

Dimensionless Numbers and Scales in the Navier–Stokes Equations

— 4th Edition: The Reynolds Number as a Boundary, and Why the Kolmogorov Length Is Not a Theorem —

[Paper 03]

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August 2026 (4th Edition)

— *From thinking to syncing.* —

ABSTRACT

Non-dimensionalising the incompressible Navier–Stokes equations reduces **the dimensionless parameters to the single Reynolds number $\text{Re} = UL/\nu$** . Starting from that fact, this paper writes out the standing of the scales that appear in turbulence. **First, the Kolmogorov length is the output of a dimensional equation.** Solving $\eta = \nu^a \varepsilon^b$ for a length determines $(a, b) = (\frac{3}{4}, -\frac{1}{4})$ uniquely, giving $\eta = (\nu^3/\varepsilon)^{1/4}$. **The dimension-exponent matrix of (ν, ε) has largest invariant factor 4, so the entries of its inverse are quarter-integers — and that is why a fourth root appears. What fixes the denominator is not the determinant but the largest invariant factor** (Paper 149). Here $|\det|$ is also 4, but that is only an **upper bound** on what the denominator divides: $\text{diag}(2, 2)$ has $|\det| = 4$ and yields half-integers only. **The matrix here has a cyclic cokernel, so the two happen to agree.** This is **the same theorem, with a different invariant factor**, as the one Paper 39 established for $(\hbar, G, c)$: largest invariant factor 2, hence half-integers, hence square roots. **Second, η is precisely the place where a dimensionless number crosses one.** With the Kolmogorov velocity $u_\eta = (\nu\varepsilon)^{1/4}$ one has $\text{Re}_\eta = u_\eta\eta/\nu = 1$ identically (verified numerically here). The module boundary of Paper 113 is, in this case, not an analogy but a **definition**. **Third, η therefore has the same standing as the Planck length.** Both are **the unique solution of a dimensional equation**, and **neither is a proven minimum length**. η is a statistical and phenomenological scale for developed turbulence, not a rigorous lower bound on the size of structures in the Navier–Stokes equations. **That distinction is the spine of this paper.** **Fourth, the exponent $\frac{3}{4}$ is not a dimension.** By the sorting of Papers 28 (3rd edition) and 94, it is **the solution of a dimensional equation** and neither a fractal nor a topological dimension. **Fifth, the Navier–Stokes equations know what dimension they are in.** In two dimensions the vortex-stretching term $(\omega \cdot \nabla)\mathbf{u}$ vanishes identically and global regularity is known; in three it does not. **By the measure of Paper 114 this places the equations on the dimension-selecting side**, unlike 4π or the exponents of η , which do not select. **Sixth, blow-up and the singularities of Ricci flow are alike in picture but the machinery does not transfer.** Perelman controlled the singularities of three-dimensional Ricci flow with a monotone quantity (the $\mathcal{W}$ -entropy) and surgery. **No corresponding monotone quantity is known for Navier–Stokes.** The picture is shared; **the tools are not.** **Scope:** a structural account of established mathematical theorems (Layer 2). **Global regularity for the three-dimensional Navier–Stokes equations is a Clay Millennium Prize Problem and is unsolved.** **This paper claims neither its solution, nor a partial solution, nor the exclusion of blow-up.**

Positioning of this paper (discipline): This paper offers a **structural interpretation** of established physical law and mathematical theorems. It claims neither the discovery of new physical laws nor the proof of open problems. The relations shown are transformations of known expressions; the aim is to propose a structural reading of them. No claim contradicting established theory is made. **The appearance of the same form in several contexts is not treated as evidence of a common origin** (Papers 48, 86, 100, 115). **The existence and smoothness of the Navier–Stokes equations is one of the Clay Millennium Prize Problems and is unsolved.** **Nothing here changes that situation.**

1. Introduction: how many dimensionless numbers does this equation have?

The incompressible Navier–Stokes equations

$$\partial_t \mathbf{u} + (\mathbf{u} \cdot \nabla) \mathbf{u} = -\nabla p + \nu \Delta \mathbf{u}, \quad \nabla \cdot \mathbf{u} = 0$$

contain the dimensionful kinematic viscosity ν . Non-dimensionalising with a characteristic velocity U and length L gives

$$\partial_t \mathbf{u} + (\mathbf{u} \cdot \nabla) \mathbf{u} = -\nabla p + \frac{1}{\text{Re}} \Delta \mathbf{u}, \quad \text{Re} = \frac{UL}{\nu}.$$

Setting boundary conditions aside, the only dimensionless parameter this equation possesses is the Reynolds number.
The whole of the difficulty is packed into a single number.

2. The Kolmogorov length is the output of a dimensional equation

2.1 Solving it

Build the smallest, viscosity-dominated scale from the kinematic viscosity ν and the dissipation rate per unit mass ϵ . In (L, T) the exponents are $[\nu] = (2, -1)$ and $[\epsilon] = (2, -3)$ (mass drops out). Requiring $\eta = \nu^a \epsilon^b$ to be a length $(1, 0)$ gives

$$a(2, -1) + b(2, -3) = (1, 0),$$

whence $a = -3b$ from the T component and $2(-3b) + 2b = -4b = 1$ from the L component. Hence

$$(a, b) = \left(\frac{3}{4}, -\frac{1}{4}\right), \quad \eta = \nu^{3/4} \epsilon^{-1/4} = \left(\frac{\nu^3}{\epsilon}\right)^{1/4}$$

Quantity	$a(\nu)$	$b(\epsilon)$	Closed form
Length η	3/4	-1/4	$(\nu^3/\epsilon)^{1/4}$
Time τ_η	1/2	-1/2	$(\nu/\epsilon)^{1/2}$
Velocity u_η	1/4	1/4	$(\nu\epsilon)^{1/4}$

2.2 Why a fourth root? Because the largest invariant factor is 4

Theorem 2.1 (The origin of the quarter-integer exponents)

Let A be the dimension-exponent matrix of (ν, ε) ; then

$$A = \begin{pmatrix} 2 & 2 \\ -1 & -3 \end{pmatrix}, \quad \det A = -4, \quad |\det A| = 4.$$

For an integer matrix, $A^{-1} = \text{adj}(A)/\det A$ with $\text{adj}(A)$ integral, so the denominators of the entries of A^{-1} divide $|\det A| = 4$. That, however, is an upper bound and not an equality ($\text{diag}(2, 2)$ has $|\det| = 4$ and yields halves only; Paper 149). The denominator that actually occurs is the largest invariant factor d_n , and the invariant factors of this A are $(1, 4)$, so $d_n = 4$ (the cokernel is $\mathbb{Z}/4$). Indeed the rows of A^{-1} are $(\frac{3}{4}, \frac{1}{2})$ and $(-\frac{1}{4}, -\frac{1}{2})$.

That the exponents of the Kolmogorov scales are without exception quarter-integers — and therefore that η is written with a fourth root — is a consequence of that largest invariant factor being 4. The cokernel of this A being cyclic, $|\det A|$ and d_n agree.

Observation 2.2 (The same theorem as Paper 39)

Paper 39 showed that the dimension-exponent matrix of $(\hbar, G, c)$ has invariant factors $(1, 1, 2)$, so that all exponents in Planck units are half-integers and square roots pervade them.

The present paper is an instance of that theorem with a different invariant factor: a largest invariant factor of 2 gives square roots and one of 4 gives fourth roots. The answer to "why this particular radical?" is, in both cases, the largest invariant factor (Paper 149; the determinant is merely a multiple of it).

2.3 η is precisely where a dimensionless number crosses one

Established Fact 2.3 (The Reynolds number at the Kolmogorov scale is identically one)

From $\eta = (\nu^3/\varepsilon)^{1/4}$ and $u_\eta = (\nu\varepsilon)^{1/4}$,

$$\text{Re}_\eta = \frac{u_\eta \eta}{\nu} = \frac{(\nu\varepsilon)^{1/4}(\nu^3/\varepsilon)^{1/4}}{\nu} = \frac{(\nu^4)^{1/4}}{\nu} = 1.$$

This is an identity, not an approximation. (Numerical check: indoor air with $\nu = 1.5 \times 10^{-5}$, $\varepsilon = 10^{-3}$ gives $\eta = 1.355$ mm and $\text{Re}_\eta = 1.000000$; water in a pipe with $\nu = 10^{-6}$, $\varepsilon = 1$ gives $\eta = 0.032$ mm and $\text{Re}_\eta = 1.000000$.)

Corollary 2.4 (Paper 113's boundary is here a definition)

Paper 113 recorded that the **boundary between an older and a newer description always lies where a dimensionless number crosses one.**

The Kolmogorov length is defined to be exactly that place. Above η the inertial term dominates the viscous one ($\text{Re} > 1$); below η viscosity governs ($\text{Re} < 1$). **Here the frame of Paper 113 is not an analogy but the definition itself.**

Note, however, that ε is an input. The numbers above depend on the assumed ε (changing it moves η as $\varepsilon^{-1/4}$). **They are values "for that choice of ε ", not universal constants.**

2.4 Hence η has the same standing as the Planck length

Corollary 2.5 (Both are dimensional-analysis outputs; neither is a proven minimum length)

$\eta = (\nu^3/\varepsilon)^{1/4}$ and $l_p = (\hbar G/c^3)^{1/2}$ are produced by **the same procedure**: extracting, from given dimensionful quantities, the unique combination with the dimensions of a length.

Paper 39 recorded that **the Planck length is not a "minimum length"**. The same holds of η . **It is a statistical and phenomenological scale for developed turbulence, not a rigorous lower bound on the size of structures in the Navier–Stokes equations.**

This distinction is the heart of the problem. If one could assert that no structure smaller than η arises, global regularity would follow — but **dimensional analysis supplies no such theorem**. What it supplies is **a unique combination**, not **a proof of a bound**.

3. The exponent $\frac{3}{4}$ is not a dimension

Paper 94 sorted fractal dimension (non-integer, Hausdorff), topological dimension and special integer dimensions as distinct roots, and Paper 28 (3rd edition) recorded that **taking a scaling exponent for a dimension is a category mistake**.

Non-integer number	What it is	Origin
1.26 . . . (Koch curve)	Fractal dimension	Hausdorff dimension (Paper 94)
3/2 (Kepler)	Scaling exponent of dynamics	the inverse-square law (Paper 28, 3rd ed.)
3/4 (this paper)	Solution of a dimensional equation	the unique solution of a 2 × 2 linear system

$\frac{3}{4}$ is not a **property of space**. It is a coefficient settled by the dimensions of ν and ε alone; **there is no such thing as "0.75 dimensions"**. Its standing is the same as that of the Planck exponents of Paper 39.

Fractal dimension does genuinely appear elsewhere in turbulence: Kolmogorov's 1941 theory assumes uniform dissipation, whereas real flows exhibit **intermittency**, and models have been proposed in which the dissipation field is supported on a set of non-integer dimension (multifractal descriptions). **But that is a different matter from the $\frac{3}{4}$ of this paper and must not be conflated with it.** This paper does not enter into intermittency corrections.

4. The Navier–Stokes equations know what dimension they are in

Paper 114 set up the measure "does the object know what dimension it is in?" and recorded that **a family with one member per dimension belongs on the dimension-blind side.**

Established Fact 4.1 (In two dimensions the vortex-stretching term vanishes identically)

The vorticity $\boldsymbol{\omega} = \nabla \times \mathbf{u}$ obeys

$$\partial_t \boldsymbol{\omega} + (\mathbf{u} \cdot \nabla) \boldsymbol{\omega} = \underbrace{(\boldsymbol{\omega} \cdot \nabla) \mathbf{u}}_{\text{vortex stretching}} + \nu \Delta \boldsymbol{\omega}.$$

In a two-dimensional flow $\boldsymbol{\omega} = (0, 0, \omega)$ and $\mathbf{u} = (u_1, u_2, 0)$ with $\mathbf{u}$ independent of z , so

$$(\boldsymbol{\omega} \cdot \nabla) \mathbf{u} = \omega \partial_z \mathbf{u} = 0.$$

The stretching term vanishes identically.

Corollary 4.2 (This equation is on the dimension-selecting side)

Because the stretching term vanishes, a maximum principle applies to the vorticity in two dimensions and **global regularity is known**. In three dimensions it does not vanish, and **whether the vorticity can diverge in finite time is open** (the Beale–Kato–Majda criterion, 1984).

The Navier–Stokes equations therefore behave qualitatively differently according to whether they sit in two or three dimensions. By the measure of Paper 114, they are on the **dimension-selecting** side.

Every other quantity in this paper is on the non-selecting side: the exponent $\frac{3}{4}$ of η is settled by the dimensions of ν and ε and never refers to the dimension of space. **Objects that select a dimension and objects that do not coexist within one paper.**

5. Is $\text{Re} \rightarrow \infty$ a limit or a wall?

Paper 113 took **Newtonian mechanics as a limit of relativity** ($c \rightarrow \infty$ contracting the Poincaré group to the Galilei group) as its model of a module boundary.

Observation 5.1 (A boundary that does not contract — a second kind)

Setting $\nu \rightarrow 0$ (that is, $\text{Re} \rightarrow \infty$) in the Navier–Stokes equations formally yields the Euler equations. **But that limit is singular.**

The coefficient of the highest derivative vanishes, so **solutions do not converge uniformly near a boundary** (boundary layers; Prandtl 1904). However small ν becomes, the layer merely thins as $\sim \nu^{1/2}$ without disappearing, and the gradients within it grow.

This is therefore not a smooth group contraction of the kind $c \rightarrow \infty$ provides. Paper 113's frame needs a second kind: a boundary that does not contract.

Boundary	Parameter	Character
Relativity $\rightarrow$ Newton	$c \rightarrow \infty$	smooth contraction (of groups)
Quantum $\rightarrow$ classical	$\hbar \rightarrow 0$	asymptotic (WKB; with caustics)
NS $\rightarrow$ Euler	$\nu \rightarrow 0$	singular limit (boundary layers persist)

"Boundaries always lie where a dimensionless number crosses one" holds; "boundaries are always smooth limits" does not. Paper 113's claim is refined on exactly this point.

6. Blow-up and the singularities of Ricci flow — the machinery does not transfer

The open problem for the three-dimensional Navier–Stokes equations is **whether a singularity forms in finite time**. This series already possesses **an instance in which a question of the same shape was answered**: the Ricci flow of Paper 103.

	Ricci flow (Paper 103)	Navier–Stokes
Object	the metric g_{ij}	the velocity field $\mathbf{u}$ (with incompressibility)
Equation	$\partial_t g = -2\text{Ric}$	$\partial_t \mathbf{u} + (\mathbf{u} \cdot \nabla) \mathbf{u} = -\nabla p + \nu \Delta \mathbf{u}$
Question	does a singularity form?	does a singularity form?
Monotone quantity	$\mathcal{W}$ -entropy (Perelman)	none known
Surgery	available (excise and continue)	no counterpart
Status	solved (3D; Perelman 2002–03)	open

Corollary 6.1 (It fails the machinery-transfer test)

The two share a **picture**: singularity formation in a nonlinear evolution equation, and the structure "control the singularities and a global conclusion follows".

But they do not share tools. Perelman's resolution rests on **the discovery of a monotone functional (the $\mathcal{W}$ -entropy)** and on **continuation by surgery**. **No monotone quantity capable of controlling blow-up is known for the Navier–Stokes equations.** The energy inequality (Leray 1934) exists but does not constrain the L^∞ norm.

The resemblance is therefore a rhyme, not a tool (Papers 100, 110). **It must not be read as "it worked for Ricci flow, so it should for Navier–Stokes".**

The same applies to the cascade and the renormalisation group. The flow of energy from large eddies to small ones is a **flow along scale** and shares its picture with RG flow; renormalisation-group methods have indeed been applied to turbulence (Forster–Nelson–Stephen 1977 and later work). **But there is no counterpart in turbulence of what Paper 110 called "gold"**: Friedan's theorem, the **equality** of the sigma-model metric's RG flow with Ricci flow. In the three tiers of Paper 110, **this is not gold but, at best, a rhyme.**

Personal reflection of the author (Layer 3; labelled non-scientific / no claim of mechanism)

Of all my papers, this one was **the emptiest**. After the second edition withdrew the claimed proof, I wrote in the scope section, in my own hand, that the established facts were "all known, and this paper contributes nothing". It was an honest sentence, but **it left nothing standing**.

Writing the 3rd edition I learned that **it looked empty because I lacked the tools to read it**. The fourth root in $\eta = (\nu^3/\varepsilon)^{1/4}$ had been there all along — but **I only saw that it was a consequence of a determinant after writing Paper 39, and that it is properly a consequence of the largest invariant factor only after writing Paper 149. $\text{Re}_\eta = 1$** had been there all along — but **I only saw that it was a module boundary after writing Paper 113**.

The paper was not empty; I had no vocabulary with which to read it.

Even so, what I learned most from this paper is something else. **Ricci flow yielded; Navier–Stokes does not**. The pictures are so alike, and yet nothing here answers to Perelman's monotone quantity. **Resembling is not the same as being usable**. One stops at the edge of the cliff (Paper 101).

7. Scope / Conclusion

What is shown: that non-dimensionalisation reduces the parameters to **the single Re (§1)** / that **η is the unique solution of a dimensional equation** and that the **largest invariant factor 4** of (ν, ε) makes its exponents quarter-integers (§2.1–2.2, the same theorem as Paper 39) / that **$\text{Re}_\eta = 1$ identically**, so that **η is Paper 113's boundary itself (§2.3)** / that **η has the same standing as the Planck length and is not a proven minimum (§2.4)** / that **$\frac{3}{4}$ is not a dimension (§3)** / that **the vanishing of vortex stretching in two dimensions places the equations on the dimension-selecting side (§4)** / that **$\nu \rightarrow 0$ is a singular limit, adding a "non-contracting boundary" to Paper 113's frame (§5)** / and that **the resemblance to Ricci flow is a rhyme, not a tool (§6)**.

What is not shown (restraint): no proof of global regularity for the three-dimensional Navier–Stokes equations, no partial proof, no exclusion of blow-up — all outside the scope of this paper / **η is not treated as a lower bound on structure size** (it is a statistical, phenomenological scale) / **$\frac{3}{4}$ is not conflated with a fractal dimension / intermittency corrections are not entered into / Ricci flow machinery is not transferred to Navier–Stokes / the cascade is not identified with RG flow** (a rhyme, not a theorem) / no new mathematics and no prediction (Layer 2).

The existence and smoothness of the three-dimensional Navier–Stokes equations is unsolved. Nothing here changes that.

What this paper exhibits is the standing of the numbers appearing in this equation. **Re is the sole dimensionless parameter**, and **η is determined uniquely by dimensional analysis as the place where that Re reaches one**. The exponent

$\frac{3}{4}$ is a consequence of the largest invariant factor being 4, and not a dimension.

And η is not a bound.

Extracting the unique combination and proving a bound are different things:
that single line is the whole content of this paper.

Revision Record

4th edition (August 2026): No conclusion has changed. Following Paper 149, the origin of the quarter-integer exponents has been rewritten from “the determinant $|\det| = 4$ ” to “the largest invariant factor 4” (2.2, abstract, 7). What $|\det|$ gives is an **upper bound on what the denominator divides**, not the denominator itself: $\text{diag}(2, 2)$ has $|\det| = 4$ and yields half-integers only. The invariant factors of (ν, ϵ) are $(1, 4)$ and **the cokernel is cyclic**, so the conclusion of the 3rd edition — that the Kolmogorov exponents come in quarters — **stands unchanged**. Only the way the reason is written has been corrected.

3rd edition (August 2026): removed the word "Withdrawal" from the title, which now names **what the paper shows** (the Reynolds number as a boundary, and the standing of the Kolmogorov length); the list of withdrawals is collected in this section.

Added in the 3rd edition: that non-dimensionalisation leaves **Re as the only parameter** (§1); a derivation of η as **the unique solution of a dimensional equation**, with the $|\det| = 4$ of (ν, ϵ) making the exponents quarter-integers (§2.1–2.2, the same theorem as Paper 39's " $|\det| = 2$ hence square roots"); that **$\text{Re}_\eta = 1$ is an identity**, so η is the module boundary of Paper 113 itself (§2.3); that **η and the Planck length share a standing, neither being a proven minimum length** (§2.4, Paper 39); that **the exponent $\frac{3}{4}$ is not a dimension**, connected to the sorting of Papers 28 (3rd edition) and 94 (§3); that **the vanishing of vortex stretching in two dimensions places this equation on the dimension-selecting side** (§4, Paper 114); a **second kind of boundary — one that does not contract — added to Paper 113's frame on the grounds that $\nu \rightarrow 0$ is singular** (§5); and a table showing that **the resemblance to Ricci flow fails the machinery-transfer test** (§6, Papers 103, 110, 100).

Withdrawn in the 2nd edition (July 2026): the first edition's title claimed "a proof of global smoothness for the three-dimensional Navier–Stokes equations". **That claim was withdrawn in full**, for three reasons, each elementary to check.

1. **Begging the question.** The first edition's Theorem 2.1 imposed an upper bound on the vorticity as a boundary condition, but **whether the vorticity stays bounded is precisely the Millennium problem**. Smoothness cannot be derived by assuming the bound.

2. **An internal contradiction.** The profile $|\boldsymbol{\omega}(\boldsymbol{r})| \sim \boldsymbol{r}^{-2}$, which the first edition said "saturates the geometric bound", diverges as $\boldsymbol{r} \rightarrow \mathbf{0}$, so that $\|\boldsymbol{\omega}\|_{L^\infty} = \infty$. **That is a blow-up profile, in direct contradiction with the conclusion the first edition wished to draw.**

3. **Confusing an integral with a pointwise supremum.** The first edition inferred boundedness of the L^∞ norm from boundedness of the total vorticity mass, but **boundedness of an integral does not constrain a pointwise supremum.**

First edition: Zenodo 10.5281/zenodo.21404030.

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