History and Critical Appraisal of Engineering Science, and a Rational Engineering Science

Eugene F. Adiutori

efadiutori@aol.com

1-239-537-4107

Ventuno Press

April 10, 2023

Abstract
Until 1822, scientists and engineers generally agreed that equations *cannot* rationally describe how parameters are related because *parameter* ***dimensions*** *cannot rationally* be multiplied or divided. That is why Hooke's law, Newton's law of cooling, and Newton's second law of motion are *not* equations. They are *proportions*. In the first part of the nineteenth century, Fourier made *three revolutionary and unproven claims*: (1) dimensions *can rationally* be assigned to numbers; (2) dimensions *can rationally* be multiplied or divided; (3) parametric equations *must be dimensionally homogeneous*. These *unproven* claims are tenets in modern engineering science, and they result in modern engineering laws. Modern engineering laws are generally *proportional* equations, and *proportional* laws work well when applied to problems that concern *proportional* behavior. Proportional laws *do not work well* when applied to problems that concern *linear or nonlinear* behavior because *proportional* laws *cannot* describe *linear or nonlinear* behavior. When *proportional* laws are applied to problems that concern *linear or nonlinear* behavior, the laws *cease* to be equations because they do *not* describe behavior, and they become *definitions.* Proportionality ***constants*** in the laws *cease* to be proportionality ***constants***, and become ***extraneous variables*** that *greatly* complicate problem solutions. The tenets of modern engineering science should be *replaced* by the tenets in Section 4 because they define a *rational* engineering science in which laws apply to ***all*** forms of behavior, and ***do not create extraneous variables***, *greatly* simplifying the solution of the many engineering problems that concern *linear or nonlinear* behavior.

Key words
Engineering history, engineering laws, engineering proportions, engineering tenets, Fourier, irrational engineering laws, irrational engineering proportions, irrational engineering science, Newton, rational engineering science.

1. Engineering science until 1822.

1.1 The tenets of engineering science until 1822:

- Parameter symbols in proportions and equations represent numerical values *and* dimensions.

- Parameter dimensions *cannot* rationally be multiplied or divided.

- Equations *cannot* rationally describe how parameters are related because equations generally *require* that parameters be multiplied or divided, whereas parameter *dimensions cannot* rationally be multiplied or divided.

- Proportions *can* describe how two parameters are related because they do *not* require that parameter dimensions be multiplied or divided.

- Because equations *cannot* describehow parameters are related, whereas proportions *can* describe how two parameters are related, proportions are generally used instead of equations.

1.2 Hooke's law

Hooke's law is generally said to be "strain is proportional to stress". Even though Hooke was a world class mathematician, he did *not* express his empirical result in the form of an equation because in the seventeenth century, scientists and engineers generally agreed that equations *cannot* rationally describe how parameters are related because parameter dimensions *cannot* rationally be multiplied or divided.

1.2.1 A critical appraisal of Hooke's law, and the r*ational* form of Hooke's law.

Strain *cannot* be proportional to stress because the dimension of strain *cannot* be proportional to the dimension of stress, and because ***things*** *cannot* be proportional. (For example, mice *cannot* be proportional to airplanes, corn cannot be proportional to children, etc.) Only *the* ***numerical values*** *of things* can rationally be proportional. Therefore the *rational* form of Hooke's law is "the *numerical value* of strain *is* proportional to the *numerical value of stress*".

1.3 Newton's law of cooling

American heat transfer texts generally refer to Eq. (1) as "Newton's law of cooling", and claim that *h* and Eq. (1) were created by Newton, and were first published in 1701 in Newton's [1] article "Scala graduum caloris" ("A Scale of the Degrees of Heat"). (In 1745, Newton's article was translated and published by the Royal Society of London. At that time, the word "temperature" had not yet been coined, and "heat" in the title meant temperature.)

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

However, as noted in [2], Newton's article concerns *only* his law of cooling, Proportion (2), and his proposed temperature scale from 0 degrees, "The Heat of Winter air, when Water begins to freeze", to 192 degrees, "The Heat of burning Coals in a small Kitchen Fire, made of Bituminous fossile Coals, and without blowing with Bellows.".

$$d\Delta T/dt \;\alpha\; \Delta T \qquad (2)$$

Newton's article has *nothing to do* with Eq. (1), or heat flux *q*, or heat transfer coefficient *h*. It concerns *only* Proportion (2) and his proposed temperature scale.

1.3.1 A critical appraisal of Newton's law of cooling, Proportion (2).

Based on conventional symbolism, Proportion (2) states "The numerical value *and* dimension of $d\Delta T/dt$ are proportional to the numerical value *and* dimension of ΔT". Proportion (2) is *irrational* because only *the numerical values of things* can rationally be proportional. Proportion (2) is rational *only* if it is interpreted to mean "the *numerical value* of $d\Delta T/dt$ is proportional to the *numerical value* of ΔT".

1.4 Newton's second law of motion

Newton's second law of motion is generally said to be Eq. (3).

$$f = ma \tag{3}$$

However, Newton's second law of motion in *Principia* [3] is *not* an equation, and it does *not* include mass. It is:

> Law 2 *A change in motion is* ***proportional*** *to the motive force impressed and takes place along the straight line in which that force is impressed.*

Symbolically, Newton's second law of motion in *Principia* is Proportion (4) which, based on conventional parameter symbolism, states that the numerical value *and* dimension of acceleration are proportional to the numerical value *and* dimension of force.

$$a \propto f \tag{4}$$

1.4.1 A critical appraisal of Newton's second law of motion, Proportion (4).

Proportion (4) is *irrational* because only *the numerical values of things* can rationally be proportional. Proportion (4) is rational *only* if it is interpreted to mean "the *numerical value of acceleration* is proportional to the *numerical value of force*".

2 Engineering science in much of the nineteenth century.

2.1 Fourier's *revolutionary* and *unproven* claims that made it possible *for the very first time* to *create* the modern laws of engineering science (such as $q = h\Delta T$, $\sigma = E\varepsilon$, $E = IR$, *etc.)*

In *The Analytical Theory of Heat* [4], Fourier presented a new engineering science founded on the following *revolutionary* and *unproven* claims:

- Dimensions can *rationally* be assigned to *numbers*. This made it possible to create parameters such as *h, E,* and *R* by assigning dimensions to the proportionality *constants* in equations such as $q = c\Delta T$, $\sigma = c\varepsilon$, and $E = cI$.

- Parameter dimensions can *rationally* be multiplied and divided. This made it rational to have terms such as $h\Delta T$, $E\varepsilon$, and IR.

- Parametric equations *must* be dimensionally homogeneous. This made it *necessary* to *create* parameters such as *h, E,* and *R* so that engineering laws in the form of proportional equations would be *dimensionally homogeneous*.

2.2 A critical appraisal of Fourier's claim that dimensions can rationally be assigned to *numbers*.

In *Dimensional Analysis and Theory of Models* [5] published in 1951, Langhaar stated:

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

The laws of modern engineering science have been *irrational* since sometime before 1951 because parameters such as *h, E,* and *R* were ***in fact*** *created by assigning dimensions to numbers*.

2.3 Why modern engineering laws have *not* been *abandoned.*

The reason modern engineering laws have *not* been *abandoned* is because, for many years, it has generally *not* been known that parameters such as *h, E, and R* were created by *assigning dimensions to numbers*, as evidenced by the fact that, for more than eighty years, American heat transfer texts have *generally* claimed that Newton created *h* and Eq. (1) in 1701, when *in fact* Fourier created them in 1822 *by assigning dimensions to a number*.

2.4 A critical appraisal of Fourier's claim that parameter dimensions can rationally be multiplied and/or divided.

"Multiply six times eight." means "Add eight six times.". Therefore "Multiply meters times kilograms." *must* mean "Add kilograms meters times.". Because "Add kilograms meters times." has ***no meaning***, it is *irrational* to multiply dimensions.

"Divide twelve by four." means "How many fours are in twelve." Therefore "Divide meters by minutes." *must* mean "How many minutes are in meters." Because "How many minutes are in meters." has ***no meaning***, it is *irrational* to divide dimensions.

In summary, parameter dimensions *cannot rationally* be multiplied or divided. Therefore parameter symbols in equations *must* represent the *numerical values **of** dimensions* (rather than the numerical values ***and*** dimensions) because the *numerical values **of** dimensions* ***can*** be multiplied or divided.

2.5 A critical appraisal of Fourier's claim that rational parametric equations *must* be dimensionally homogeneous.

It is *not necessary* to *require* that equations be dimensionally homogeneous because *rational equations* are ***inherently*** *dimensionless,* and therefore *inherently* dimensionally homogeneous.

2.6 Fourier's heat transfer experiment, and why he *created h*

Fourier performed an experiment in which a solid warm body was cooled by the steady-state forced convection of ambient air. He concluded that his data are well correlated by Proportion (5) and Eq. (6).

$q \; \alpha \; \Delta T$ (5)

$q = c \; \Delta T$ (6)

Newton and his colleagues would have been satisfied with Proportion (5), but Fourier was *not*. He wanted an equation, and it *had* to be dimensionally homogenous. Fourier was *not* satisfied with Equation (6) because it is *not* dimensionally homogeneous. Consequently he created *dimensioned parameter h* and substituted it for *number c*, resulting in *dimensionally homogeneous* Eq. (7).

$q = h\Delta T$ (7)

- Note that Proportion (5) *is in fact* dimensionally homogeneous because ***only*** the ***numerical values** of things* can be proportional. Also note that Equation (6) *is in fact* dimensionally homogeneous because parameter symbols must ***not*** represent numerical values ***and*** dimensions. They must represent numerical values ***of*** dimensions.

- If Fourier had known that Proportion (5) and Eq. (6) ***are*** dimensionally homogeneous:
    - There would have been *no need* to *create* dimensioned parameter *h*.
    - Fourier would have correctly concluded that Eq. (6) is a *dimensionally homogeneous* **law**, and it states that, if a solid warm body is cooled by the steady-state forced convection of ambient air, the *numerical value* ***of*** the *q* dimension equals a *constant* times the *numerical value* ***of*** the *ΔT* dimension.
    - If Fourier had correctly concluded that Eq. (6) is a *dimensionally homogeneous law*, parameter symbols in ***all*** engineering proportions and equations would ***now*** contain ***only*** numerical values, parameters such as *h*, *E*, and *R* would ***never*** have been created, and ***all*** laws would ***inherently*** be dimensionless and dimensionally homogeneous.

2.7 How Fourier *created* parameter *h*

Fourier recognized that Eq. (6) could be transformed to a dimensionally homogeneous equation *only* if it were *rational* to claim that:

- ***Dimensions*** can be assigned to ***numbers***.

- ***Dimensions*** can be ***multiplied and divided.***

In the following, Fourier explains why these claims are rational, and stresses that there is ***no proof*** they are rational.

It must now be remarked that every undetermined magnitude **or constant** *has one dimension proper to itself, and that the terms of one and the same equation could not be compared, if they had not the same exponent of dimension. . .* (these claims are) *the equivalent of the fundamental lemmas which the Greeks have left us* ***without proof***. Article 160

Fourier *created h* by *assuming* that it is rational to assign dimensions to *numbers*, assigning to ***number c*** the dimensions that would make Eq. (6) dimensionally homogeneous, and substituting *h* for *c*.

Even though Fourier's claims have *never* been validated, they are tenets in modern engineering science, and Eq. (7) is the modern law of convection heat transfer.

2.8 Fourier's view of the proper application of Eq. (7).

Fourier emphasized that, because Eq. (7) is a *proportional* equation, it applies *only* if q is proportional to ΔT—*only* if h is a *constant*. In much of the nineteenth century, Eq. (7) was *in fact* applied *only* if q is *proportional* to ΔT.

Fourier was a world class mathematician. If he had wanted a law that applies to *all forms* of convection heat transfer, he would *not* have created Eq. (7). He *might* have created *dimensionally homogeneous* Eq. (8) because it applies to *all* forms of convective heat transfer.

$$q = hf\{\Delta T\} \quad (8a)$$

$$h = q/f\{\Delta T\} \quad (8b)$$

$$q = (q/f\{\Delta T\})f\{\Delta T\} \quad (8c)$$

However, Fourier might have rejected Eq. (8) because, if q is *not* proportional to ΔT, the dimension of h would include a *function of the dimension of* ΔT, and that would mean that the *dimension* of h is a *variable dependent on* ΔT.

2.9 Ohm's law

Ohm's law is generally said to be Eq. (9).

$$E = IR \quad (9)$$

However, Ohm's law in Ohm's treatise *The Galvanic Circuit Investigated Mathematically* [6] published in 1827 is *not* Eq. (9). It is Eq. (10) in which L is the length of a copper wire of a standard diameter.

$$I = E/L \quad (10)$$

It is more than likely that Ohm was aware of Fourier's claim that *rational* equations *must* be dimensionally homogeneous. Apparently Ohm did not agree with Fourier because Eq. (10) is obviously *not* dimensionally homogeneous. However, Eq. (10) prevailed from 1827 until sometime between 1856 and 1873. In 1856, de la Rive [7] referred to Eq. (10) in the following:

> *It is a* ***very convenient*** *mode of expressing the resistance . . . by a certain length of wire of a given nature and diameter.*

In 1873, Maxwell [8] referred to Eq. (9) in the following:

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

Note that Eq. (10) is more intuitive than Eq. (9) because *L* is more intuitive than *R*.

2.10 A critical appraisal of Ohm's law, Eq. (9).

Maxwell [8] also stated:

> (Electrical resistance) *would have been of* ***no scientific*** *value unless Ohm had shown, as he did experimentally, that it has a definite value which is altered* ***only*** *when the nature of the conductor is altered.*

In other words, electrical resistance has scientific value *only* if the resistance of *all* conductors is *independent* of electric current—*only* if the electric current in *all* conductors is *always* proportional to electromotive force—*only* if semiconductors are *never* discovered or created. If semiconductors are ever discovered or created, the "resistance" concept *should be abandoned* because it would have ***"no scientific value".***

If Maxwell had lived until semiconductors were created, Eq. (9) and *R* would probably have been *abandoned*.

3 Engineering science from the beginning of the twentieth century until now.

3.1 Modern engineering science

In modern electrical engineering science, Eq. (9) is applied *only* if *E* is proportional to *I* (as Fourier would have insisted). If *E* is *not* proportional to *I*, Eq. (9) and *R* are *not* used. They are *not* replaced because they are *not* necessary. (They are *never* necessary.)

In a very real sense, there are now *two* electrical engineering sciences—the science of *proportional* electrical behavior, and the science of *nonlinear* electrical behavior. The *two* sciences could be reduced to *one* by simply *abandoning* Eq. (9) and *R*.

In modern heat transfer and stress/strain engineering sciences, proportional laws are applied to *all* forms of behavior—proportional, linear, and nonlinear—and there is only *one* heat transfer science and *one* stress/strain science.

3.2 How Fourier's law has been applied.

Sometime near the beginning of the twentieth century, the heat transfer community apparently decided to ignore Fourier's warning that, because Eq. (7) is a proportional equation, it should be applied *only* if heat flux is *proportional* to temperature difference. They decided to use proportional Eq. (7) for *all* forms of behavior—proportional, linear, and nonlinear.

Because a proportional equation *cannot* describe linear or nonlinear behavior, Eq. (7) is *neither* a law nor an equation when applied to problems that concern linear or nonlinear behavior. It is a *definition of h* in the inappropriate form of a proportional equation. And *h* is *not* a proportionality constant. It is an *extraneous variable* dependent on ΔT, and it greatly complicates the solution of problems that concern linear or nonlinear behavior.

3.3 The tenets of modern engineering science.

The tenets of modern engineering science are:

- Parameter symbols in proportions and equations represent numerical values ***and*** dimensions.
- Equations are dimensionally homogeneous.
- Proportions (such as Hooke's law) need *not* be dimensionally homogeneous.
- Parameter dimensions *can* be multiplied or divided.
- Dimensions *can* be assigned to *numbers*, resulting in parameters such as *h*, *E*, and *R*.
- Equations *can* describe how the numerical values *and* dimensions of parameters are related because parameter dimensions *can rationally* be multiplied and divided.
- Proportional engineering laws such as $q = h\Delta T$ *and* $\sigma = E\varepsilon$ apply to *all* forms of behavior (proportional, linear, and nonlinear).

3.4 A critical appraisal of the tenets of modern engineering science.

- Parameter symbols in proportions *must* represent *only* the *numerical values of things*.
- If an equation is *qualitative*, parameter symbols merely identify parameters.
- If an equation is *quantitative*, parameter symbols *must* represent the numerical values ***of*** dimensions (rather than the numerical values ***and*** dimensions), and the dimensions *must* be specified in an accompanying nomenclature.
- *All* rational equations are *inherently* dimensionless and dimensionally homogeneous.
- Dimensions *cannot* rationally be assigned to numbers in equations. (See Section 2.2.)
- Dimensions *cannot* rationally be multiplied or divided. (See Section 2.3.)
- There is *no reason* to claim that equations *must* be dimensionally homogeneous because *all rational equations* are *inherently* dimensionally homogeneous. (See Section 2.4.)
- Conventional engineering laws are *irrational* because:
  - They were created by assuming that dimensions *can* rationally be assigned to *numbers*.
  - They are based on the assumption that dimensions *can* rationally be multiplied or divided.
  - They are based on the assumption that parameter symbols in engineering laws *must* represent numerical value *and* dimension.

- They are based on the assumption that parametric equations *must* be dimensionally homogeneous. This assumption made it *necessary to create* parameters such as *h*, *E*, and *R* so that proportional engineering laws would be dimensionally homogeneous.

- *Proportional* laws apply *only* if the behavior is *proportional* because *proportional* laws *cannot* describe *linear or nonlinear* behavior.

4 The tenets of rational engineering science.

The tenets of rational engineering science are:

- Parameter symbols in proportions *must* represent *only the numerical values of things*. For example, it is *irrational* to state that apples are proportional to apple trees because apples and apple trees are *things*, and *things cannot* be proportional. But it is *rational* to state that the *number* of apples is proportional to the *number* of apple trees.

- If an equation is *qualitative*, parameter symbols merely identify parameters.

- If an equation is *quantitative*, parameter symbols *must* represent the numerical values ***of*** dimensions (rather than the numerical values ***and*** dimensions), and the dimensions *must* be specified in an accompanying nomenclature.

- *All* rational equations are inherently *dimensionless* and *dimensionally homogeneous* because *all* rational equations contain *only numbers*.

- ***All*** engineering laws are analogs of Eq. (11).

$$q = f\{\Delta T\} \quad (11)$$

  Equation (11) states that parameter q is *always* a function of parameter ΔT, and the function may be proportional, linear, or nonlinear.

- Equation (12) states that the *numerical value* ***of*** q dimensions equals 14 times the *numerical value* ***of*** ΔT dimensions. The dimensions of q and ΔT *must* be specified in an accompanying nomenclature.

$$q = 14\Delta T \quad (12)$$

5. Conclusions

- Modern engineering science should be *abandoned* because it is *irrational*.

- The engineering science defined by the tenets in Section 4 should replace modern engineering science because ***it is rational***. It is described in [9].

Meaning of parameter symbols in modern engineering science.

a numerical value ***and*** dimensions of acceleration

E numerical value ***and*** dimension of electromotive force or σ/ε

f numerical value ***and*** dimension of force

h numerical value ***and*** dimension of $q/\Delta T$

I numerical value ***and*** dimension of electric current

L numerical value ***and*** dimension of a copper wire of a standard diameter

m numerical value ***and*** dimension of mass

q numerical value ***and*** dimension of heat flux

R numerical value ***and*** dimension of E/I

t numerical value ***and*** dimension of time

T numerical value ***and*** dimension of temperature

ε numerical value of strain

σ numerical value ***and*** dimension of stress

Meaning of parameter symbols in *quantitative* equations in rational engineering science.

a numerical value ***of*** dimension of acceleration

E numerical value ***of*** dimension of electromotive force

f numerical value ***of*** dimension of force

I numerical value ***of*** dimension of electric current

m numerical value ***of*** dimension of mass

q numerical value ***of*** dimension of heat flux

t numerical value ***of*** dimension of time

T numerical value ***of*** dimension of temperature

ε numerical value ***of*** strain

σ numerical value ***of*** dimension of stress

References

1. Newton, I., 1701, "A Scale of the Degrees of Heat", *Phil Trans Royal Soc (London)*, **22**, p. 824

2. Adiutori, E. F., 1990, "Origins of the Heat Transfer Coefficient", *Mechanical Engineering*, August, pp 46-50

3. Newton, I., 1726, *Principia*, 1726, 3rd edition, translation by Cohen, I. B. and Whitman, A. M., 1999, p. 460, University of California Press

4. Fourier, J., 1822, *The Analytical Theory of Heat*, 1955 Dover edition (1955) of 1878 English translation, Articles 31 and 160

5. Langhaar, H. L., 1951, *Dimensional Analysis and Theory of Models*, p. 13, John Wiley & Sons

6. Ohm, G. S., 1827, *The Galvanic Circuit Investigated Mathematically*, p. 50, 1891 translation, Van Nostrand

7. De La Rive, 1856, *Treatise on Electricity*, Vol ii, pp 80, 81

8. Maxwell, J. C., 1873, *Electricity and Magnetism*, pp. 295, 296, Macmillan

9. Adiutori, E. F., 2017, *The New Engineering*, 3rd edition, Ventuno Press