Why engineering laws have been *irrational* for more than 70 years, and *rational* laws to replace them.

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Abstract

In order to confirm that conventional engineering laws are rational, it is necessary to know *how* the coefficients in the laws were created. Until 1822, scientists and engineers agreed that equations *cannot* describe how parameters are related because parameter *dimensions* cannot be multiplied or divided. (That is why Newton's second law of motion in *The Principia* (1726) is *not* an equation—it is a *proportion*.) In *The Analytical Theory of Heat* (1822), Fourier made the *revolutionary and unproven* claims that dimensions *can* be assigned to numbers, and parameter *dimensions can* be multiplied and divided. These *unproven claims* made it rational for Fourier to create h by assigning the dimensions of $q/\Delta T$ to number c in his empirically determined *proportional* equation $q = c\Delta T$, and rational to multiply h (ie c with assigned dimensions) and ΔT , resulting in dimensionally homogeneous $q = h\Delta T$. After 1822, engineering laws were generally created using Fourier's unproven claims. However, *Dimensional Analysis and Theory of Models* by H. L. Langhaar (1951) states: *Dimensions must not be assigned to numbers, for then any equation could be regarded as dimensionally homogeneous*. Because conventional engineering laws were generally created by violating the *widely accepted* view that dimensions *must not* be assigned to numbers, laws such as $q = h\Delta T$, $\sigma = E\varepsilon$, $E = IR$ became *irrational* sometime before 1951. *Rational* engineering laws determined by induction are presented herein.

1. Introduction

In order to confirm that conventional engineering laws are rational, it is necessary to know *how* the coefficients in the laws were created. Fourier [1] created the coefficient h , and the methodology he used to create h has generally been used to create coefficients in similar engineering laws.

Fourier's methodology *requires* that dimensions be assigned to numbers. However, sometime before 1951, it was generally agreed that dimensions *cannot* rationally be assigned to numbers. Therefore engineering laws created by assigning dimensions to numbers have been *irrational* since sometime before 1951.

Rational engineering laws determined by induction are presented herein.

2. Parametric equations from the beginning of science until 1822.

From the beginning of science until 1822, scientists and engineers globally agreed that equations *cannot* rationally describe how parameters are related because parameter *dimensions* cannot rationally be multiplied and divided. Proportions are generally used instead of equations because they do *not* require that parameter dimensions be multiplied or divided. That is why Newton's second law of motion in *The Principia* [2] is *not* Eq. (1). It is Proportion (2).

$$f = ma \tag{1}$$

$$a \propto f \tag{2}$$

3. Fourier's experiment, and the dimensionally *inhomogeneous* equation that resulted.

Fourier performed an experiment in heat transfer by the steady-state forced convection of ambient air flowing over a solid, warm body. From his data, he concluded that if a solid, warm body is cooled by the steady-state forced convection of ambient air, the heat flux from the surface of the solid, warm body to the ambient air is *always* proportional to the temperature difference between the surface of the solid, warm body and the ambient air, as in Proportion (3).

$$q \propto \Delta T \tag{3}$$

Proportion (3) would have satisfied Newton and his colleagues, but it did *not* satisfy Fourier. He wanted an *equation*, and it *had* to be dimensionally homogeneous.

The transformation of Proportion (3) to an equation results in Eq. (4). Note that Eq. (4) is a *proportional* equation, and c is a *number* that *equals* the *numerical value* of $q/\Delta T$.

$$q = c\Delta T \tag{4}$$

Fourier was *not* satisfied with Eq. (4) because it is *not* dimensionally homogeneous—the dimension of q does *not* equal the dimension of ΔT , and c is *dimensionless*. Fourier recognized that Eq. (4) could be made dimensionally homogeneous *only* if it were rational to assign dimensions to numbers, *and* rational to multiply and divide parameter dimensions.

4. How Fourier created h.

In *The Analytical Theory of Heat* published in 1822, Fourier made the following *revolutionary* and *unproven* claims:

- Dimensions *can* be assigned to numbers.
- Parameters *can* be multiplied and divided because parameter *dimensions can* be multiplied and divided.

Fourier described his revolutionary and unproven claims in the following paragraph:

... every undetermined magnitude **or constant** has one dimension proper to itself, and the terms of one and the same equation could not be compared, if they had not the same exponent of dimension. . . this consideration is derived from primary notions on quantities; for which reason, in geometry and mechanics, it is the equivalent of the fundamental lemmas (axioms) which the Greeks have left us **without proof**.

It is important to note that the above paragraph has been the *foundation* of conventional engineering science for 200 years. It is the *only* reason it has been rational to *create* laws by assigning dimensions to *numbers*, and rational to multiply and divide parameter dimensions (in *violation* of the view that prevailed from the beginning of science until 1822).

It is also important to note that Fourier made *no effort* to prove that his revolutionary claims are rational. In his nearly 500 page treatise, he did *not* include the Greek lemmas, he did *not* cite a reference where the lemmas could be found, and he did *not* offer his own proof that his revolutionary claims are rational.

Fourier's revolutionary and unproven claims made it rational to transform dimensionally *inhomogeneous* Eq. (4) to dimensionally homogeneous Eq. (5) by making it rational to assign to pure number c the dimensions of $q/\Delta T$ in order to make Eq. (5) dimensionally homogeneous, and rational to multiply h (ie c with dimensions) and ΔT .

$$q = h\Delta T \tag{5}$$

Equation (5) should be referred to as Fourier's law of steady-state forced convection heat transfer to ambient air. It is a *proportional* equation, and it applies *only* if heat transfer is by the steady-state forced convection of ambient air flowing over a solid, warm body. To Fourier and his colleagues, Eq. (5) meant that, if heat transfer is by the steady-state forced convection of ambient air flowing over a solid, warm body:

- The numerical value and dimension of q are *always* proportional to the numerical value and dimension of ΔT .
- h and $q/\Delta T$ are *always* identical *and* interchangeable because c in Eq. (4) is numerically equal to $q/\Delta T$, and c was *assigned* the dimension of $q/\Delta T$.
- h and $q/\Delta T$ are *always proportionality constants*—ie they are *never* variables. In other words, Eq. (5) *always* has only *two* variables, q and ΔT .
- Equation (5) is *always* dimensionally homogeneous because the dimension of q *always* equals the dimension of $h\Delta T$ —ie the dimension of q *always* equals the dimension of $(q/\Delta T)\Delta T$.

In summary, Fourier was able to create the *very first* dimensionally homogeneous engineering law because of his revolutionary and *unproven* claims that dimensions *can* be assigned to numbers, and parameter dimensions *can* be multiplied and divided. Later engineering laws were generally created using Fourier's unproven claims.

5. Why Fourier's claim that dimensions *can* be assigned to numbers is *irrational*.

Page 13 of *Dimensional Analysis and Theory of Models* by H. L. Langhaar published in 1951 states:

*Dimensions **must not** be assigned to numbers, for then any equation could be regarded as dimensionally homogeneous.*

Fourier's pioneering method of assigning dimensions to numbers is *irrational* because it assumes that dimensions *can* rationally be assigned to numbers, when in fact it has been widely agreed for more than 70 years that dimensions **must not** be assigned to numbers.

6. Why Fourier's claim that parameter dimensions can be multiplied and divided is *irrational*.

From the beginning of science until 1822, scientists and engineers such as Galileo and Newton agreed that equations *cannot* describe how different parameters are related because parameter dimensions *cannot* be multiplied or divided. Fourier claimed, without proof, that parameter dimensions *can* rationally be multiplied or divided. Note that:

- "Multiply five times eight" means "add eight five times". Therefore "multiply meters times kilograms" *must* mean "add kilograms meters times". Because "add kilograms meters times" has no meaning, parameter dimensions *cannot* rationally be multiplied.
- "Divide thirty by six" means "how many sixes are in thirty". Therefore "divide meters by seconds" *must* mean "how many seconds are in meters". Because "how many seconds are in meters" has no meaning, dimensions *cannot* rationally be divided.

In summary, parameters *cannot* be multiplied or divided because parameter dimensions *cannot* be multiplied or divided, in accordance with the view that prevailed from the beginning of science until 1822.

7. Why the laws and equations of modern engineering science do *not* rationally describe how parameters are related.

The laws and equations of modern engineering science do *not* rationally describe how parameters are related because they are based on the *erroneous* assumptions that dimensions *can* rationally be assigned to numbers, and parameter dimensions *can* rationally be multiplied and divided.

It is important to note that even if a law in the form of a *proportional* equation were *rational*, it could *not* describe *nonlinear* phenomena. When a *proportional* equation is applied to *nonlinear* phenomena, it ceases to be an equation because it *cannot* describe how parameters are related if the phenomenon is nonlinear.

For example, Eq. (5) is a proportional equation and therefore it *cannot* describe the nonlinear behavior of heat transfer by natural convection, condensation, or boiling. When Eq. (5) is

applied to a nonlinear phenomenon, it *ceases* to be an equation because it makes *no statement* about the relationship between q and ΔT . It merely states the following:

To determine the value of q , first determine the value of $q/\Delta T$ (ie the value of h), then multiply by ΔT .

8. What equations *can* rationally describe about how parameters are related.

Equations *can* rationally describe how the *numerical values* of parameters are related because, if parameter symbols represent *only* numerical values, equations do *not* require that dimensions be assigned to numbers, and do *not* require that parameter dimensions be multiplied and divided.

9. The rational law of stress and strain.

Data indicate that the *numerical value* of stress is a function of the *numerical value* of strain, and the function may be proportional, linear, or nonlinear. Therefore Eq. (6) is the rational law of stress and strain.

$$\sigma = f\{\varepsilon\} \quad (6a)$$

$$\varepsilon = f\{\sigma\} \quad (6b)$$

Equation (6a) states that the *numerical value* of stress is a function of the *numerical value* of strain, and the function may be proportional, linear, or nonlinear. And similarly for Eq. (6b).

Note that E was *created* for only *one* reason—so that the law of stress and strain could be dimensionally homogeneous. Because Eq. (6) is *inherently* dimensionally homogeneous, E is *not* required for homogeneity, and is *abandoned*. Abandoning E greatly simplifies the solution of inelastic problems because, in the inelastic region, E is an *unnecessary* and *undesirable variable*, and it greatly complicates problem solutions.

10. The rational law of convection heat transfer.

Data indicate that, if heat transfer is by convection, the *numerical value* of heat flux is a function of the *numerical value* of temperature difference, and the function may be proportional, linear, or nonlinear. Therefore Eq. (7) is the law of convection heat transfer.

$$q = f\{\Delta T\} \quad (7a)$$

$$\Delta T = f\{q\} \quad (7b)$$

Equation (7a) states that the *numerical value* of heat flux is a function of the *numerical value* of temperature difference, and the function may be proportional, linear, or nonlinear. And similarly for Eq. (7b).

Note that h was *created* for only *one* reason—so that the law of convection heat transfer could be dimensionally homogeneous. Because Eq. (7) is *inherently* dimensionally homogeneous, h is *not* required for homogeneity, and is *abandoned*. Abandoning h greatly simplifies the solution of nonlinear problems because h is an *unnecessary* and *undesirable variable* if q is a nonlinear function of ΔT .

11. An analog of rational engineering laws.

Equation (8) is an analog of rational engineering laws.

$$y = f\{x\} \quad (8)$$

Equation (8) states that the *numerical value* of parameter y is a function of the *numerical value* of parameter x , and the function may be proportional, linear, or nonlinear.

12. Quantitative equations when engineering laws are analogs of Eq. (8).

If an equation is *quantitative* and engineering laws are analogs of Eq. (8), the dimension units that underlie parameter symbols *must* be specified in an accompanying nomenclature. This applies *only* to parameter symbols that are *not* in dimensionless groups.

13. How textbooks must be transformed when analogs of Eq. (8) replace conventional engineering laws.

When analogs of Eq. (8) replace conventional engineering laws, textbooks must be transformed by *eliminating* parameters such as h and E —*ie* by eliminating $q/\Delta T$ and σ/ε . For example, a heat transfer textbook is transformed in the following manner:

- Note that, because $q = h\Delta T$, h and $q/\Delta T$ are *identical* and *interchangeable*.
- Note that $k/t = q/\Delta T$.
- In *all* equations, replace h and k/t by $q/\Delta T$, even if h or k/t is in a dimensionless group such as Nusselt number. Note that Nusselt number is *abandoned* because it contains h —*ie* it contains $q/\Delta T$.
- Separate q and ΔT , resulting in equations in the form of Eq. (9).

$$\Delta T = f\{q\} \quad (9)$$

For example, when q and ΔT are separated, Eq. (10) is transformed to Eq. (11).

$$U = (1/h_1 + t/k + 1/h_2)^{-1} \quad (10)$$

$$\Delta T_{total} = \Delta T_1\{q\} + \Delta T_{wall}\{q\} + \Delta T_2\{q\} \quad (11)$$

Note that Eqs. (10) and (11) are *identical*—they state *exactly* the same thing. When Eq. (7) replaces Eq. (5), Eq. (11) replaces Eq. (10). And similarly for E.

13. Conclusions

- Dimensions *cannot* rationally be assigned to numbers.
- Parameters *cannot* rationally be multiplied or divided because parameter *dimensions* cannot be multiplied or divided.
- Conventional engineering laws are *irrational* because they are based on the erroneous assumptions that dimensions *can* be assigned to numbers, *and* parameter dimensions *can* be multiplied and divided.
- Because parameter dimensions *cannot* be multiplied or divided, parameter symbols in equations *must* represent *only* numerical values.
- Data indicate that Eq. (6) is a *rational* law of stress and strain. Equation (6a) states that the *numerical value* of stress is a function of the *numerical value* of strain, and the function may be proportional, linear, or nonlinear. Similarly for Eq. (6b).

$$\sigma = f\{\varepsilon\} \quad (6a)$$

$$\varepsilon = f\{\sigma\} \quad (6b)$$

- Data indicate that Eq. (7) is a rational law of convection heat transfer. Equation (7a) states that the *numerical value* of heat flux is a function of the *numerical value* of temperature difference, and the function may be proportional, linear, or nonlinear. Similarly for Eq. (7b).

$$q = f\{\Delta T\} \quad (7a)$$

$$\Delta T = f\{q\} \quad (7b)$$

- Equation (8) is an analog of rational engineering laws. Equation (8) states that the *numerical value* of parameter y is a function of the *numerical value* of parameter x , and the function may be proportional, linear, or nonlinear.

$$y = f\{x\} \quad (8)$$

- When conventional engineering laws are replaced by analogs of Eq. (8), parameters such as h and E are *unnecessary* and *undesirable*, and they are *abandoned*.
- If an equation is *quantitative* and engineering laws are analogs of Eq. (8), the dimension units that underlie parameter symbols *must* be specified in an accompanying nomenclature. This applies *only* to parameter symbols that are *not* in dimensionless groups.

- If engineering laws are analogs of Eq. (8), textbooks must be transformed so that parameters such as h and E are eliminated. For example, a heat transfer text is transformed by substituting $q/\Delta T$ for h and for k/t , then separating q and ΔT to result in equations in the form $\Delta T = f\{q\}$. Similarly for E and other coefficients in engineering laws that are in the form of proportional equations.

Symbols

a	acceleration
c	arbitrary constant
f	force or function of
h	symbol for $q/\Delta T$
k	symbol for $q/(dT/dx)$
m	mass
q	heat flux
t	time
T	temperature
U	symbol for $q/\Delta T_{total}$

References

- [1] Fourier, J., 1822d, *The Analytical Theory of Heat*, p. 2 of Preliminary Discourse and Article 160, 1955 Dover edition of 1878 English translation
- [2] Newton, I., *The Principia*, 1726, 3rd edition, translation by Cohen, I. B. and Whitman, A. M., 1999, p. 460, University of California Press