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

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Received March 12, 2023; Revised April 17, 2023; Accepted April 26, 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.

Keywords: 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 describe how 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 Rational 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.)

$$q = h\Delta T$$

(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.”.

$$d\Delta T / dt \propto \Delta T$$

(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.


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 $\Delta T$”. 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 $\Delta T$.

1.4. Newton’s Second Law of Motion

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

$$f = ma$$

(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.

$$a \propto f$$

(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 $q = h\Delta T$, \( \sigma = E\varepsilon, E = I R, \) 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 $E = c\ell$.
- 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 homogeneous. 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 \( \Delta T \) 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 \( \Delta T \)—only if \( h \) is a constant. In much of the nineteenth century, Eq. (7) was in fact applied only if \( q \) is proportional to \( \Delta T \).

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.

\[
q = hf\{\Delta T\}
\]

(8a)

\[
h = q / f\{\Delta T\}
\]

(8b)

\[
q = (q / f\{\Delta T\})f\{\Delta T\}
\]

(8c)

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

2.9. Ohm’s Law

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

\[
E = IR
\]

(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.

\[
I = \frac{E}{L}
\]  
(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 \( \Delta T \), 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 \( \Delta T \), 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 \( \Delta T \) dimensions. The dimensions of \( q \) and \( \Delta T \) 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 \( \sigma \epsilon \)
- \( f \) 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
- \( \epsilon \) numerical value of strain
- \( \sigma \) 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
- \( \epsilon \) numerical value of strain
- \( \sigma \) numerical value of dimension of stress

References


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