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Why Conventional Engineering Science should be Abandoned, and the New Engineering Science that should Replace It

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Abstract Conventional engineering science should be abandoned because: Engineering laws that are *proportional* equations (such as $q = h\Delta T$) *cannot* describe *nonlinear* phenomena (such as boiling heat transfer). Engineering laws were created by assigning dimensions to *numbers*, in violation of the conventional view that dimensions must *not* be assigned to numbers. Contrived parameters (such as heat transfer coefficient) make it *impossible* to solve nonlinear problems with the variables *separated*, greatly complicating solutions. *All* engineering equations are *irrational* because they attempt to describe how the numerical values *and* dimensions of parameters are related, when in fact equations can rationally describe *only* how *numerical values* are related. In the new engineering science described herein: Engineering laws describe proportional, linear, and nonlinear phenomena. *No* engineering laws were created by assigning dimensions to numbers. There are *no* contrived parameters (such as heat transfer coefficient), and therefore nonlinear problems are solved with the variables *separated*. *All* engineering equations are rational because they describe *only* how the *numerical values* of parameters are related.

Keywords: *conventional engineering science, dimensional homogeneity, Fourier, heat transfer coefficient, laws of engineering, nonlinear phenomena, parameter symbols*

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1. The Genesis of Conventional Engineering Science

Conventional engineering science is largely Fourier's brainchild [1]. Until the publication of his treatise, *The Analytical Theory of Heat,* in 1822:

- There were *no* engineering laws in the form of dimensionally homogeneous equations.
- The concept of "flux" had *not* yet been conceived.
- It had *not* yet been determined how to solve boundary condition problems.
- In the view of dimensional homogeneity that prevailed at the beginning of the nineteenth century, it was *irrational* to multiply or divide engineering parameters. That is why Hooke's law is a proportion rather than an equation, and why Newton's second law of motion in his treatise *The Principia* [2] published in 1726 is a proportion rather than an equation.

Fourier's revolutionary view of dimensional homogeneity made it possible, *for the first time* in the history of science, to rationally multiply and divide engineering parameters, thereby making it possible to conceive dimensionally homogeneous equations that describe how engineering parameters are related.

Fourier conceived the first equations/laws of conventional engineering science, the law of convection heat transfer and the law of conduction heat transfer. Fourier's revolutionary view of dimensional homogeneity, and other engineering methodologies he conceived, enabled others to conceive and apply many of the laws of conventional engineering science.

2. What Eq. (1) Means

Equation (1) is the law of convection heat transfer conceived by Fourier (but often erroneously credited to Newton).

$$q = h\Delta T \tag{1}$$

Based on conventional symbolism, Eq. (1) means:

- q is *always* proportional to ΔT.
- h is *always* a symbol for $q/\Delta T$.
- $q = h\Delta T \equiv (q/\Delta T)\Delta T$
- h (ie $q/\Delta T$) is *always* independent of ΔT.
- h (ie $q/\Delta T$) is *always* a constant.
- Eq. (1) is *always* dimensionally homogeneous because q is *always* proportional to ΔT.

3. Why Eq. (1) does *not* Generically Describe *q{ΔT}* or *h*, and Therefore *cannot* be a Law

In conventional engineering science, Eq. (1) is generally said to be a law. If Eq. (1) were in fact a law, q would *always* be proportional to ΔT, and h would *always* be a symbol for $q/\Delta T$.

It has been known for more than a century that, if heat transfer is by natural convection, condensation, or boiling, q is a *nonlinear function* of ΔT. Therefore:

- Equation (1) *cannot* be a law because it does *not generically* describe convection heat transfer. It *can* describe *proportional* phenomena (such as forced convection heat transfer to a one phase fluid) because it is a *proportional* equation, but it *cannot* describe *nonlinear* phenomena (such as boiling heat transfer) because it is a *proportional* equation.
- Equation (1) does *not generically* describe h because h is a *constant* if q is *proportional* to ΔT, and h is a *variable* if q is *not* proportional to ΔT.

4. Why Eq. (2) *should* be the Law of Convection Heat Transfer in Conventional Engineering Science

Equation (2) *should* be the law of convection heat transfer in conventional engineering science because, in conventional engineering science, it would be a rigorously correct and dimensionally homogeneous equation that *generically* describes $q\{\Delta T\}$ and h.

$$q = hf\{\Delta T\} \quad (2)$$

Equation (2) states that $q\{\Delta T\}$ may be proportional, or linear, or nonlinear. And h *always* equals $q/f\{\Delta T\}$. If $f\{\Delta T\}$ equals ΔT, h equals $q/\Delta T$. If $f\{\Delta T\}$ does *not* equal ΔT, h equals $q/f\{\Delta T\}$.

5. How Fourier Created $q = h\Delta T$ by Assigning Dimensions to a *Number*

Until the nineteenth century, there were *no* equations/laws that describe how stress is related to strain, or how convection heat flux is related to boundary layer temperature difference. Until the nineteenth century, the prevailing view of dimensional homogeneity considered it *irrational* to multiply or divide parameters, thereby making it *impossible* to conceive dimensionally homogeneous equations/laws that describe how engineering parameters are related.

Fourier performed experiments in forced convection heat transfer to atmospheric air, and concluded that, if heat transfer is by steady-state forced convection to atmospheric air, heat flux q is *always* proportional to temperature difference ΔT, as in Proportion (3).

$$q \;\alpha\; \Delta T \quad (3)$$

Proportion (3) would have satisfied Hooke and Newton, but it did *not* satisfy Fourier. He wanted an equation, and it *had* to be dimensionally homogeneous. When Proportion (3) is transformed to an equation, Eq. (4) results in which c is a *number*.

$$q = c\Delta T \quad (4)$$

Fourier [3] recognized that Eq. (4) is unacceptable because it is *not* dimensionally homogeneous. He realized that Eq. (4) could be transformed to a homogeneous equation *only* if dimensions could rationally be assigned to numbers, *and* parameters could rationally be multiplied and divided. Consequently he conceived a revolutionary view of dimensional homogeneity in which it is rational to assign dimensions to numbers, *and* rational to multiply and divide parameters.

Fourier's revolutionary view of dimensional homogeneity made it possible to conceive dimensionally homogeneous equations that describe how engineering parameters are related. Using his view of dimensional homogeneity, and other engineering methodologies he conceived, Fourier conceived, and explained how to apply, the heat transfer laws of convection and conduction, the *first* laws of conventional engineering science.

Fourier described his revolutionary view of dimensional homogeneity in the following: [4]

. . . 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 which the Greeks have left us without proof.*

In his nearly 500 page treatise, *The Analytical Theory of Heat* published in 1822, Fourier:

- Made *no effort* to prove the validity of his revolutionary view of dimensional homogeneity.
- Did *not* include the fundamental lemmas in his treatise.
- Did *not* cite a reference that included the fundamental lemmas.

It has *never* been proven that Fourier's view of dimensional homogeneity is rational. Presumably, his colleagues accepted his unproven view because it enabled him to solve problems they were unable to solve.

Fourier's description of his view of dimensional homogeneity includes the statement "every . . . *constant* has one dimension proper to itself". In other words, Fourier states that *numbers* in equations *inherently* have dimension, and therefore it is rational to assign dimensions to *numbers* in equations.

To *number c* in Eq. (4), Fourier assigned the symbol h and the dimensions that made Eq. (4) homogeneous. That is how Fourier created h, and how he transformed dimensionally *in*homogeneous Eq. (4) to dimensionally homogeneous Eq. (1).

$$q = h\Delta T \quad (1)$$

6. How Fourier Defined *h*, and what Eq. (1) and *h* Meant in the Nineteenth Century

Fourier defined *h* in the following: [5]

We have taken as the measure of the external conducibility of a solid body a coefficient h, which denotes the quantity of heat which would pass, in a definite time (a minute), from the surface of this body, into atmospheric air, supposing that the surface had a definite extent (a square metre), that the constant temperature of the body was 1, and that of the air 0, and that the heated surface was exposed to a current of air of a given invariable velocity.

Fourier defined *h* to be a proportionality *constant* and the symbol for $q/\Delta T$. Fourier's definition *requires* that the heat transfer fluid be *atmospheric air*, and that there be a *steady-state current of air* over the heat transfer surface. In other words, Eq. (1) applies *only* if the heat transfer fluid is atmospheric air, *and* there is a steady-state current of air over the heat transfer surface.

In the nineteenth century, Eq. (1) was *not* just an equation. It was a *law*, and the law meant that, *if* the heat transfer fluid is *atmospheric air*, and *if* there is a *steady-state current of air* over the heat transfer surface, *q* is *always* proportional to ΔT, *h* is *always* independent of ΔT, *h* is *always* a proportionality *constant*, and *h* is *always* a symbol for $q/\Delta T$.

7. Why Laws such as $q = h\Delta T$ are *irrational*

The coefficient in $q = h\Delta T$, and coefficients in other laws that are proportional equations, were created by assigning dimensions to *numbers*. In Fourier's view of dimensional homogeneity, it was rational to assign dimensions to numbers in equations.

Although Fourier is generally credited with the conventional view of dimensional homogeneity, the conventional view differs from Fourier's view in one important way. Langhaar [6] states:

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

Therefore $q = h\Delta T$ and *h*, and other laws in the form of proportional equations and their coefficients, are *irrational* because they were created by assigning dimensions to numbers, in violation of the conventional view that dimensions must *not* be assigned to numbers.

If laws such as $q = h\Delta T$ are *not* abandoned, the conventional view of dimensional homogeneity *must* be revised in order to again make it rational to assign dimensions to numbers.

8. Maxwell's (1831–1879) View of Ohm's Law and Electrical Resistance *R*, and what He Would Have Recommended if He Had Known that *h* is *not* always Independent of ΔT

In *A Treatise on Electricity and Magnetism* [7] published in 1873, Clerk Maxwell explained why Ohm's Law[1], Eq. (5), was a *true* law, and why *R* had scientific value.

$$E = IR \quad (5)$$

Maxwell wrote:

. . .the Resistance of a conductor . . . is defined to be the ratio of the electromotive force to the strength of the current which it produces . . .

. . . the Resistance of a conductor . . .would have been of ***no scientific value*** *unless Ohm had shewn, as he did experimentally, . . . (that) the resistance of a conductor is* ***independent*** *of the strength of the current flowing through it.*

The resistance of a conductor may be measured to within one ten thousandth or even one hundred thousandth part of its value, and so many conductors have been tested that our assurance of the truth of Ohm's Law is now very high.

In 1873, Ohm's law was a true law *only* because it applied to *all* known conductors, and electrical resistance had scientific value *only* because the resistance of *all* known conductors was "*independent* of the strength of the current flowing through it".

Maxwell's words make it certain that, had he lived until semiconductors were invented, he would *surely* have said that Ohm's law is *no longer* a true law because it is *not* always obeyed, and *R no longer* has scientific value because it is *not* always independent of *I*. And Maxwell would *surely* have recommended that Ohm's law and *R* be *abandoned*.

Maxwell's words also make it certain that, had he known that *h* is *not* always independent of ΔT, he would *surely* have concluded that $q = h\Delta T$ is *no longer* a true law because it is *not* always obeyed, and *h no longer* has scientific value because it is *not* always independent of ΔT. And Maxwell would *surely* have recommended that $q = h\Delta T$ and *h* be *abandoned*.

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[1] Eq. (5) is *not* Ohm's law by Ohm. Ohm's law by Ohm is E = IL in which L is the length of a copper wire of a standard diameter. Although E = IL is *not* dimensionally homogeneous, it prevailed for 30 or 40 years. It seems likely that Ohm was familiar with Fourier's view of dimensional homogeneity, and that he did *not* agree that rational equations are necessarily dimensionally homogeneous. From a practical standpoint, E = IL is *preferable* to E = IR because L is tangible, and R is *not*—ie preferable because it contains only *real* parameters.

9. Engineering Science in the Twentieth Century, Why Fourier's Law of Convection Heat Transfer had to be *abandoned or revised*, and the *de facto* Law of Convection Heat Transfer Used in Conventional Engineering Science

Sometime near the beginning of the twentieth century, it was realized that, if heat transfer is by natural convection, condensation, or boiling, *q* is a *nonlinear* function of *ΔT*, and Eq. (1) does *not* apply because it is a *proportional* equation. Consequently it became necessary to decide what equation would replace Eq. (1). The viable alternatives were:

- Abandon Eq. (1), and conceive a *new* law of convection heat transfer that *generically* describes *q{ΔT}*.

$$q = h\Delta T \tag{1}$$

- Replace Eq. (1) with Eq. (2). Equation (2) is *always* dimensionally homogeneous. It states that *q* is *always* a function of *ΔT*, the function may be proportional, linear, or nonlinear, and *h* is *always* a symbol for the *variable q/f{ΔT}.*

$$q = h\, f\{\Delta T\} \tag{2}$$

- Describe Eq. (1) as the law of convection heat transfer, and use Eq. (2) as the *de facto* law of convection heat transfer.

In conventional engineering science, Eq. (1) is described as the law of convection heat transfer, and Eq. (2) is the *de facto* law of convection heat transfer.

The proof that Eq. (2) is the *de facto* law of convection heat transfer lies in the fact that many *h* correlations in the literature indicate that *h* is a *variable dependent on ΔT* (as in Eq. (2)), and *not* a *constant independent of ΔT* (as in Eq. (1)).

10. How *Contrived* Parameters such as *h* (ie *q/f{ΔT}*) Greatly Complicate the Solution of Problems that Concern Nonlinear Behavior

One of the first lessons in mathematics is that it is desirable to separate the variables in nonlinear equations because the solution of nonlinear equations is much simpler if the variables are separated. If a contrived parameter such as *h* is used in a nonlinear equation, it is *impossible* to *separate* the variables *q* and *ΔT* because *h* is a symbol for *q/f{ΔT}.*

If *q* and *ΔT* are not separated, *h* (ie *q/f{ΔT}*) is an *extraneous variable* in nonlinear equations, and it greatly complicates their solution because equations in *three* variables (*q, q/f{ΔT},* and *ΔT*) are much more difficult to solve than equations in *two* variables (*q* and *ΔT*).

11. Why *All* Engineering Proportions in Conventional Engineering Science Are *Irrational*

- Pigs *cannot* be proportional to trees because pigs and trees are different things, and different things *cannot* be proportional.
- Worms *cannot* be proportional to airplanes because worms and airplanes are different things, and different things *cannot* be proportional.
- Stress *cannot* be proportional to strain because stress and strain are different things, and different things *cannot* be proportional.

All engineering proportions in conventional engineering science are *irrational* because they state that the numerical values and dimensions of parameters are proportional, whereas they can rationally state only that the *numerical values* of different things are proportional.

In the new engineering science, *all* proportions state that numerical values are proportional. For example, Hooke's law is *the numerical value of stress is proportional to the numerical value of strain*. Therefore, if Hooke's law is described symbolically, the symbols *must* represent numerical value, but *not* dimension.

It has long been assumed that, although equations *must* be dimensionally homogeneous, proportions need *not* be dimensionally homogeneous. Because a *proportion* that relates σ and ε is *identical* to a proportional *equation* that *qualitatively* relates σ and ε, proportions *should* be dimensionally homogeneous. In the new engineering science, *all* proportions *are* dimensionally homogeneous.

12. Why *All* engineering Equations in Conventional Engineering Science Are *Irrational*

- Equations *cannot* describe how pigs and trees are related because pigs and trees are different things, and different things *cannot* be related.
- Equations *cannot* describe how worms and airplanes are related because worms and airplanes are different things, and different things *cannot* be related.
- Equations *cannot* describe how stress and strain are related because stress and strain are different things, and different things *cannot* be related.
- Equations *cannot* describe how different things are related because different things *cannot* be related.
- Equations can describe *only* how the *numerical values* of parameters are related.

In conventional engineering science, *all* engineering equations are *irrational* because they *all* attempt to describe how numerical values *and* dimensions of parameters are related, when in fact they can only describe how *numerical values* are related.

In the new engineering science, parameter symbols in *all* equations represent numerical value, but *not* dimension.

Consequently *all* engineering equations are *rational* because they *all* describe *only* how the *numerical values* of parameters are related, and therefore they *all* are *inherently* dimensionless and dimensionally homogeneous. (If an equation is *quantitative*, the dimension units that underlie parameter symbols *must* be specified in an accompanying nomenclature.)

13. Why It Is Important to Know that, in the New Engineering Science, Proportions and Equations Are *Inherently* Dimensionless

In conventional engineering science, parameters such as *h* and *E* are required for only one reason: so that engineering laws in the form of proportional equations (*such as* $q = h\Delta T$) can be dimensionally homogeneous. In the new engineering science, equations are *inherently* dimensionally homogeneous because parameter symbols in equations represent *only* numerical value.

It is important to know that, in the new engineering science, proportions and equations are *inherently* dimensionless and dimensionally homogeneous because it means that contrived parameters such as *h* and *E* are *not* required for dimensional homogeneity, and *can be abandoned*.

14. The New Engineering Science

In the new engineering science:

- Engineering laws are analogs of $y = f\{x\}$.
- Parameter symbols in equations represent numerical values, but *not* dimensions. If an equation is quantitative, the dimension units that underlie parameter symbols *must* be specified in an accompanying nomenclature.
- *All* parametric equations are *inherently* dimensionless and dimensionally homogeneous because *all* parameter symbols in equations represent numerical value, but *not* dimension.
- *No* parameters are created by assigning dimensions to numbers. In other words, there are *no* contrived parameters such as *E, h, U, R, etc.*
- *All* problems are solved with the primary parameters *separated* because there are *no* contrived parameters (such as *h* (ie $q/f\{\Delta T\}$) that *combine* them.

15. How to Transform Textbooks from Conventional to New Engineering Science

In order to transform heat transfer textbooks from conventional to new engineering science:

- Revise the nomenclature by removing *U, h,* and *k*. Include the statements: *All* parameter symbols represent numerical value but *not* dimension. If a parameter symbol is used in a *quantitative* equation, the dimension units that underlie the symbol are specified in the nomenclature.
- Replace $q = h\Delta T$ with $q = f\{\Delta T\}$.
- Transform $h\{\Delta T\}$ equations to $\Delta T\{q\}$ equations by substituting $q/\Delta T$ for *h* in *all* equations that explicitly or implicitly include *h*, then separating *q* and ΔT. (Substitute $q/\Delta T$ rather than $q/f\{\Delta T\}$ because in conventional engineering science, *h* is a symbol for $q/\Delta T$.)
- Replace Eq. (6) with Eq. (7). Note that Eq. (7) is intuitively simple, whereas Eq. (6) is so complex it *requires* proof of validity. (To prove that Eqs. (6) and (7) are *identical*, substitute $q/\Delta T$ for U, h_1, h_2, and k/t, then separate *q* and ΔT.)

$$U = \left(1/h_1 + t_{wall}/k_{wall} + 1/h_2\right)^{-1} \tag{6}$$

$$\Delta T_{total} = \Delta T_1\{q\} + \Delta T_{wall}\{q\} + \Delta T_2\{q\} \tag{7}$$

Equation (6) may have one, two, or three unknown variables (because h_1 and h_2 may be variables), whereas Eq. (7) has only *one* unknown variable. If Eq. (6) has two or three unknown variables, it is *much* more difficult to solve than Eq. (7).

Textbooks for other branches of engineering science are transformed in a similar way.

16. Conclusions

The new engineering science should replace conventional engineering science because it:

- Is *much* more rational because there are *no contrived* parameters such as *h*, and consequently *real* engineering phenomena (such as heat transfer) are *always* described by equations that contain *only real* parameters (such as *q* and ΔT).
- Makes it *much* easier to think about and understand engineering phenomena and engineering problems because there are only *real* parameters to think about and understand.
- Is *much* more rational because engineering equations describe how the *numerical values* of parameters are related, and *not* how the *numerical values and dimensions* of parameters are related.
- Makes it *much* easier to learn engineering science (as demonstrated by Eqs. (6) and (7)), because it reduces the number of parameters that must be understood and applied.
- Makes it easier to learn engineering science because the abandonment of contrived parameters means that it is *not* necessary to learn how to solve nonlinear equations *without* separating the variables. (Solving nonlinear equations *without* separating the variables is *not* something generally taught in courses on mathematics.)
- Greatly simplifies the solution of problems that concern nonlinear behavior because the abandonment of contrived parameters reduces the number of variables in problems that concern nonlinear behavior.

Nomenclature

Note: Symbols may represent numerical value and dimension, or numerical value alone.

a	acceleration
c	arbitrary constant
f	force
h	symbol for $q/f\{\Delta T\}$
q	heat flux
T	temperature
ε	strain
σ	stress

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