Why modern engineering laws are *irrational*, and the *rational* laws that will replace them.

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Abstract
For more than one hundred years, engineering laws have been founded on the following tenets: (1) Dimensions *can* be multiplied or divided. (2) Dimensions *can* be assigned to numbers. (3) *Faux* parameters such as $h$ and $E$ *can* be created. (4) *Proportional* laws *can* be used to solve *nonlinear* problems. (5) Parameter symbols in equations *must* represent numerical values *and* dimensions. (6) Equations *must* be dimensionally homogeneous, but proportions need *not* be dimensionally homogeneous. Critical appraisal of these tenets proves that the tenets and the laws founded on them are *irrational*. This article presents new tenets and laws that are *rational*. The new laws are analogs of $y = f(x)$ which 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. The new laws *require* that parameter symbols in all equations and proportions represent *only* numerical values, and *require* that all *faux* parameters such as $h$ and $E$ be *abandoned*. If parameter symbols are in *quantitative* equations, the dimension units that underlie parameter symbols *must* be specified. If parameter symbols are in *qualitative* equations or proportions, dimension units are *not* specified. This article explains how modern engineering textbooks can be transformed to textbooks founded on laws that are analogs of $y = f(x)$, and parameter symbols that represent *only* numerical values.


1. Introduction
Until 1822, *all* engineering laws were *proportions*. A book by Fourier (1822) proposed a paradigm shift in which engineering laws would *also* be *equations*. Fourier created *faux* parameter $h$ and Eq. (1), the *first* engineering law in the form of an equation, and the first *faux* parameter. The methodology he used to create *faux* parameter $h$ and Eq. (1) was later used to create other *faux* parameters and laws.¹ Fourier warned that because Eq. (1) is a *proportional* equation, it applies *only* if $q$ is proportional to $\Delta T$.

$$q = h\Delta T$$  \hspace{1cm} (1)

¹ Most American heat transfer texts state that Eq. (1) is “Newton’s law of cooling” and cite Newton (1701). Equation (1) *cannot* be “Newton’s law of cooling” because cooling is a *transient* phenomenon, and Eq. (1) is a *steady-state* equation, and because until 1822, scientists and engineers globally agreed that parametric equations such as Eq. (1) are *irrational*. The origin of $h$ and Eq. (1) is described in Adiutori (1990) and Adiutori (2005).
This article:
• Describes and appraises engineering science from the Middle Ages until now.

• Explains why modern engineering laws are *irrational*.

• Describes the *rational* engineering laws that will replace modern engineering laws.

• Explains how modern engineering textbooks can be transformed to textbooks founded on the proposed engineering laws, and parameter symbols that represent *only* numerical values.

2. **Engineering science from the Middle Ages until 1822.**
From the Middle Ages until 1822:

• *All* engineering laws were *proportions*. Scientists and engineers such as Galileo, Hooke, and Newton agreed that equations *cannot* describe how parameters are related because parameter dimensions *cannot* rationally be multiplied and/or divided.

• Scientists and engineers agreed that proportions that describe how two parameters are related *can* describe engineering phenomena because they do *not* require that parameter dimensions be multiplied or divided.

3. **Why engineering proportions must be dimensionless**
Engineering proportions *must* be dimensionless because parameter dimensions *cannot* be proportional, and because proportions *cannot* be dimensionally homogeneous. The *correct expression* of engineering laws that prevailed in the 18th century are:

• Hooke’s law in Hooke (1676): The *numerical value* of strain is proportional to the *numerical value* of stress.

• Newton’s law of cooling in Newton (1701): The *numerical value* of the rate of temperature change of a warm body is proportional to the *numerical value* of the temperature difference between the warm body and the coolant.

• Newton’s second law of motion in Newton (1726): The *numerical value* of acceleration is proportional to the *numerical value* of force.
4. The first engineering law in the form of an equation

4.1 Fourier’s experiment and results

Fourier (1822) performed an experiment in which a warm, solid body is cooled by the steady-state flow of ambient air. He concluded that the heat flux is proportional to the temperature difference between the surface of the warm body and the ambient air. Correlation of his data resulted in Proportion (2) and Eq. (3).

\[ q \propto \Delta T \]  \hspace{1cm} (2)

\[ q = c\Delta T \]  \hspace{1cm} (3)

Newton and his colleagues would have been satisfied with Proportion (2) because it does not require that parameter dimensions be multiplied or divided. But Fourier wanted an equation that is always dimensionally homogeneous, and Eq. (3) is not dimensionally homogeneous.

4.2 How Fourier transformed dimensionally inhomogeneous Eq. (3) into dimensionally homogeneous Eq. (1)

Fourier recognized that he could transform Eq. (3) into a dimensionally homogeneous equation only if it were rational to:

- Multiply or divide parameter dimensions.
- Assign to constant \( c \) the dimensions that would make Eq. (3) dimensionally homogeneous.

To constant \( c \) in Eq. (3), Fourier assigned the symbol \( h \), the name heat transfer coefficient, and the dimensions that made Eq. (3) dimensionally homogeneous, resulting in faux parameter \( h \) and Eq. (1), the first engineering law in the form of an equation. The methodology Fourier used to create faux parameter \( h \) and Eq. (1) was later used to create other engineering laws and faux parameters such as \( E \) and \( R \).

4.3 How Fourier (1822) validated his revolutionary view that dimensions can be multiplied and/or divided, dimensions can be assigned to numbers, and parametric equations must be dimensionally homogeneous.

Fourier emphasized that he could not validate his revolutionary view that dimensions can be multiplied and/or divided, dimensions can be assigned to numbers, and parametric equations must be dimensionally homogeneous. However, in the following, Fourier states that ancient Greeks used similar methodology, but unfortunately they left no proof that their methodology is valid.
Article 160: *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.* We have introduced this consideration into the theory of heat, in order to make our definitions more exact, and to serve to verify the analysis; it 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.

Fourier’s nearly 500 page treatise is predicated on the validity of the fundamental lemmas of Greek methodology, yet he did not present the lemmas, nor did he cite a reference where the lemmas could be found.

### 4.4 Fourier’s definition of $h$

Fourier (1822) defined $h$ in the following:

Article 36. *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. This value of $h$ is determined by observation.* (The temperatures are degrees Reaumur.)

### 4.5 Why Fourier chose $q = h\Delta T$ instead of $q = h[\Delta T]\Delta T$

Fourier was a world class mathematician, and he knew that, if heat transfer is by natural convection, $q$ is *not* proportional to $\Delta T$, and $h$ is *not* a constant—$h$ is a *variable dependent on $\Delta T$*. Fourier also knew that, in order that his law would apply to *both* forced convection *and* natural convection, the law would have to be Eq. (4) which *correctly* states that $h$ may be a constant or a variable dependent on $\Delta T$.

$$ q = h[\Delta T]\Delta T $$

Presumably, Fourier chose Eq. (1) because he knew that Eq. (4) would *not* be dimensionally homogeneous if $h$ were a variable dependent on $\Delta T$, and he wanted a law that is *always* dimensionally homogeneous.

### 4.6 Fourier’s warning

Fourier warned that, because Eq. (1) is a *proportional* equation, it applies *only* if $q$ is *proportional* to $\Delta T$—ie *only* if $h$ is a constant.
5. Engineering science from sometime near the end of the 19th century until now

5.1 The engineering community decided to ignore Fourier’s warning

Sometime near the end of the 19th century, the engineering community decided to ignore Fourier’s warning, and to apply proportional laws such as Eq. (1) even if the behavior is nonlinear.

5.2 How proportional laws are used to solve nonlinear problems in modern engineering

If the value of \( h \{ \Delta T \} \) is determined from a nonlinear \( h \{ \Delta T \} \) correlation, the value of \( q \) is determined from the calculated value of \( h \{ \Delta T \} \), the given value of \( \Delta T \), and Eq. (1).

Although the correct answer results, it is irrational to use Eq. (1) because it is a proportional equation, and \( h \{ \Delta T \} \) is a variable dependent on \( \Delta T \).

6. Why \( h \) and \( E \) are faux parameters.

As indicated by Eqs. (6) and (9), \( h \) and \( E \) are not parameters. They are ratios of parameters—i.e. they are faux parameters. \( h \) is a symbol for \( q/\Delta T \), and \( E \) is a symbol for \( \sigma/\varepsilon \). Note that Eqs. (7) and (10) are revealing forms of Eq. (5) and (8).

\[
q = h \Delta T \quad (5)
\]
\[
\therefore h = q/\Delta T \quad (6)
\]
\[
\therefore q = (q/\Delta T) \Delta T \quad (7)
\]
\[
\sigma = E \varepsilon \quad (8)
\]
\[
\therefore E = \sigma/\varepsilon \quad (9)
\]
\[
\therefore \sigma = (\sigma/\varepsilon) \varepsilon \quad (10)
\]

7. Tenets that have been the foundation of engineering laws for more than 100 years.

(1) Dimensions can be multiplied or divided.

(2) Dimensions can be assigned to numbers.

(3) Faux parameters such as \( h \) and \( E \) can be created.

(4) Proportional laws can be used to solve nonlinear problems.
(5) Parameter symbols in equations must represent numerical values and dimensions.

(6) Equations must be dimensionally homogeneous, but proportions need not be dimensionally homogeneous.

8. Why tenets that have been the foundation of engineering laws for more than 100 years are irrational, and the rational tenets that will replace them.

8.1 Tenets (1) and (1a)
Tenet (1): Dimensions can be multiplied 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.

Tenet (1a): Parameter dimensions cannot be multiplied or divided. Only the numerical values of parameters can be multiplied or divided.

8.2 Tenets (2) and (2a)
Tenet (2): Dimensions can be assigned to numbers.
A book by Langhaar (1951) states: Dimensions must not be assigned to numbers, for then any equation could be regarded as dimensionally homogeneous.

Tenet (2a): Dimensions must not be assigned to numbers because then any equation could be dimensionally homogeneous.
Since sometime before 1951, the laws of modern engineering science should have been considered irrational because faux parameters such as h and E were created by assigning dimensions to numbers.

8.3 Tenets (3) and (3a):
Tenet (3): Proportional laws can be used to solve nonlinear problems.
(See Section 5.2).

Tenet (3a): It is irrational to solve nonlinear problems using proportional laws.

8.4 Tenets (4) and (4a)
Tenet (4): Faux parameters such as h and E can be created.
American heat transfer texts generally do not reveal what h is, presumably because authors generally assume that h is a real parameter. That is why nomenclatures in texts generally state
only that \( h \) is named “heat transfer coefficient”. However, \( h \) is not a real parameter. \( h \) is a faux parameter, and nomenclatures in heat transfer texts should state “\( h \) is a symbol for \( q/\Delta T \)”, as indicated by Eqs. (11) to (13). Note that Eqs. (11) and (13) are identical and interchangeable.

\[
q = h \Delta T \quad (11)
\]

\[
.: h = (q/\Delta T) \quad (12)
\]

\[
.: q = (q/\Delta T) \Delta T \quad (13)
\]

Equations (11) and (13) apply only if \( h \) (i.e. \( q/\Delta T \)) is a constant. If \( h \) is a variable dependent on \( \Delta T \), Equation (14) applies, but it would be irrational because it would not be dimensionally homogeneous.

\[
.: q = (q/\Delta T) \{\Delta T\} \Delta T \quad (14)
\]

Equations (11) and (13) are analogs of Eq. (15), and Eq. (14) is an analog of Eq. (16).

\[
y = (y/x)x \quad (15)
\]

\[
y = (y/x)\{x\}x \quad (16)
\]

In pure mathematics:

- Eq. (15) is used only if \( y/x \) is a constant.

- If \( y/x \) is a variable dependent on \( x \), Eq. (16) is never used because \( y/x \) would be an extraneous variable.

- If \( y/x \) is a variable dependent on \( x \), Eq. (17) is always used.

\[
y = f[x] \quad (17)
\]

The proposed laws are analogs of desirable Eq. (17), and the de facto laws of modern engineering are analogs of undesirable Eq. (16).

**Tenet (4a):** Faux parameters such as \( h \) (symbol for \( q/\Delta T \)) must not be used because when they describe linear or nonlinear behavior, they are extraneous variables that complicate problem solutions, and they result in laws that are not dimensionally homogeneous.
8.5 Tenets (5) and (5a):
Tenet (5): Parameter symbols in equations must represent numerical values and dimensions.

Tenet (5a): Parameter symbols in equations must represent only numerical values because only numerical values can be multiplied or divided, and only numerical values can be related.

8.6 Tenets (6) and (6a):
Tenet (6): Equations must be dimensionally homogeneous, but proportions need not be dimensionally homogeneous.

Tenet (6a): Equations and proportions are inherently dimensionally homogeneous because parameter symbols represent only numerical values.

9 Data, correlations, and Hooke’s error
9.1 What are data?
Data are the numerical values of parameters measured in an experiment.

9.2 Are parameter dimensions data?
No. Parameter dimensions are required information only if parameter symbols are in quantitative equations. Parameter dimensions are not required information if parameter symbols are in qualitative equations or proportions.

9.3 What can data correlations describe?
Data correlations can describe only how the numerical values of parameters are related. Data correlations cannot describe how numerical values and dimensions are related because:

- Dimensions cannot be related.

- Dimensions cannot be multiplied or divided

9.4 Dimensionally homogeneous proportions
All proportions are dimensionless and dimensionally homogeneous because all parameter symbols in proportions represent only numerical values.

9.5 Hooke’s error
Hooke probably placed his data in two columns. One column was the numerical value of strain, the other column the numerical value of stress. Presumably, Hooke looked at his two data columns and concluded “strain is proportional to stress”.
Hooke was wrong. He should have concluded that “The numerical value of strain is proportional to the numerical value of stress.” because that is in fact what his data indicated.

9.6 Rational engineering equations
Rational engineering equations are inherently dimensionless and dimensionally homogeneous because parameter dimensions cannot be related and cannot be multiplied or divided.

10 Engineering laws.
10.1 The purpose of engineering laws
The purpose of engineering laws is to identify the primary parameters, and qualitatively describe how they are related.

10.2 How rational engineering laws are determined.
Rational engineering laws are determined by performing experiments that include all forms of behavior, and correlating all of the data—i.e. all of the numerical values of parameters measured in the experiments. For example, to determine the law of convection heat transfer, experiments in all types of convection heat transfer must be performed, then all of the data must be correlated in order to find an equation/law that identifies the primary parameters, and qualitatively describes how the primary parameters are related.

10.3 Rational engineering laws
Correlation of engineering data indicates that rational engineering laws are analogs of Eq. (18) which 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.

$$y = f(x)$$ (18)

For example, correlation of convection heat transfer data indicates that Eq. (19) is the law of convection heat transfer. It states that the numerical value of $q$ is a function of the numerical value of $\Delta T$, and the function may be proportional, linear, or nonlinear.

$$q = f(\Delta T)$$ (19)

Similarly, correlation of engineering data indicates that Eq. (20) is the law of stress and strain. It states that the numerical value of $\sigma$ is a function of the numerical value of $\varepsilon$, and the function may be proportional, linear, or nonlinear.

$$\sigma = f(\varepsilon)$$ (20)
How modern engineering texts are transformed into texts in which laws are analogs of \( y = f(x) \), and parameter symbols represent only numerical values

Modern engineering texts are founded on de facto laws that are analogs of \( y = (y/x)\{x\}x \), and parameter symbols that represent numerical values and dimensions. Modern engineering texts can be transformed into texts in which laws are analogs of \( y = f(x) \), and parameter symbols represent only numerical values, by doing the following:

- Replace all engineering laws with analogs of \( y = f(x) \) which 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.

- Require that all parameter symbols in proportions and equations represent only numerical values.

- Replace all faux parameters with the ratio of primary parameters that created them, then separate the primary parameters. For example, replace both \( h \) and \( k/t \) with \( q/\Delta T \), then separate \( q \) and \( \Delta T \).

- Require that, if an equation is quantitative, the dimension units that underlie parameter symbols are specified. Note that all engineering laws and proportions are qualitative.

For example, when faux parameters have been eliminated, Eq. (21) is replaced by Eq. (22), and Eq. (23) is replaced by Eq. (24).

\[
\begin{align*}
    h_1\{\Delta T\} &= 0.40 \ (\Delta T_i)^{33} \\
    \Delta T_1\{q\} &= 1.99q^{75} \\
    U &= \frac{1}{(1/h_1\{\Delta T_i\} + t_{wall}/k_{wall} + 1/h_2\{\Delta T_2\})} \\
    \Delta T_{total}\{q\} &= \Delta T_1\{q\} + \Delta T_{wall}\{q\} + \Delta T_2\{q\}
\end{align*}
\]

Note that Eqs. (22) and (24) are simpler and more obvious than Eqs. (21) and (23). Also note that Eq. (24) is much easier to solve than Eq. (23) because it has only one unknown variable, \( q \), whereas Eq. (23) has two unknown variables, \( h_1 \) and \( h_2 \)–i.e. \( q/\Delta T_i \) and \( q/\Delta T_2 \).

12. Conclusions

Modern engineering science is irrational because it is founded on irrational tenets and laws. It should be replaced by the engineering science that results from the following:

- Parameter symbols in proportions and equations represent only numerical values.
• All laws are analogs of \( y = f(x) \) which states that the numerical value of parameter \( y \) is a function of the numerical value of \( x \), and the function may be proportional, linear, or nonlinear.

• All proportions and equations are inherently dimensionless and dimensionally homogeneous.

• If parameter symbols are in quantitative equations, dimension units are specified. If parameter symbols are in qualitative equations or proportions, dimension units are not specified.

• There are no faux parameters such as \( h \) (the symbol for \( q/\Delta T \)) and \( E \) (the symbol for \( \sigma/\varepsilon \)).

Nomenclature

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Meaning</th>
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<tbody>
<tr>
<td>( a )</td>
<td>acceleration</td>
</tr>
<tr>
<td>( c )</td>
<td>unspecified constant</td>
</tr>
<tr>
<td>( E )</td>
<td>symbol for ( \sigma/\varepsilon ) or volts</td>
</tr>
<tr>
<td>( f )</td>
<td>force</td>
</tr>
<tr>
<td>( h )</td>
<td>symbol for ( q/\Delta T )</td>
</tr>
<tr>
<td>( I )</td>
<td>electric current</td>
</tr>
<tr>
<td>( k )</td>
<td>symbol for ( q(\Delta x/\Delta T) )</td>
</tr>
<tr>
<td>( q )</td>
<td>heat flux</td>
</tr>
<tr>
<td>( R )</td>
<td>symbol for ( E/I )</td>
</tr>
<tr>
<td>( T )</td>
<td>temperature</td>
</tr>
<tr>
<td>( x )</td>
<td>unspecified parameter</td>
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<tr>
<td>( y )</td>
<td>unspecified parameter</td>
</tr>
<tr>
<td>( \varepsilon )</td>
<td>strain</td>
</tr>
<tr>
<td>( \sigma )</td>
<td>stress</td>
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References


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