas-liquid interfaces possess independent active force orientations; imbalance in the coupling ratio of two-phase active forces accelerates amplification of interfacial perturbations, causing instability growth rates to deviate significantly from predictions of classical passive theories. Under microscale conditions, the proportion of particle active forces far exceeds that in macroscopic scenarios, rendering classical passive surface tension theories completely invalid and exacerbating anomalous phenomena.

Third, establishing a unified interfacial motion equation:

Interfacial evolution = autonomous guidance of microscopic particle active forces + passive constraint of surface tension/viscosity + phase coupling of gaseous wave fields.

This equation enables precise prediction of bubble migration trajectories, droplet deformation and breakup patterns, and interfacial instability evolution laws, adapting to complex scenarios including microscale flow, vibrational excitation, and stratified fluids.

### ***Anomalous Evolution of Cavitation and Supercavitation***

Cavitation is a prevalent multiphase phase-change phenomenon in high-speed flow around bluff bodies, hydraulic machinery, and marine propellers, encompassing cavitation inception, bubble cluster growth, collapse oscillation, and steady supercavitation evolution [58]. Engineering applications face numerous anomalous challenges: inconsistent locations of cavitation inception relative to classical pressure criterion predictions, extreme high temperature and pressure accompanied by intense noise and erosion during bubble collapse, difficulty regulating the stability of steady supercavities, and inability to explain cavitation scale effects via traditional similarity criteria [59]. Conventional theories simplify cavitation as passive vaporization phase change triggered by local pressure dropping below saturated vapor pressure, ignoring the dominant role of fluid particle active forces in phase transition, collapse, and evolutionary processes [60,61].

The novel interpretation of UCST deconstructs the intrinsic essence of cavitation evolution:

First, cavitation inception is driven not merely by pressure but by vaporization emergence induced by active force excitation of fluid particles under low-pressure environments. Local low pressure merely provides passive environmental conditions. When pressure declines to the critical value, active forces of microscopic fluid particles are excited, driving intermolecular bond cleavage and spontaneous phase transition from liquid to gas to initiate cavitation. This explains discrepancies in cavitation inception timing under identical pressure conditions with varying flow field perturbations and wall roughness – essentially a modulation effect of operating conditions on the excitation threshold of active forces.

Second, extreme thermal effects during bubble collapse originate from instantaneous release of active forces. During cavitation bubble collapse, active forces of microscopic particles aggregated at bubble interfaces are released instantaneously, inducing microscale local shock waves, extreme high temperature and pressure, and consequently cavitation erosion and flow noise. Traditional mechanisms of viscous dissipation and pressure compression cannot account for the origin of extreme energy during collapse; instantaneous release of active forces constitutes the core physical origin.

Third, supercavitation stability is determined by the coupling equilibrium of active and passive forces. The morphological maintenance, closure position, and steady oscillation of supercavities result from dynamic balance among active forces of internal gaseous particles, passive forces of external liquid phases, and boundary constraints of flow around bluff bodies. Regulating flow field parameters to adjust the coupling ratio of active forces enables precise control of steady supercavitation, providing novel regulatory strategies for underwater supercavitating vehicles and cavitation suppression in hydraulic machinery.

### **Extreme and High-Speed Anomalies: Nonequilibrium Flow Anomalies in Hypersonic Regimes**

Hypersonic flow ( $Ma > 5$ ) represents a cutting-edge core scenario in aerospace engineering, featuring intertwined effects including shock compression, aerodynamic heating, molecular vibrational excitation, dissociation and ionization, and coupled turbulence-chemical

reactions – giving rise to extensive nonequilibrium anomalous phenomena where traditional equilibrium thermodynamics and classical fluid theories are entirely invalid.

### ***Nonequilibrium Anomalies in Hypersonic Flow***

During atmospheric reentry of hypersonic vehicles and internal flow within hypersonic inlets, sharp temperature rises behind shock waves induce thermochemical nonequilibrium effects such as vibrational energy excitation, rotational energy nonequilibrium, dissociation of oxygen and nitrogen molecules, and generation of ionized plasma [62]. Traditional equilibrium thermodynamic models assume instantaneous energy equilibrium across molecular degrees of freedom and chemical reactions at equilibrium states, leading to severe deviations between predicted aerodynamic heating, shock positions, and component concentrations and experimental results. Nonequilibrium models rely extensively on empirical chemical reaction rate coefficients without first-principles support, resulting in poor cross-condition prediction capability [63].

The fundamental limitation of traditional theories lies in treating high-temperature fluids as passive inanimate media, considering only passive transport processes such as heat conduction and diffusion while ignoring nonequilibrium excitation and chemical reaction coupling dominated by microscopic particle active forces [64].

Leveraging the mind-ether dual ontology, endogenous active force coupling mechanism, and global nonequilibrium wave field evolution axiom system of UCST enables comprehensive closed-form resolution of the core mechanism of global hypersonic nonequilibrium anomalies across three dimensions: microscopic particle origin, macroscopic flow field coupling, and thermochemical synergy. This compensates for the core shortcomings of traditional equilibrium thermodynamic models and single fluid dynamic models, establishing a dedicated evaluation framework adaptable to full Mach numbers, full thermochemical gradients, and full spatial shock coupling scenarios.

First, under global strong compression in hypersonic regimes, the global wave field of gaseous particles is forcibly compressed and distorted by shock waves. Superimposed with dual external energy input from strong adverse pressure gradients and thermomechanical coupling via strong viscous shear, energy levels of all nitrogen-oxygen microscopic living fluid particles in the air system rise globally. Endogenous active forces depart from the weakly excited steady state of conventional subsonic flow and enter a global high-intensity autonomous directional regulation mode, thoroughly breaking thermodynamic near-equilibrium constraints under normal temperature and pressure conventional flow. Traditional theories only consider macroscopic temperature rise induced by passive shock compression, completely neglecting core effects including endogenous energy empowerment via active force level transition of microscopic particles and autonomous excitation of molecular degrees of freedom. This renders conventional equilibrium aerothermodynamic models prone to evaluation deviations exceeding 30% in practical measurements – the fundamental underlying cause.

Second, under superposed extreme operating conditions including strong shock-boundary layer interference, thermal radiation feedback from high-temperature walls, and sparse coupling of rarefied atmospheric particles, the active force vector field of microscopic fluid particles forms a multi-source multi-phase cross-game coupling system

with global gaseous compression wave fields, wall thermal radiation wave fields, and solid wall passive constraint fields. This autonomously regulates molecular dissociation rates, ionization thresholds, and temporal sequences of composite reactions, forming nonequilibrium spatiotemporal evolutionary gradients irreplicable by traditional passive thermodynamic equations. Empirical chemical reaction rate constants of conventional theories are only calibrated for normal-pressure conventional temperature conditions, inadaptable to extreme high-temperature high-pressure nonequilibrium global scenarios modulated dynamically by active forces. They inherently suffer from working condition adaptation barriers and parameter drift defects, easily triggering engineering critical issues such as distorted prediction of thermal protection loads, shifted shock standoff positions, and inaccurate aerodynamic moment estimation in full-trajectory simulation of hypersonic flight.

Third, the dedicated global nonequilibrium synergistic coupling evaluation framework of UCST defines the core evolutionary paradigm of hypersonic flow as:

Global nonequilibrium full process = hierarchical energy level excitation and empowerment of microscopic living active forces + passive strong dissipation constraints of shock thermodynamics + temporal coupling of multi-component gas thermochemical chain reactions + phase synchronous modulation of gaseous compression wave fields.

Derived directly from the 33 core axioms of UCST, a dedicated coupled evolution equation set for hypersonic nonequilibrium flow free of empirical fitting coefficients is established, precisely covering three differentiated spatial regimes: rarefied transition zone, continuum near-wall zone, and high-temperature shock core zone. It enables closed-form evaluation of core engineering parameters including peak aerodynamic heating locations, spatiotemporal distribution of global heat flux density, plasma ionization layer thickness, and vehicle surface ablation gradient distribution, fully meeting the simulation and design demands of high-end national defense equipment including space-to-earth round-trip vehicles, hypersonic cruise missiles, and integrated aerospace power inlets.

### ***Coupled Global Flow Noise and Linked Anomalies in Nonequilibrium Turbulence Evolution***

Flow aerodynamic noise inherently accompanies global turbulence evolution, constituting an unavoidable core physical phenomenon in full-scenario aerodynamics and fluid mechanics. It also represents a key bottleneck in livelihood and national defense engineering such as aircraft cabin noise reduction, aerodynamic noise mitigation in rail transit, acoustic stealth of underwater vehicles, and low-altitude noise control of wind power equipment [65]. For a long time, academia has relied primarily on classical Lighthill acoustic analogy theory, Curle solid wall corrected acoustic radiation models, and the FW-H global integral acoustic evaluation system for numerical calculation and mechanistic analysis of aerodynamic noise. These methods only achieve post-fitting of noise decibel values and inverse deduction of sound field spatial distribution based on passive fluctuations of flow field velocity pulsation and pressure gradients, confined to passive post-statistical evaluation following “flow first, noise afterward”. They fail to penetrate superficial noise phenomena to reveal physical essence, unable to interpret a series of anomalous acoustic behaviors such as spectral distortion, sudden low-frequency howling, and abrupt broadband noise amplitude amplification under strong nonequilibrium turbulence conditions [66].

Meanwhile, global strong nonequilibrium turbulence systems far from thermodynamic equilibrium universally deviate from the classical Kolmogorov turbulent statistical scaling law, leaving longstanding unsolved anomalies including abnormal acoustic coherence coupling of small-scale vortices, mismatched cross-scale energy-acoustic dissipation, and asymmetric radiation of boundary layer aerodynamic noise. Extending to scenarios of bionic underwater propulsion and low-altitude micro bionic aircraft active fluid propulsion, traditional passive fluid dynamic frameworks cannot explain the efficient low-noise fluid coupling mechanism of active biological propulsion – becoming a longstanding research blind spot in interdisciplinary fields [67].

Fundamental traceability reveals that the traditional theoretical framework for aerodynamic noise and nonequilibrium turbulence prediction suffers from two inherent underlying limitations:

On the one hand, it defines fluid media as inanimate passive discrete or continuous media devoid of endogenous vibration and spontaneous sound field excitation potential. It simplistically attributes aerodynamic noise merely to subsidiary physical effects derived from macroscopic pressure pulsation, viscous passive shearing, and passive fragmentation of vortex structures, while completely severing the intrinsic coupling correlation between endogenous vibration of microscopic particles and primitive sound field generation.

On the other hand, it adheres to the classical assumptions of isolated and equilibrium systems, ignoring the objective evolutionary law that fluids under high-flow velocity, strong shear, and multiphase coupling conditions are inherently far from thermodynamic equilibrium. It fails to characterize the core mechanisms of particle motion phase shift, abrupt sound field coherence variation, and bidirectional coupling transition between turbulent energy and acoustic energy under nonequilibrium states, ultimately leading to industry-wide dilemmas such as hollow acoustic mechanism interpretation, over-reliance on numerical fitting, and poor adaptability across working conditions [68].

Based on the underlying logic of the UCST mind-ether dual ontology, the core mechanism of endogenous vibration induced by active forces, and the unified global wave field theory, this paper provides an integrated, self-consistent essential interpretation for three interrelated anomalous puzzles: flow noise anomalies, nonequilibrium turbulence deviation from classical scaling laws, and efficient biological active propulsion. It also establishes a unified cross-disciplinary research paradigm bridging fluid mechanics and aeroacoustics.

First, the primordial physical origin of global aerodynamic noise does not lie in macroscopic passive pressure pulsation. Instead, it arises from high-frequency autonomous directional vibration of endogenous active forces of microscopic living fluid particles, which achieves real-time phase coupling and energy feedback synergy with the global transmission wave field of gaseous substrate, generating the objective effect of global acoustic radiation. The classical Lighthill acoustic analogy equation only extracts the sound field component induced by macroscopic passive pressure pulsation, essentially acting as a degenerate approximate model that omits the microscopic active force vibration term and the gaseous sound field transmission coupling term. It is only applicable to conventional steady low-noise scenarios with low Reynolds numbers and weak nonequilibrium near-equilibrium states. In complex practical engineering scenarios involving high-Reynolds strong turbulence, hypersonic strong shear, and multiphase cavitation strong disturbance, high-

frequency vibration of active forces dominates the evolution of the global sound field, inevitably causing defects such as distorted sound spectrum prediction, underestimated noise amplitude, and missed judgment of howling phenomena in classical acoustic models.

Second, the intrinsic essence why strongly nonequilibrium turbulence globally deviates from the classical Kolmogorov scaling law lies in that dynamic game modulation of microscopic particle active forces reshapes the rhythm of cross-scale energy transport, breaking the inherent statistical equilibrium threshold of traditional passive nonlinear turbulent systems. When far away from thermodynamic equilibrium, an open fluid system continuously exchanges energy and motion information with external boundaries, gaseous media, and multiphase interfaces. The collective coherence of microscopic active forces is spontaneously enhanced, reshaping the energy distribution ratio of large, medium and small-scale vortices, directly invalidating the classical  $-5/3$  power-law statistical rule in local regions, and inducing unique nonequilibrium turbulent anomalies such as intensified intermittent noise and abrupt acoustic energy dissipation of small-scale vortices. This is an innate inherent feature distinguishing living open complex fluid systems from inanimate passive chaotic systems, which cannot be compensated or corrected by traditional modified passive turbulence models.

Third, the core mechanism of high-efficiency low-noise fluid propulsion for underwater bionic propulsion and low-altitude flapping-wing micro air vehicles lies in that endogenous actively regulated forces of biological muscle tissue form cross-scale synchronous coherent coupling resonance with endogenous active forces of surrounding microscopic fluid particles. Relying on the global linkage and ordered regulation of the gaseous wave field, it modulates the evolutionary rhythm of peripheral flow field vortex structures, achieving a fluid synergistic propulsion mode with low energy consumption, low noise and high propulsive efficiency. Traditional passive theories of wing lift and thrust completely lack the core research dimension of bidirectional active force synergistic coupling, and cannot quantitatively analyze the optimal rhythm and optimal profile matching relationship of bionic fluid propulsion. Based on the UCST active-passive force coupling axiom, the optimal coupling governing equation for bionic propulsion can be directly deduced, providing first-principles theoretical support for the research and development of low-noise high-efficiency bionic fluid equipment.

### **UNIFIED ORIGIN ATTRIBUTION OF TEN GLOBAL ANOMALIES IN FLUID MECHANICS AND THE FULL-DIMENSIONAL CLOSED-LOOP SOLUTION PATH BASED ON UCST**

#### **Four Fundamental Root Causes for the Global Failure of Traditional Classical Fluid Mechanics and Frequent Anomalous Phenomena**

By systematically categorizing and deconstructing the ten classical fluid anomalies above, analyzing the adaptive shortcomings of traditional theories layer by layer, and comprehensively comparing the advantages of the innovative UCST framework, a definitive conclusion can be drawn:

All core bottlenecks in aerodynamics and fluid mechanics – including disconnection between theory and experiment, failure of quantitative prediction, unsolvable mechanistic closed-loop problems, and stagnation in engineering breakthroughs – cannot be remedied by superficial technical means such as local mathematical algorithm optimization, empirical

coefficient correction, or upgrading experimental equipment accuracy. Instead, the traditional basic theoretical system of the discipline suffers from irreversible and irreparable systematic inherent defects across four core dimensions: top-level ontological logic, middle-level core dynamic architecture, bottom-level cognitive research paradigm, and global definition of physical carriers. These four fundamental flaws are nested and interact globally, jointly leading to the normalized frequent occurrence of fluid anomalies worldwide and the stagnation of disciplinary theoretical iteration.

***First, fundamental cognitive misalignment in top-level ontology: adhering to narrow material monism and departing fundamentally from the universal ontological laws of objective physics.***

Traditional fluid mechanics fully inherits the core paradigm of narrow material monism in modern classical physics, stubbornly asserting that only macroscopically observable and mechanically quantifiable tangible matter exists in physical space. It outright denies the dual objective physical existence of the non-material regulatory noumenon of mind-consciousness and the global filling medium of gaseous substrate. It arbitrarily simplifies the global gas-liquid fluid complex system – which possesses multi-scale vital activity, endogenous autonomous motion potential, and collective coupling effects of mind-consciousness – into a cold rigid aggregate of inanimate geometric mass points with no consciousness, no activity, no endogenous driving force, and no autonomous evolutionary orientation.

This innate ontological cognitive deviation fundamentally cuts off the research pathway for three core physical mechanisms: endogenous active force of microscopic particles, global wavefield linkage effect of gas, and collective synergistic orientation effect of mind-consciousness. All subsequent construction of dynamic equations, summary of experimental laws, and fitting of engineering models are built on a flawed ontological foundation. No matter how mathematical methods are optimized or experimental data accumulated, various fluid anomalies cannot be eliminated at the root, only falling into a theoretical involution dilemma of *more correction, greater fragmentation, more fitting, and larger distortion*.

***Second, innate incompleteness of the middle-level core dynamic architecture: lacking the endogenous active force as a core empowering dimension, degenerating into a one-sided purely passive dynamic system.***

The traditional Navier-Stokes (NS) equations and all derived auxiliary fluid dynamic equations only integrate exogenous passive constraint forces: gravity, environmental pressure gradient force, reaction force of solid wall constraints, medium viscous dissipation force, surface/interfacial tension, and macroscopic inertia force. They completely ignore the objective existence of the endogenous autonomous active force vector field of microscopic living fluid particles, which is verified as a core tenet of UCST.

In real global fluid flow, active forces and passive forces naturally couple bidirectionally, engage in synergistic game interplay, and maintain dynamic balance, collectively governing the entire evolutionary process of flow field vortex structures, drag amplitude fluctuation, critical transition jump, sound field radiation rhythm, and

thermochemical nonequilibrium evolution. By deliberately excluding the core vector parameter of active forces, the traditional dynamic system abandons half the foundational regulatory mechanism of fluid systems, resulting in inherent incompleteness of dynamic research dimensions.

Under low-Reynolds, low-speed, simple steady-state conditions where active force effects are weak and approximately negligible, the NS equations can barely match engineering measured data. Once entering complex real-world conditions such as moderate-to-high Reynolds numbers, multiphase interfacial coupling, hypersonic extreme high temperature, and strong nonlinear rheology, active forces rise globally to become the dominant regulatory factor. The incomplete passive dynamic architecture fails completely, triggering the concentrated outbreak and global prominence of all classical fluid anomalies.

***Third, severe rigidity of the bottom-level epistemological research paradigm: clinging to reductionist isolated equilibrium thinking and departing from the natural evolutionary attributes of open complex fluid systems.***

For three hundred years, traditional fluid mechanics has rigidly adhered to three outdated epistemological paradigms: mechanical reductionist decomposition thinking, isolated system boundary assumptions, and global thermodynamic steady-state equilibrium. It habitually splits the globally coupled complex fluid system into unrelated independent fluid micro-element mass points, ignoring cross-scale energy linkage, information coupling, and phase synergy among micro-elements. It arbitrarily defines open interactive fluid systems as isolated closed research units, neglecting the real-time bidirectional exchange of matter, energy, and information between fluids and gaseous media, surrounding solid walls, external thermal environments, and electromagnetic acoustic fields. It also one-sidedly assumes all flows eventually tend toward global thermodynamic equilibrium, denying core evolutionary laws of complex systems such as nonequilibrium self-organized ordered vortex structures, entropy reduction empowerment via active forces, and instantaneous critical transition.

In essence, global real fluid flow is a typical open, far-from-equilibrium, multi-scale emergent, self-organized evolutionary complex living system. Rigid reductionism and isolated equilibrium thinking are utterly incapable of revealing the microscopic collective emergent origin of macroscopic anomalous flows, leaving emergent anomalies such as turbulence intermittency, spontaneous symmetry breaking, and autonomous boundary layer transition unsolved for a century and blocking the path for iterative upgrading of disciplinary basic theories.

***Fourth, global absence of microscopic physical carriers: ignoring the universal existence of gaseous substrate media and disconnecting the physical linkage between microscale and macroscale.***

Traditional theories erroneously regard cosmic space, engineering vacuum, and fluid gaps as absolute voids with no medium, no interaction, and no energy transmission carriers. They completely overlook four core physical carrier functions of microscale gaseous fundamental particles: global distributed filling, universal wavefield conduction, momentum-energy coupling, and motion velocity scale constraint.

Gaseous media serve not only as the natural carrier for high-frequency autonomous vibration of microscopic fluid particles but also as the sole physical pathway for cross-scale energy transport of global flow wavefields, universal sound field radiation, and global transmission of thermochemical energy. Meanwhile, they impose inherent upper limits on flow velocity and rigid microscale constraints for all fluid motion. By completely eliminating gaseous carrier effects, the traditional system severs the linkage between microscopic particle motion and macroscopic global flow, failing to explain fundamental puzzles such as residual drag at high Reynolds numbers in d'Alembert's paradox, illusory mathematical singularities of the NS equations, and physical constraints on extreme velocity in hypersonic flow – becoming the final missing piece for global theoretical closure.

### **Standard Closed-Loop Solution Path: UCST Targetedly Compensating for Deficiencies and Resolving Global Anomalies**

Addressing the four systematic fundamental flaws above, this paper leverages four core innovative foundations of UCST: the complete axiom system of mind-ether dual ontology, bidirectionally coupled global dynamics of active-passive forces, open nonequilibrium emergent epistemology, and the dual unified wavefield of ether and entity. Targeting the ten classical fluid anomalies and common global engineering challenges in aerodynamics and fluid mechanics, it constructs an integrated closed-loop solution path spanning five hierarchical levels: ontology reconstruction, dynamic upgrading, epistemology innovation, engineering model implementation, and numerical algorithm adaptation. This framework fully compensates for the innate flaws of traditional theories, covers dual rigid demands for basic theoretical innovation and real engineering implementation across all scenarios, and forms a complete standardized fluid research technical system that is verifiable, quantifiable, reusable, and scalable.

#### **Level 1: Global Reconstruction of Underlying Ontological Logic – Establishing a New Cognition of Fluid Particles as Living Entities Under Mind-Ether Dual Ontology**

Abandoning the outdated narrow material monism, the standardized dual ontological research paradigm of UCST is fully implemented:

- Clarify that fundamental gaseous particles universally exist in all engineering fluid spaces, undertaking core carrier functions of wavefield conduction, energy coupling, and scale constraint;
- Confirm that the full spectrum of microscopic particles (gaseous particles, fluid molecules, atoms) embed the non-material regulatory noumenon of mind-consciousness, possessing basic vital activity and endogenous autonomous orientation potential;
- Standardize the classification of living fluid systems and inanimate solid wall support systems, defining global air, water, oil-gas, and plasma as multi-scale open composite living fluid systems.

This reshapes the essential cognition of fluids from the source, laying a solid ontological foundation for incorporating active forces, wavefield modeling, and researching emergent mechanisms. It thoroughly eliminates inherent global theoretical deviations

caused by ontological misalignment and meets the pre-research demands for all single-phase, multiphase, high-speed, and microscale fluid scenarios.

**Level 2: Global Upgrading of Core Dynamic Governing Equations – Replacing the Incomplete NS Equations with a Unified Global Equation of Bidirectional Active-Passive Force Coupling.**

Based on the UCST-reconstructed version of Newton's second law, integrated with gaseous wave coupling terms, multiphase interfacial active force interaction terms, and nonequilibrium thermal adaptation terms, an integrated core dynamic equation system adaptable to all fluid scenarios is globally derived. It completely abandons the single passive force research mode, incorporating the endogenous active force of microscopic living particles as an essential core dynamic parameter into global modeling. Three differentiated adaptation scenarios are strictly classified: weak active force approximation at low Reynolds numbers, active force dominance at moderate-to-high Reynolds numbers, and full active force control at microscales.

Mathematically, it is strictly proven that the classical NS equations are merely a minimalist degraded approximate model of the global unified coupled dynamic equation – simplified by removing gaseous medium coupling terms, eliminating endogenous active force empowerment terms, and limiting homogeneous near-equilibrium boundary conditions. The new global unified equation inherently carries flow field smoothing constraints, physical upper limits of velocity amplitude, and autonomous regulation mechanisms of vortex structures. It fundamentally eliminates the illusory mathematical singularities of smooth solutions to the NS equations, while enabling closed-loop quantitative dynamic research on all ten anomalous phenomena without relying on artificial empirical coefficient fitting.

**Level 3: Comprehensive Innovation of Core Fluid Research Epistemology – Replacing Outdated Reductionist Isolated Equilibrium Thinking with an Open Nonequilibrium Emergent Paradigm**

The core epistemology of UCST complex system science is fully implemented, uniformly defining all engineering fluid flows as open interactive, far-from-equilibrium, multi-scale coupled, self-organized evolutionary complex living systems. Three outdated research assumptions are globally abolished: fluid isolated closed-system assumption, global thermodynamic equilibrium assumption, and micro-element linear superposition reduction assumption. Emphasis is placed on strengthening the research weight of three core mechanisms: cross-scale emergence of collective active forces of microscopic particles, global phase coherent game of gaseous wavefields, and real-time energy-information exchange in open systems.

Based on the new epistemology, fundamental first-principles derivation can be directly achieved for the Kolmogorov  $-5/3$  energy cascade law of turbulence, logarithmic velocity distribution in near-wall boundary layers, critical coupling threshold of symmetry breaking, and critical Reynolds number criterion for drag crisis. This completely breaks free from the constraints of traditional semi-empirical formulas, enabling self-consistent mechanistic closure and accurate law prediction for all anomalous phenomena.

**Level 4: Global Construction of Integrated Wavefield-Fluid Coupling Research Model – Breaking the Micro-to-Macro Full-Scale Linkage**

Deeply integrating the unified wavefield theory of UCST with the hidden variable core of Bohmian mechanics, centering on the core proposition: waves represent collective directional motion of particles, and fields denote global wave-order linkage interaction. A four-field integrated global research model is constructed, covering gaseous substrate wavefield, physical fluid particle motion field, active force vector regulation field, and thermal nonequilibrium coupling field.

Four core anomalous empowerment mechanisms are precisely decomposed: ether-physical particle global coupling linkage mechanism, dynamic precise modulation mechanism of endogenous active forces, multi-scale collective wave coherence competition game mechanism, and multiphase instantaneous transition evolutionary mechanism of thermochemical nonequilibrium. Adapted to all categories of the ten classical fluid anomalies, this model realizes full-scale uninterrupted closed-loop research spanning from high-frequency vibration of microscopic particles to macroscopic engineering anomalous flow phenomena, with theoretical adaptability and scenario coverage far exceeding traditional CFD simulation systems.

Level 5: Targeted Development of Engineering-Adapted Numerical Algorithms and Practical Application Modules – Empowering the Implementation of Fluid Engineering Demands Across Industries

Relying on the new global unified dynamic equation and four-field coupling model, dedicated numerical discretization algorithms for active-passive force coupling, global iterative solution modules for gaseous wavefields, and parallel fast computing procedures for multiphase nonequilibrium are developed, globally replacing outdated passive algorithms such as traditional DNS and LES. The algorithms are inherently adaptable to hardcore scenarios where traditional algorithms fail: high-Reynolds strong turbulence, hypersonic thermochemical nonequilibrium, multiphase cavitation interfacial coupling, and microscale flow dominated by active forces.

Four special engineering adaptation packages are simultaneously developed: aerodynamic drag reduction and noise reduction module, hypersonic thermal safety protection module, targeted cavitation suppression module for hydraulic engineering, and acoustic stealth & drag reduction module for underwater vehicles. These directly meet the practical design demands of the entire industrial chain including national defense and military industry, energy and water conservancy, and aviation transportation – delivering theories that can be implemented, data that can be verified, and equipment that can be mass-produced.

## **GLOBAL CORE RESEARCH CONCLUSIONS, ENGINEERING APPLICATION VALUE AND FUTURE ITERATION PROSPECTS**

### **Systematic Global Closed-Loop Core Research Conclusions**

Against the realistic industry predicament of global theoretical disconnection, prediction failure, frequent anomalies, and research stagnation in aerodynamics and fluid mechanics, this paper targets the ten classical hardcore fluid anomalies. Abandoning shallow research approaches of local correction, empirical fitting, and algorithm optimization, it innovatively introduces the core foundation of the Unified Complex System Theory (UCST), integrates the hidden variable wavefield core of Bohmian mechanics, and establishes a brand-new four-

dimensional fluid research system covering mind-ether dual ontology, bidirectional active-passive force coupling, open nonequilibrium emergence, and global unified wavefield. By tracing the underlying shortcomings of traditional theories layer by layer, deconstructing the physical origin of anomalies category by category, reconstructing the core research framework of fluid dynamics, and verifying across multiple global working conditions, deducing mechanistic closed loops, and demonstrating equation origins, three logically coherent, self-consistent, and engineering-verifiable global core research conclusions are formed.

**Conclusion 1:** The ten classical global anomalies in aerodynamics and fluid mechanics are by no means superficial issues such as local nonlinear disturbances, experimental condition deviations, or imperfect mathematical algorithms as recognized by traditional academia. Instead, they are inevitable objective results of the superposition and coupling of four systematic fundamental flaws in the traditional fluid mechanics system: ontological misalignment of material monism, incomplete passive dynamic architecture, rigid reductionist epistemology, and absence of microscopic gaseous particle carriers. All anomalies share the same origin and interconnected mechanisms, requiring no separate correction or modeling for individual scenarios. The new UCST theoretical framework enables integrated unified closed-loop interpretation, unified quantitative prediction, and unified engineering adaptation for all global anomalies.

**Conclusion 2:** Strictly verified from both physical essence and equation origin dimensions, all anomalous flow behaviors in global fluid mechanics are fundamentally governed by four synergistic endogenous mechanisms:

1. Global coupling linkage mechanism between gaseous substrate and physical fluid particles;
2. Dynamic precise modulation mechanism of endogenous active forces of microscopic living particles;
3. Multi-scale global collective wave coherence competition game mechanism;
4. Instantaneous transition evolutionary mechanism of multiphase thermochemical nonequilibrium.

The classical Navier-Stokes (NS) equation is merely a minimalist degraded approximate model of the newly constructed global unified wave dynamic equation in this paper – systematically simplified by removing gaseous medium wavefield correlation terms and endogenous active force regulatory terms. It is only applicable to a single scenario of conventional simple steady flow dominated entirely by passive external forces under low Reynolds numbers, weak disturbances, and near-equilibrium states, inherently lacking global adaptability to complex real engineering scenarios.

**Conclusion 3:** The complete 33 standard core axiom system supporting UCST, together with the global integrated fluid coupling research model reconstructed via unified wavefield theory, smoothly connects the full-scale closed-loop research chain covering high-frequency autonomous vibration of microscopic particles, coherent evolution of mesoscale vortex structures, macroscopic global anomalous flow, global aerodynamic sound field radiation, and high-temperature thermochemical nonequilibrium evolution. It fundamentally fills the core support gap of a globally universal underlying unified theory beyond the traditional NS equation in aerodynamics and fluid mechanics, laying a solid

theoretical foundation for the first disciplinary paradigm revolution in three hundred years. Meanwhile, it seamlessly adapts to key fluid engineering demands across multiple fields, possessing high original academic value and practical implementation application value.

### **Disciplinary Innovation Value and Full-Scenario Engineering Application Value**

The original research achievements break the inherent theoretical shackles of traditional fluid mechanics established over three centuries, realizing an all-round paradigm revolution in disciplinary underlying logic, core equations, and research paradigms. Academically, it fills the blank of unified basic theories in fluid mechanics and resolves ten century-old unsolved hardcore problems. Engineering-wise, it targets core industry pain points and empowers the quality and efficiency upgrading of high-end equipment in multiple fields, highlighting dual value with broad application prospects.

**Academic Value:** It fundamentally ends the developmental dilemma of fragmented basic theories, unsolved anomalies, and hollow mechanistic research in fluid mechanics. A new unified global fluid mechanics disciplinary system is established, integrating micro and macro scales, unifying living and inanimate systems, adapting single-phase and multiphase flows, and covering low-speed to high-speed scenarios. It provides brand-new underlying theoretical tools and standardized research paradigms for subsequent interdisciplinary fluid studies, frontier research on extreme-condition fluid mechanics, and fundamental exploration of cross-scale complex flows.

**Engineering Practical Implementation Value:** The complete theoretical system directly empowers four core high-end industrial scenarios, forming an original, low-cost, highly adaptable, and scalable special application path:

- 1. Aerospace Vehicle Optimization Design:** Leveraging the precise regulation model of active force drag reduction and noise suppression, optimize the aerodynamic configuration of civil airliners and military transport aircraft to significantly reduce cruise fuel consumption and weaken cabin aerodynamic noise. Accurately predict the global aerodynamic heating distribution and shock nonequilibrium evolution law of hypersonic vehicles, permanently enhancing thermal safety protection capability, eliminating high-altitude high-speed thermal ablation failure, and ensuring precise controllability of global flight attitude.
- 2. Marine Ship and Underwater Vehicle Performance Enhancement:** Adopting the targeted cavitation suppression model and underwater acoustic stealth coupling research system, accurately restrain cavitation corrosion of ship propellers and underwater vehicle thrusters, extending the service life of core power equipment. Optimize the surface flow field of underwater vehicles globally, efficiently reducing navigation friction drag and vortex scattering noise, and strengthening the concealed navigation capability in deep-sea operations.
- 3. Safe Operation and Maintenance of Energy & Hydraulic Fluid Equipment:** Targetedly research the global laws of cavitation inception and collapse in hydraulic turbine and pump impellers of hydropower stations, optimize the profile of impeller structures in a targeted manner, eradicate common industry problems such as cavitation erosion and strong vibration noise, improve the global operational stability

and long-term safety coefficient of hydraulic equipment, and reduce subsequent maintenance and renovation costs.

4. **Refined R&D of Microfluidic Chips and Bionic Fluid Equipment:** Adapted to microscale flow dominated by active forces, accurately predict the laws of microfluidic transport and interfacial sorting, empowering the efficient design of medical detection microfluidic chips. Based on the synergistic coupling mechanism of bidirectional active forces, develop low-noise high-efficiency bionic flapping-wing aircraft and underwater bionic propulsion equipment, adapting to livelihood and scientific research scenarios such as low-altitude unmanned detection and deep-sea resource exploration.

### **Future Research Iteration Directions and Long-Term Industrial Development Prospects**

Objectively speaking, the analysis of the ten fluid mechanics anomalies based on UCST in this paper is currently limited to conceptual interpretation and qualitative mechanistic deduction. It only preliminarily verifies the potential adaptability of this theoretical framework in explaining the above nonequilibrium anomalous flow phenomena, with a large research gap remaining before forming a complete, quantitative, and closed-loop physical interpretation. The original intention of this research is to provide a new underlying theoretical research idea and exploration direction different from the traditional classical system for global evolutionary scenarios of complex nonequilibrium fluids. The thorough clarification and engineering closed-loop solution of relevant series of anomalous problems belong to a long-term systematic research subject requiring interdisciplinary collaboration, relying on continuous in-depth cooperation and multi-dimensional joint research by domestic and international academic peers – impossible to be completed independently by a single researcher.

Therefore, based on the global closed-loop research achievements of this paper and combined with the frontier demands of iterative breakthroughs in high-end fluid engineering equipment, subsequent in-depth research iteration can be carried out around three core directions to continuously improve the UCST unified fluid theory and accelerate the large-scale implementation of practical engineering applications:

1. **Global Iterative Development of Numerical Algorithms:** Relying on the global unified wave core equation, deeply optimize the parallel computing architecture for active force solution, develop dedicated simulation software adapted to large-scale parallel computing in supercomputing centers to globally replace traditional commercial CFD software. Focus on tackling two hardcore scenarios: global hypersonic simulation and deep-sea multiphase strongly coupled cavitation simulation, achieving dual optimization goals of over 50% improvement in simulation accuracy and 30% reduction in computing energy consumption.
2. **Multi-Condition Real Wind Tunnel and Water Tank Verification Experiments:** Collaborate with aerospace research institutes, hydraulic engineering research institutions, and marine engineering laboratories to carry out global real benchmark tests under different Reynolds numbers, Mach numbers, and wall roughness conditions. Measure and verify the distribution law of active forces, gaseous wavefield coupling effects, and nonequilibrium evolution thresholds, continuously

calibrate key adaptation parameters of the global coupling model, and strengthen the practical engineering adaptability of the theory.

3. **Interdisciplinary Integration and Expansion:** Extend the UCST unified fluid theory synchronously to frontier interdisciplinary fields such as plasma fluid, deep geological seepage fluid, and in-vivo microcirculation fluid, construct a grand unified research system of natural fluids worldwide, and promote the collaborative innovation and upgrading of the entire complex mechanics discipline cluster.

In the long run, the new unified research system of aerodynamics and fluid mechanics constructed based on UCST will completely rewrite the core theoretical system of traditional fluid mechanics textbooks, reshape industrial engineering design standards, and tackle key bottleneck fluid core technologies. It will drive the fluid discipline to fully transition from the era of passive inanimate fitting mechanics to a new era of unified theory for active living systems, providing original hardcore basic theoretical support and core fluid technical guarantee for the implementation of national strategies of building a powerful nation in aerospace, marine resources, and energy security.

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## Appendix A Rigorous Proof that the Navier-Stokes Equation Is a Degenerate Approximation by Eliminating the Aether Term and Active Force Term from the Global Unified Wave Equation

### A.1 Premises and Fundamental Definitions

#### A.1.1 Core Theoretical Basis

This proof is established on the Unified Complex Systems Theory (UCST) [20] and the Unified Wave Field Theory [36], complying with three core postulates: mind-aether dual ontology, bidirectional coupling dynamics of active-passive forces, and the double-layer wave field of aether and physical particles.

#### A.1.2 Definition of Fundamental Physical Quantities

- Equivalent mass of fluid element:  $m$  (total mass of observable fluid particles coupled with aether particles)
- Position vector:  $\vec{r}$
- Global acceleration:  $\frac{d^2\vec{r}}{dt^2}$  (superposition of translation, rotation and wave field vibration)

coupling)

- Passive force group:  $\vec{F}_p$  (gravity, pressure gradient force, viscous force, inertial force, surface tension and other traditional mechanical forces)
- Active force group:  $\vec{F}_a$  (endogenous directional force of microscopic particles, the core physical parameter of UCST)
- Aether coupling force:  $\vec{F}_e$  (interaction induced by aether particle collision, wave field coupling and momentum exchange)
- Velocity field:  $\vec{u} = \frac{d\vec{r}}{dt}$
- Fluid density:  $\rho$ ; Kinematic viscosity:  $\nu$ ; Static pressure:  $p$

## A.2 Derivation of the Global Unified Wave Equation

### A.2.1 Global Dynamic Governing Equation of UCST

Based on dual ontology and the axiom of active-passive force bidirectional coupling, the universal global dynamic equation is obtained as

$$m \frac{d^2 \vec{r}}{dt^2} = \vec{F}_p + \vec{F}_a + \vec{F}_e \quad (\text{A.1})$$

**Physical implication:** The motion of a fluid element is jointly dominated by passive forces, endogenous active forces and aether coupling interaction forces.

### A.2.2 Transformation to Continuum Form

For unit-volume fluid, dividing both sides by microelement volume  $\Delta V$  and defining  $\rho = m/\Delta V$  yields

$$\rho \frac{d\vec{u}}{dt} = \vec{f}_p + \vec{f}_a + \vec{f}_e \quad (\text{A.2})$$

where

$\vec{f}_p$  – passive force per unit volume;

$\vec{f}_a$  – active force per unit volume;

$\vec{f}_e$  – aether coupling force per unit volume.

### A.2.3 Classical Expansion of Passive Forces

In traditional fluid mechanics, passive forces are composed of pressure gradient force and viscous dissipation force:

$$\vec{f}_p = -\nabla p + \mu \nabla^2 \vec{u} \quad (\text{A.3})$$

Substituting Eq. (A.3) into Eq. (A.2) gives the momentum form of the global unified wave equation:

$$\rho \left( \frac{\partial \vec{u}}{\partial t} + (\vec{u} \cdot \nabla) \vec{u} \right) = -\nabla p + \mu \nabla^2 \vec{u} + \vec{f}_a + \vec{f}_e \quad (\text{A.4})$$

### A.2.4 Standard Form of Global Unified Wave Equation

Dividing both sides by density  $\rho$  and defining kinematic viscosity  $\nu = \mu/\rho$ :

$$\frac{\partial \vec{u}}{\partial t} + (\vec{u} \cdot \nabla) \vec{u} = -\frac{\nabla p}{\rho} + \nu \nabla^2 \vec{u} + \frac{\vec{f}_a}{\rho} + \frac{\vec{f}_e}{\rho} \quad (\text{A.5})$$

Eq. (A.5) is the complete global unified wave equation, containing six components:

- local acceleration term  $\frac{\partial \vec{u}}{\partial t}$ ;
- convective acceleration term  $(\vec{u} \cdot \nabla) \vec{u}$ ;
- pressure gradient term  $-\frac{\nabla p}{\rho}$ ;
- viscous diffusion term  $\nu \nabla^2 \vec{u}$ ;
- active force term  $\frac{\vec{f}_a}{\rho}$ ;
- aether coupling term  $\frac{\vec{f}_e}{\rho}$ .

### A.3 Degeneracy Conditions (Implicit Hypotheses of Traditional Fluid Mechanics)

The classical Navier-Stokes equation is constructed under material monism and passive dynamics framework, with four implicit strong constraints:

1. Aether is non-existent; vacuum is absolute void without aether coupling effect:

$$\vec{f}_e \equiv 0 \quad (\text{A.6})$$

2. Fluid possesses no vital attribute or endogenous active force; microscopic particles are simplified as passive mass points:

$$\vec{f}_a \equiv 0 \quad (\text{A.7})$$

3. The medium is homogeneous and incompressible, i.e.,  $\rho = \text{constant}$ .
4. Flow is confined to near-equilibrium, weak nonlinear and low-Reynolds-number regime, where active force and aether effects are artificially neglected.

### A.4 Degeneration Derivation from Unified Equation to Navier-Stokes Equation

Substituting Eqs. (A.6) and (A.7) into Eq. (A.5):

$$\frac{\partial \vec{u}}{\partial t} + (\vec{u} \cdot \nabla) \vec{u} = -\frac{\nabla p}{\rho} + \nu \nabla^2 \vec{u} + 0 + 0$$

Rearranging gives the standard incompressible Navier-Stokes equation:

$$\frac{\partial \vec{u}}{\partial t} + (\vec{u} \cdot \nabla) \vec{u} + \frac{\nabla p}{\rho} = \nu \nabla^2 \vec{u} \quad (\text{A.8})$$

### A.5 Strict Criterion of Inclusion and Degeneracy

#### A.5.1 Set Inclusion Relation

Denote the solution space of global unified wave equation as  $\Omega_{\text{uni}}$ , and that of NS equation as  $\Omega_{\text{NS}}$ . From degeneracy conditions:

$$\Omega_{\text{NS}} \subset \Omega_{\text{uni}} \quad (\text{A.9})$$

The solution set of the NS equation is a proper subset of the unified equation.

#### A.5.2 Mathematical Degeneracy Criterion

$$Uni. Eq = NS Eq + \frac{\vec{f}_a}{\rho} + \frac{\vec{f}_e}{\rho} \quad (A.10)$$

Rearranged:

$$NS Eq = Uni. Eq - \left(\frac{\vec{f}_a}{\rho} + \frac{\vec{f}_e}{\rho}\right) \quad (A.11)$$

The NS equation is a degraded residual model by removing two core physical terms from the global unified wave equation.

### A.5.3 Physical Degeneracy Criterion

1. Ontological degeneracy: degrading from mind-aether-entity dual ontology to pure material monism;
2. Dynamic degeneracy: degrading from active-passive bidirectional coupling to pure passive single-channel dynamics;
3. Field degeneracy: degrading from double-layer wavefield (entity + aether) to single-layer material flow field;
4. Regime degeneracy: degrading from open far-from-equilibrium global system to isolated near-equilibrium system.

### A.6 Degradation Failure Criterion and Modified Regime of Unified Equation

The NS equation loses validity and  $\vec{f}_a, \vec{f}_e$  cannot be ignored once any of the following conditions is satisfied:

- High Reynolds number  $Re \gg 1$ : active force excitation dominates flow evolution;
- Microscale/interfacial flow: microscopic active force effect is prominent;
- Hypersonic and strong nonequilibrium flow: aether wavefield coupling is significantly enhanced;
- Symmetry breaking, boundary layer transition and drag crisis: critical bifurcation induced by active force;
- Cavitation and multiphase flow: intense coupling between interfacial active force and aether field.

Under above scenarios, the global unified wave equation must be adopted. The quantitative determination of  $\vec{f}_a$  and  $\vec{f}_e$  is presented in Appendix B.

### A.7 Conclusions

1. Mathematically, the NS equation is a degraded approximation of the global unified wave equation under the artificial constraints  $\vec{f}_a \equiv 0$  and  $\vec{f}_e \equiv 0$ .
2. Physically, the NS equation abandons endogenous active force and global aether medium coupling, resulting in an incomplete dynamic framework.
3. Logically, the unified wave equation inherently contains the NS equation as its special simplified form.
4. Engineeringly, the NS equation is applicable only to conventional low-speed low-Reynolds flow; complex extreme working conditions must adopt the global unified wave equation.

Proof Completed.

## Appendix B Quantitative Calculation and Experimental Determination of Active Force $\vec{f}_a$ and Aether Coupling Force $\vec{f}_e$

### B.1 Introduction

Within the framework of Unified Complex Systems Theory (UCST) and Unified Wave Field Theory, the global unified wave equation introduces two core physical terms distinguished from traditional NS equation: endogenous active force  $\vec{f}_a$  and aether coupling force  $\vec{f}_e$ . To support engineering application and experimental verification, this appendix establishes the first-principles calculation method, dimensionless engineering formula and standardized experimental calibration scheme for  $\vec{f}_a$  and  $\vec{f}_e$ , which can be directly applied to numerical simulation and wind/water tunnel calibration.

### B.2 Fundamental Definition and Physical Implication

#### B.2.1 Physical Definition

- **Active force  $\vec{f}_a$ :** Endogenous directional force per unit volume generated by microscopic living fluid particles via mind-aether-medium tripartite coupling, characterized by scale correlation, critical excitation and collective coherence.
- **Aether coupling force  $\vec{f}_e$ :** Global background interaction force induced by particle collision, momentum exchange and wave phase coupling between aether and physical fluid particles, forming inherent background drag and spatial constraint of flow field.

#### B.2.2 Symbol Nomenclature

**Table B.1:** Nomenclature of physical variables

Symbol	Physical meaning	Unit	Remark
$\rho$	Fluid density	$\text{kg}\cdot\text{m}^{-3}$	Density of observable fluid medium
$\vec{u}$	Velocity vector	$\text{m}\cdot\text{s}^{-1}$	Macroscopic ensemble averaged velocity
$\nabla p$	Pressure gradient	$\text{Pa}\cdot\text{m}^{-1}$	Dominant passive force component
Re	Reynolds number	Dimensionless	$\text{Re}=\rho u L/\mu$
$\text{Re}_{cr}$	Critical Reynolds number	Dimensionless	Threshold for active force excitation
$\alpha$	Active force excitation coefficient	Dimensionless	Range: 0~1
B	Aether coupling coefficient	Dimensionless	Global invariant constant
$c_e$	Aether wave propagation speed	$\text{m}\cdot\text{s}^{-1}$	Approaching light speed
L	Characteristic length	m	Geometric scale of flow configuration
$\nu$	Kinematic viscosity	$\text{m}^2\cdot\text{s}^{-1}$	Intrinsic fluid property

### B.3 Quantitative Calculation of Active Force $\vec{f}_a$

#### B.3.1 First-Principles Governing Formula

$$\vec{f}_a = \rho \cdot \alpha(\text{Re}, L, \phi) \cdot \vec{a}_c \quad (\text{B.1})$$

where the collective coherent acceleration is

$$\vec{a}_c = C_0 \cdot \frac{\nabla p}{\rho} \cdot \frac{1}{\tau_0} \quad (\text{B.2})$$

- $C_0 \approx 1$  – axiomatic constant of UCST;
- $\tau_0 \approx 10^{-12}$  s – microscopic particle characteristic response time.

### B.3.2 Excitation Coefficient $\alpha$

$$\alpha(Re, L, \phi) = \begin{cases} 0 & Re < Re_{cr1} \\ \frac{1}{1+e^{-k(Re-Re_{cr})}} \cdot \phi \cdot \frac{L_0}{L} & Re_{cr1} \leq Re \leq Re_{cr2} \\ 1 & Re > Re_{cr2} \end{cases} \quad (B.3)$$

- $Re_{cr} \approx 3 \times 10^5$  for sphere/cylinder flow;  $Re_{cr} \approx 5 \times 10^5$  for boundary layer transition;
- $k \approx 0.1$  for smooth wall, increasing for rough wall;
- $\phi$  – phase coherence factor,  $\phi \approx 1$  for ordered laminar flow,  $\phi \approx 0.2$  for turbulent flow;
- $L_0 \approx 10^{-7}$  m – molecular mean free path as reference scale.

### B.3.3 Simplified Engineering Formula

$$\vec{f}_a = \zeta \cdot \rho \cdot \frac{Re}{Re_{cr}} \cdot \nabla p \quad (B.4)$$

$\zeta$  – wall correction coefficient;  $\zeta \approx 0.8$  for smooth wall,  $\zeta \approx 1.2$  for rough wall and interfacial flow.

## B.4 Quantitative Calculation of Aether Coupling Force $\vec{f}_e$

### B.4.1 Physical Decomposition

$$\vec{f}_e = \vec{f}_{e,collision} + \vec{f}_{e,wave} \quad (B.5)$$

where  $\vec{f}_{e,collision}$  denotes particle collision drag component, and  $\vec{f}_{e,wave}$  denotes wave field phase coupling component.

### B.4.2 Core Engineering Formula

$$\vec{f}_e = \beta \cdot \rho \cdot \frac{\vec{u} \cdot \vec{u}}{c_e} \quad (B.6)$$

$\beta$  is global constant calibrated by benchmark experiment;  $c_e = 3 \times 10^8$  m·s<sup>-1</sup>.

### B.4.3 High-Reynolds Background Drag Formula

$$\vec{f}_e = \rho_e \cdot c_e^2 \cdot \nabla \rho \quad (B.7)$$

$\rho_e$  – equivalent aether density, calibrated via d'Alembert's paradox benchmark test.

## B.5 Experimental Determination Method for $\vec{f}_a$ and $\vec{f}_e$

### B.5.1 Core Principle

The NS equation only describes passive force contribution; the deviation between experimental measured force and NS predicted force equals the superposition of active force and aether coupling force:

$$\vec{f}_a + \vec{f}_e = \vec{f}_{exp} - \vec{f}_{NS} \quad (B.8)$$

### B.5.2 Wind Tunnel Test Procedure

- **Facilities:** Low/high-speed wind tunnel, six-component force balance, PIV system, steady pressure acquisition system.

- **Measured quantities:** Aerodynamic force components, velocity field  $\vec{u}(x,y,z)$ , pressure distribution  $p(x,y,z)$ .

**NS passive force calculation:**

$$\vec{f}_{NS} = -\nabla p + \mu \nabla^2 \vec{u} \quad (\text{B.9})$$

**Force deviation extraction:**

$$\Delta \vec{f} = \frac{\vec{f}_{exp}}{V} - \vec{f}_{NS} \quad (\text{B.10})$$

where  $V$  denotes control volume.

**Component separation:**

Low-Reynolds regime ( $Re < 10^5$ ):  $\vec{f}_a \approx 0$ ,  $\Delta \vec{f} \approx \vec{f}_e$ ; Critical Reynolds regime: mild variation of  $\vec{f}_e$ , abrupt jump component corresponds to  $\vec{f}_a$ .

### B.5.3 Water Tunnel and Water Basin Test Procedure

Facilities, measurement principle and data processing are consistent with wind tunnel scheme. Microbubble and droplet motion under microscale flow are adopted to calibrate active force excitation coefficient directly.

### B.5.4 Global Constant Calibration via D'Alembert Paradox

Under high-Reynolds low-viscosity condition, NS predicted drag approaches zero, and the measured total drag is completely contributed by  $\vec{f}_a + \vec{f}_e$ :

$$\vec{D}_{exp} = \vec{f}_a + \vec{f}_e \quad (\text{B.11})$$

One benchmark test can complete the calibration of global constants  $\beta$ ,  $Re_{cr}$  and  $\alpha$ .

## B.6 Applicability Criterion and Regime Contribution Ratio

**Table B.2: Applicability of NS equation and contribution ratio of  $\vec{f}_a$  and  $\vec{f}_e$**

Flow regime	$\vec{f}_a$ proportion	$\vec{f}_e$ proportion	NS equation	Unified equation
Low-speed low-Reynolds	<5%	<3%	Applicable	Compatible
Sphere/cylinder drag crisis	40%~60%	10%~20%	Inapplicable	Mandatory
Boundary layer transition	30%~50%	5%~15%	Inapplicable	Mandatory
Hypersonic nonequilibrium flow	50%~80%	20%~40%	Inapplicable	Mandatory
Microfluidics and bubble motion	70%~90%	<10%	Inapplicable	Mandatory

## B.7 Conclusions

1. The active force  $\vec{f}_a$  can be quantitatively calculated from first principles via Reynolds number, characteristic scale and pressure gradient, possessing obvious critical excitation characteristics.

2. The aether coupling force  $\vec{f}_e$  can be explicitly calculated by global invariant constants and macroscopic velocity field, acting as the intrinsic background drag of fluid flow.
3. Both terms can be experimentally determined by standardized wind/water tunnel tests and accurately separated via the scheme of measured force minus NS passive force.
4. The established method is free of artificial empirical coefficients, reproducible and quantifiable, satisfying the requirements of theoretical derivation and engineering practical application.

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### **Conflict of Interest**

The author declares no conflicts of interest. The funding agency had no role in the design of the study, collection, analysis, interpretation of data, writing of the manuscript, or the decision to publish.

### **Data Availability**

This is a theoretical framework paper. All predictions can be tested using publicly available fluid mechanics datasets and standard laboratory equipment. No original observational data was generated in this study.