

A critical appraisal of modern engineering science, and the changes required by the appraisal conclusions.

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A critical appraisal of modern engineering science, and the changes required by the appraisal conclusions

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Abstract

Until the nineteenth century, engineering science was founded on a view of dimensional homogeneity that *required* the following:

- Parameters *must not* be multiplied or divided.
- Dimensions *must not* be assigned to numbers.
- Equations *must* be dimensionless.

This view made it *impossible* to create equations such as the laws of modern engineering science. Modern engineering science is founded on Fourier's view of dimensional homogeneity. His view *allows* the following, and makes it possible to create equations such as the laws of modern engineering science:

- Parameters *may* be multiplied or divided.
- Dimensions *may* be assigned to numbers.
- Equations *may or may not* be dimensionless.

Fourier did *not* prove the validity of his view of dimensional homogeneity. He merely stated that his view of dimensional homogeneity is equivalent to *unspecified* axioms left behind by the ancient Greeks. Presumably, his colleagues accepted his *unproven* view because it enabled him to solve problems they were unable to solve. A critical appraisal of Fourier's *unproven* view of dimensional homogeneity results in the following conclusions:

- Parameters *cannot* rationally be multiplied or divided. Only the *numerical values* of parameters can rationally be multiplied or divided.
- Dimensions *cannot* rationally be assigned to numbers. If dimensions could be assigned to numbers, *any* equation could be regarded as dimensionally homogeneous.
- Equations are *inherently* dimensionless because symbols in parametric equations can rationally represent *only* numerical value.

The appraisal and the changes in modern engineering science required by the appraisal conclusions are presented in the text.

Keywords: Dimensional homogeneity, Fourier, Heat transfer coefficient, Inelastic region, Laws of engineering, Modulus, Parameter symbols

1. Introduction

Until the 19th century, engineering science was founded on a view of dimensional homogeneity that made it *impossible* to create equations such as the laws of modern engineering science. Fourier (1822) conceived a view of dimensional homogeneity that made it *possible* to create equations such as the laws of modern engineering science, and he is generally credited with the modern view of dimensional homogeneity.

Fourier (1822) did *not* prove the validity of his view of dimensional homogeneity. He merely stated that his view of dimensional homogeneity is equivalent to *unspecified* axioms left behind by the ancient Greeks. In his nearly 500 page treatise, Fourier made *no effort* to prove that his view of dimensional homogeneity was rational, he did *not* include the axioms that he *alleged* would validate his view, and he did *not* cite a reference in which the axioms could be found.

Because Fourier did not prove the validity of his view of dimensional homogeneity, and because his view has been the foundation of engineering science for 200 years, this paper critically appraises Fourier's view of dimensional homogeneity, and determines the changes in modern engineering science required by the appraisal conclusions.

2. The multiplication and division of parameters was *irrational* until the nineteenth century.

Until the nineteenth century, the generally accepted view of dimensional homogeneity *required* the following:

- With one exception, parameters *must not* be multiplied or divided. The one exception was that a parameter *may* be divided by the same parameter. For example, the number of feet *may* be divided by the number of feet, and the number of seconds *may* be divided by the number of seconds, but the number of feet *must not* be divided by the number of seconds.
- Dimensions *must not* be assigned to numbers.
- Equations *must* be *dimensionless*.

The requirement that parameters *must not* be multiplied or divided made it *impossible* to generate equations such as the laws of modern engineering science. Because equations had to be dimensionless, each term in an equation had to be a ratio of the *same* parameter. The following verbal equation by Galileo (1638) is typical. It is *dimensionless* and dimensionally homogeneous because each term is a ratio of the same parameter.

If two moveables are carried in equable motion, the ratio of their speeds will be compounded from the ratio of spaces run through and from the inverse ratio of times.

In order to avoid the requirements of dimensional homogeneity, engineering laws were generally in the form of proportions rather than equations. That is why the original version of Newton's (1726) second law of motion is *not* Eq. (1). It is Proportion (2). For the same reason, Hooke's (1678) law is *not* an equation. It is Proportion (3).

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

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

$$\sigma \propto \varepsilon \tag{3}$$

3. Fourier's (1822a) view of dimensional homogeneity made the multiplication and division of parameters *rational*.

From his experiments in convection heat transfer, Fourier concluded that, if heat transfer is by steady-state forced convection to ambient air, heat flux q is *always* proportional to temperature difference ΔT , as in Proportion (4).

$$q \propto \Delta T \quad (4)$$

Proportion (4) would have satisfied Galileo, Hooke, and Newton, but it did *not* satisfy Fourier. Fourier wanted an equation, and it *had* to be dimensionally homogeneous. The transformation from Proportion (4) to an equation results in Eq. (5).

$$q = c \Delta T \quad (5)$$

Equation (5) is *not* dimensionally homogeneous because c is a number, and the dimension of q does not equal the dimension of ΔT . Fourier recognized that Eq. (5) could be transformed to a dimensionally homogeneous equation if the then current view of dimensional homogeneity were replaced by a view in which dimensions *can* be assigned to numbers, and parameters *can* be multiplied and divided. Consequently Fourier conceived a view of dimensional homogeneity in which dimensions *can* be assigned to numbers, and parameters *can* be multiplied and divided. Fourier described his view of dimensional homogeneity in the following:

...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 dimensions. (This view of homogeneity) is the equivalent of the fundamental lemmas which the Greeks have left us without proof.
Fourier (1822a)

It is important to note that, in Fourier's (1822) nearly 500 page treatise, he made *no effort* to prove that his view of dimensional homogeneity is valid, he did *not* present the fundamental lemmas (axioms) which he *alleged* would establish the validity of his view, and he did *not* cite a reference in which the lemmas could be found. He relied on his colleagues to accept, without proof, that his view of dimensional homogeneity is the equivalent of the *allegedly* germane and valid lemmas he did *not* present and did *not* reference.

In accordance with his unproven view of dimensional homogeneity, Fourier assigned the symbol h and the dimension of $q/\Delta T$ to c in Eq. (5). The result was the dimensionally homogeneous Eq. (6), Fourier's law of steady-state forced convection heat transfer to ambient air. In much of the nineteenth century, Equation (6) meant that, if heat transfer is by steady-state forced convection to ambient air, q is *always* proportional to ΔT , and h is *always* a proportionality *constant*.

$$q = h\Delta T \quad (6)$$

Sometime near the beginning of the twentieth century, it was decided to also apply Eq. (6) to *nonlinear* forms of convection heat transfer such as natural convection, condensation, and boiling. When that decision was made, Eq. (6) should have been replaced by Eq. (6a) in order to correctly indicate that the relationship between q and ΔT may be proportional, linear, or nonlinear, and h may be a proportionality constant or a *variable* dependent on ΔT .

$$q = h\{\Delta T\}\Delta T \quad (6a)$$

4. The importance of Fourier's unproven view of dimensional homogeneity

Fourier's unproven view of dimensional homogeneity is very important because, for 200 years, it has been the foundation of engineering science. His view of dimensional homogeneity is the *only* reason it has been considered rational to:

- Assign dimensions to numbers.
- Multiply and divide parameters.
- Generate equations and laws that describe how parameters are related.

5. How the modern view of dimensional homogeneity differs from Fourier's view, and how the difference impacts modern engineering science.

Fourier is generally credited with the modern view of dimensional homogeneity. However, the modern view differs from Fourier's view in a fundamental and very important way. Langhaar (1951) states:

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

Therefore parameters such as h and E , and laws such as Eqs. (7), (8), and (9), are *irrational* because they were created by assigning dimensions to numbers.

$$q = h\Delta T \quad (7)$$

$$\sigma = E_{elastic}\varepsilon \quad (8)$$

$$\sigma = E\{\varepsilon\}\varepsilon \quad (9)$$

6. Definitions of h and E

Rearranging Eq. (7) results in $h = q/\Delta T$. In other words:

- Equation (7) *defines* h to be a symbol for $q/\Delta T$.
- Equation (7) states that h and $q/\Delta T$ are *identical* and *interchangeable*.
- Equations (7) and (7a) are *identical*. They differ only in form.

$$q = (q/\Delta T)\Delta T \quad (7a)$$

Similarly, Eqs. (8) and (9) define E to be a symbol for σ/ε . In other words, E and σ/ε are *identical* and *interchangeable*. Therefore Eqs. (8) and (8a), and Eqs. (9) and (9a), are *identical*.

$$\sigma = E_{elastic}\varepsilon \quad (8)$$

$$\sigma = (\sigma/\varepsilon)_{elastic}\varepsilon \quad (8a)$$

$$\sigma = E\{\varepsilon\}\varepsilon \quad (9)$$

$$\sigma = (\sigma/\varepsilon)\{\varepsilon\}\varepsilon \quad (9a)$$

7. A mathematical analog of modern convection heat transfer and stress/strain

x, y data are generally correlated in the form $y = f\{x\}$ because this equation:

- Can be solved in a *direct* manner if x is given, *or* if y is given.
- *Always* concerns only *two* variables (x and y).
- *Reveals* the relationship between x and y .

In alternate methodology, x, y data are correlated in the form $(y/x) = f\{x\}$. This methodology is generally *not* used because, if y is *not* proportional to x , this equation:

- *Cannot* be solved in a direct manner if y is given and x is to be determined.
- *Always* concerns *three* variables (x , y , and y/x).
- *Masks* the relationship between x and y .

In modern convection heat transfer, an analog of the alternate method is used to correlate $q, \Delta T$ data. The analogy can be seen by substituting q for y , ΔT for x , and h for y/x .

In modern stress/strain, an analog of the alternate method is used to correlate σ, ε data. The analogy can be seen by substituting σ for y , ε for x , and E for y/x .

8. Why the multiplication or division of parameters is *irrational*.

Until the nineteenth century, scientists and engineers *correctly* considered it *irrational* to multiply or divide parameters. Their view is validated by the following:

- Multiplication is repeated addition. Six times seven means add seven six times. Therefore meters times kilograms means add kilograms meter times. Because “meter times” has no meaning, it is not possible to multiply meters times kilograms.
- Twelve divided by four means how many fours are in twelve. Therefore meters divided by seconds means how many seconds are in meters. Because “how many seconds are in meters” has no meaning, it is not possible to divide feet by seconds.

The multiplication or division of parameters is *irrational* because dimension units *cannot* rationally be multiplied or divided.

9. Why parameter symbols in proportions and equations must represent only numerical values.

- Pigs *cannot* be proportional to airplanes because pigs and airplanes are different things, and different things cannot be proportional. However, the *numerical value* of pigs *can* be proportional to the *numerical value* of airplanes.
- Stress *cannot* be proportional to strain because stress and strain are different things, and different things *cannot* be proportional. However, the *numerical value* of stress *can* be proportional to the *numerical value* of strain.
- Equations *cannot* rationally describe how pigs and airplanes are related because pigs and airplanes are different things, and different things *cannot* be related. However, equations *can* rationally describe how the *numerical value* of pigs is related to the *numerical value* of airplanes.

- Equations *cannot* rationally describe how stress and strain are related because stress and strain are different things, and different things *cannot* be related. However, equations *can* rationally describe how the *numerical value* of stress is related to the *numerical value* of strain.

Parameter symbols in equations *must* represent *only* numerical values because equations can rationally describe *only* how the numerical values of parameters are related, and because dimension units cannot be multiplied or divided. If a parametric equation is *quantitative*, the dimension units that underlie parameter symbols *must* be specified in an accompanying nomenclature.

10. How the appraisal conclusions impact modern engineering science.

The appraisal conclusions impact modern engineering science in the following ways:

- Because the modern view of dimensional homogeneity *requires* that dimensions *not* be assigned to numbers, *all* laws and parameters created by assigning dimensions to numbers, such as Eqs. (7), (8), and (9), and parameters such as E and h , are *irrational*, and *must* be abandoned. They *must* be replaced by laws that are *rational*.

$$q = h\Delta T \quad (7)$$

$$\sigma = E_{elastic}\epsilon \quad (8)$$

$$\sigma = E\{\epsilon\}\epsilon \quad (9)$$

- Parameters *cannot* be multiplied or divided because dimension units *cannot* be multiplied or divided. Only the *numerical values* of parameters can be multiplied or divided.
- Parameter symbols in equations *must* represent *only* numerical values because equations can rationally describe only how numerical values are related.
- Because parameter symbols in equations *must* represent *only* numerical values, all rational equations are *inherently* dimensionless and dimensionally homogeneous.
- If parameter symbols represent only numerical values, *and* a parametric equation is *quantitative*, the dimension units that underlie parameter symbols *must* be specified in an accompanying nomenclature.

11. Rational engineering laws

Rational engineering laws *must*:

- Have parameter symbols that represent *only* numerical value.
- Identify the primary parameters.
- Describe *exactly* the same behavior described by data.
- *Always* apply.

12. A rational law of stress and strain

Data indicate that the *numerical value* of stress is *always* a function of the *numerical value* of strain, and the function may be proportional, linear, or nonlinear. Therefore the law of stress and strain *must* be Eq. (10) because it:

- Has parameter symbols that represent *only* numerical value.
- Identifies the primary parameters.
- Describes *exactly* the same behavior described by data—ie allows that the behavior may be proportional, or linear, or nonlinear.
- *Always* applies in both the elastic and inelastic regions.

$$\sigma = f\{\varepsilon\} \quad (10)$$

Equation (10) states that the *numerical value* of stress is *always* a function of the *numerical value* of strain, and the function may be proportional, or linear, or nonlinear.

13. Why the proposed law of stress and strain, Eq. (10), has little impact on the solution of problems that concern the elastic region.

Equations (8) and (11) apply in the elastic region. Equation (8) is Young's law, Eq. (11) is the elastic region form of Eq. (10).

$$\sigma = E_{elastic}\varepsilon \quad (8)$$

$$\sigma = c\varepsilon \quad (11)$$

Because $E_{elastic}$ is a constant, *both* Eqs. (8) and Eq. (11) have only *two* variables, σ and ε . Therefore problems are very easy to solve whether Eq. (8) or (11) is used in the solution. The only difference between the two solutions is that E has numerical value *and* dimension, whereas c has only numerical value. Note that c and E are numerically equal if the dimension units that underlie σ are the same as the dimension units that underlie E .

14. Why the proposed law of stress and strain, Eq. (10), greatly simplifies the solution of most inelastic region problems.

Equations (9) and (10) apply in both the elastic and inelastic regions. In the inelastic region, $E\{\varepsilon\}$ and $\sigma\{\varepsilon\}$ are so highly nonlinear that they are generally described graphically.

$$\sigma = E\{\varepsilon\}\varepsilon \quad (9)$$

$$\sigma = f\{\varepsilon\} \quad (10)$$

In the inelastic region:

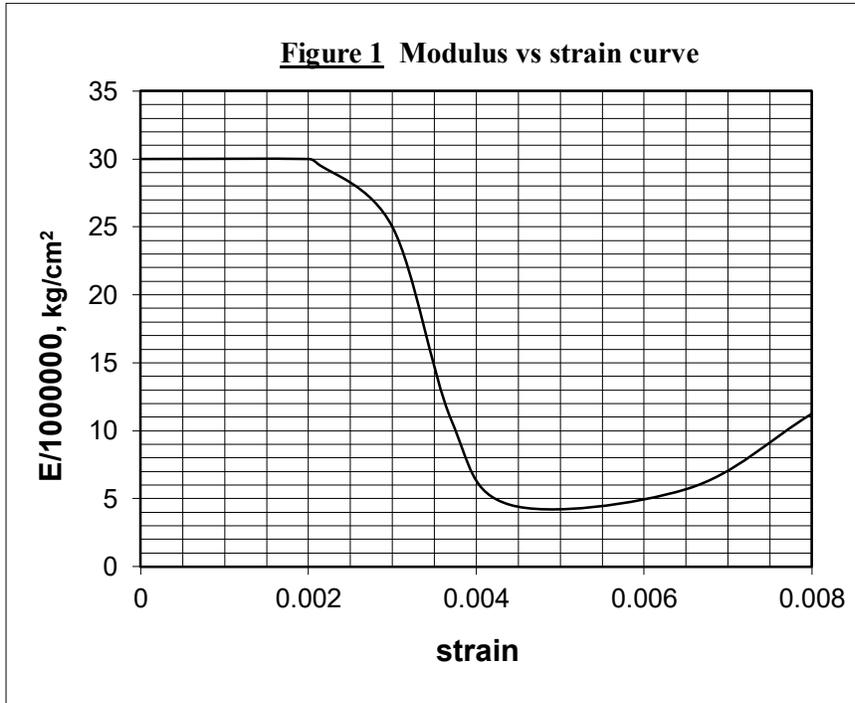
- Eq. (9) *always* has *three* variables because $E\{\varepsilon\}$ is a *variable*.
- Eq. (10) *always* has only *two* variables.

The proposed law greatly simplifies the solution of most inelastic problems because Eq. (9) always has *three* variables, whereas the proposed law, Eq. (10), always has *two* variables.

15. A simple problem that demonstrates that *not* using modulus greatly simplifies the solution of most inelastic region problems.

15.1 Statement of Problem 1 *using* modulus—ie *using* σ/ϵ .

If the stress is 40,000 kg/cm², what is the strain? Use Fig. 1.



15.2 Analysis of Problem 1 *using* modulus.

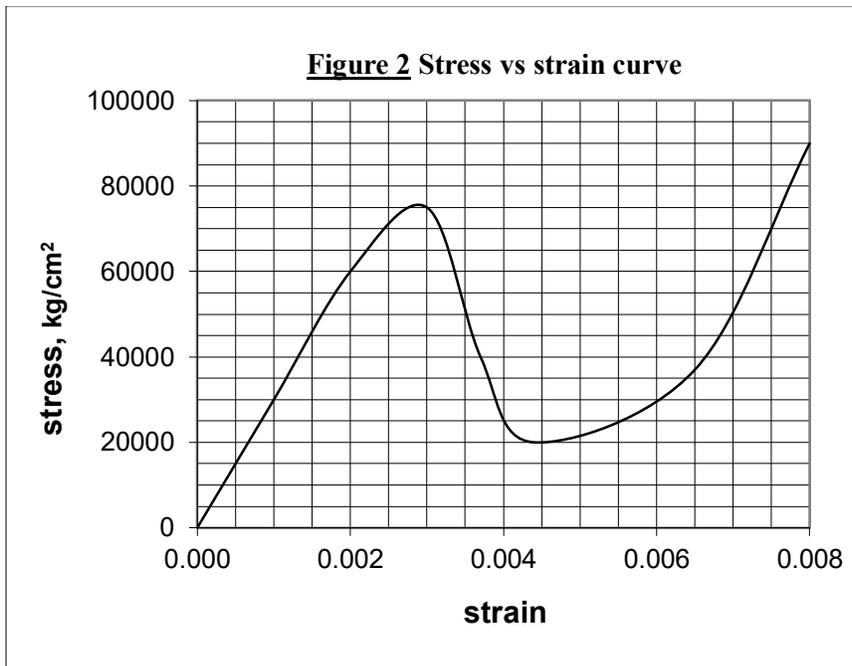
Figure 1 must be read in an indirect manner because ϵ and σ are *not* separated—they are combined in E .

15.3 Solution of Problem 1 *using* modulus.

To be completed by the reader.

15.4 Statement of Problem 1 *without using modulus*—ie *without using* σ/ϵ .

If the stress is 40,000 kg/cm², what is the strain? Use Fig. 2.



15.5 Analysis and Solution of Problem 1 *without using modulus*.

Inspection of Fig. 2 indicates that, if the stress is 40,000 kg/cm², the strain is .0013, .0037, or .0066. The problem statement does not include sufficient information to determine a unique solution.

15.6 Conclusions based on Problem 1.

The solution of Problem 1 *without* using modulus:

- Is so simple it is easily solved by someone who knows *nothing* about stress and strain and *nothing* about mathematics.
- Requires nothing more than reading Fig. 2.
- Is obtained in about 10 seconds because Fig. 2 can be read directly. Figure 2 can be read *directly* because the chart is in the form $\sigma = f\{\epsilon\}$.
- Is so simple there is little likelihood of error.

The solution of Problem 1 *using* modulus:

- Is *not* simple and *cannot* be solved by someone who knows nothing about stress and strain and nothing about mathematics.
- Requires that Fig. 1 be read *indirectly* because the chart is in the form $E\{\epsilon\}$ —ie in the form $(\sigma/\epsilon)\{\epsilon\}$.
- Cannot be obtained in about 10 seconds because reading Fig. 1 indirectly is much more difficult than reading Fig. 2 directly.

- Has a large likelihood of error because Fig. 1 must be read indirectly, and because the problem does *not* have a unique solution.

Although Problem 1 is trivial, it validates the conclusion that the solution of most inelastic problems is *much* simpler if modulus is *not* used.

16. A rational law of convection heat transfer

Data indicate that the *numerical value* of convection heat flux is *always* a function of the *numerical value* of boundary layer temperature difference, and the function may be proportional, linear, or nonlinear. Therefore the law of convection heat transfer *must* be Eq. (12) because it:

- Has parameter symbols that represent *only* numerical value.
- Identifies the primary parameters.
- Describes *exactly* the same behavior described by data.
- *Always* applies.

$$q = f\{\Delta T\} \quad (12)$$

Equation (12) states that the *numerical value* of heat flux is *always* a function of the *numerical value* of boundary layer temperature difference, and the function may be proportional, or linear, or nonlinear.

17. How h is eliminated in equations that explicitly or implicitly include h .

To eliminate h in equations that explicitly or implicitly include h , replace h and k/t with $q/\Delta T$, then separate q and ΔT . For example, Eq. (13) is used to analyze heat transfer between two fluids separated by a flat wall.

$$U = (1/h_1 + t_{\text{wall}}/k_{\text{wall}} + 1/h_2)^{-1} \quad (13)$$

To eliminate h and U in Eq. (13):

- Substitute $q/\Delta T_{\text{total}}$ for U . Substitute $q/\Delta T_1$ for h_1 and $q/\Delta T_2$ for h_2 .
- Substitute $q/\Delta T_{\text{wall}}$ for $k_{\text{wall}}/t_{\text{wall}}$.
- Separate q and ΔT , resulting in Eq. (14).

$$\Delta T_{\text{total}} = \Delta T_1\{q\} + \Delta T_{\text{wall}}\{q\} + \Delta T_2\{q\} \quad (14)$$

Equations (13) and (14) are *identical*—they differ *only* in form. Therefore, *any* problem that can be solved using Eq. (13) *and* h can also be solved using Eq. (14) *without* h . Equation (15) is a heat transfer coefficient correlation often used in the analysis of forced convection heat transfer. To eliminate h in Eq. (15), replace Nu with hD/k , then separate q and ΔT , resulting in Eq. (16a) or (16b).

$$\text{Nu} = hD/k \equiv qD/\Delta Tk = b \text{Re}^c \text{Pr}^d \quad (15)$$

$$q\{\Delta T\} = b(\Delta Tk/D)\text{Re}^c \text{Pr}^d \quad (16a)$$

$$\Delta T\{q\} = (qD/k)(b\text{Re}^c \text{Pr}^d)^{-1} \quad (16b)$$

18. Why the proposed law of convection heat transfer, Eq. (12), greatly simplifies the solution of most problems that concern nonlinear behavior—ie problems that concern natural convection, condensation, or boiling.

Equations (7) and (12) both apply to *all* forms of convection heat transfer.

$$q = h\Delta T \quad (7)$$

$$q = f\{\Delta T\} \quad (12)$$

When applied to problems that concern nonlinear behavior, Eq. (7) has *three* variables (q , ΔT , and $q/\Delta T$ (ie h)), whereas Eq. (12) has only *two* variables (q and ΔT). The proposed law, Eq. (12), greatly simplifies the solution of most problems that concern nonlinear behavior because Eq. (7) has *three* variables whereas Eq. (12) has only *two* variables.

19. A simple problem that demonstrates that *not* using heat transfer coefficients greatly simplifies the solution of most problems that concern nonlinear behavior (such as natural convection, condensation, and boiling).

19.1 Statement of Problem 2 using h (ie using $q/\Delta T$):

Use heat transfer coefficients to determine the heat flux through a wall that separates two fluids.

19.2 Given, Problem 2 using h

$$T_1 = 440 \quad (17)$$

$$T_2 = 85 \quad (18)$$

$$h_1 = 20\Delta T_1^{.25} \quad (19)$$

$$k_{\text{wall}}/t_{\text{wall}} = 100 \quad (20)$$

$$h_2 = 40\Delta T_2^{.25} \quad (21)$$

19.3 Analysis, Problem 2 using h

$$U = (1/h_1 + t_{\text{wall}}/k_{\text{wall}} + 1/h_2)^{-1} \quad (22)$$

$$U = (1/20\Delta T_1^{.25} + 1/100 + 1/40\Delta T_2^{.25})^{-1} \quad (23)$$

19.4 Solution, Problem 2 using h

To be completed by the reader.

19.5 Statement of Problem 2 *without using h* (ie *without using q/ΔT*)

Without using heat transfer coefficients, determine the heat flux through a wall that separates two fluids.

19.6 Given, Problem 2 *without using h*

$$T_1 = 440 \quad (24)$$

$$T_2 = 85 \quad (25)$$

$$\Delta T_1 = .0910q^{0.80} \quad (\text{identical to Eq. (19)}) \quad (26)$$

$$\Delta T_{\text{wall}} = .010q \quad (\text{identical to Eq. (20)}) \quad (27)$$

$$\Delta T_2 = .0523q^{0.80} \quad (\text{identical to Eq. (21)}) \quad (28)$$

19.7 Analysis and solution, Problem 2 *without using h*

$$\Delta T_{\text{total}} = \Delta T_1\{q\} + \Delta T_{\text{wall}}\{q\} + \Delta T_2\{q\} \quad (\text{identical to Eq. (22)}) \quad (29)$$

$$(440 - 85) = .0910q^{0.80} + .010q + .0523q^{0.80} \quad (30)$$

$$q = 11,000 \quad (31)$$

19.8 Conclusions based on Problem 2

Problem 2 demonstrates that the solution of most moderately nonlinear problems is *much* more difficult if *h* is used in the solution. Note that:

- Equation (30) has only *one* unknown variable.
- Using Excel and trial-and-error methodology, Eq. (30) can be solved in about a minute by someone who knows *nothing* about heat transfer and *nothing* about mathematics.
- Equation (23) has *three* unknown variables (*U*, ΔT_1 , and ΔT_2).
- Equation (23) can be solved only by someone who knows a good deal about heat transfer and a good deal about mathematics.
- In order to solve Eq. (23), it is necessary to:
 - Find two more equations that apply to the problem.
 - Solve the three equations simultaneously to determine $q/\Delta T_{\text{total}}$ —ie to determine *U*.
 - Multiply $q/\Delta T_{\text{total}}$ times ΔT_{total} to determine *q*.
- It takes much longer than a minute to solve Eq. (23).
- There is a much greater likelihood of error in the solution of Eq. (23).

20. Conclusions

- Dimensions *cannot* rationally be assigned to numbers. If dimensions could be assigned to numbers, any equation could be dimensionally homogeneous.
- Dimension units *cannot* rationally be multiplied or divided.
- Parameters *cannot* rationally be multiplied or divided because dimension units *cannot* rationally be multiplied or divided.
- Parameter symbols in equations *must* represent *only* numerical value because dimension units *cannot* rationally be multiplied or divided.
- Equations *cannot* rationally describe how parameters are related because parameter symbols in equations *must* represent only numerical value. Equations can rationally describe only how the *numerical values* of parameters are related.
- If an equation is in quantitative form, *and* parameter symbols are dimensionless, the dimension units that underlie parameter symbols *must* be specified in an accompanying nomenclature.
- Rational equations are *inherently* dimensionless and dimensionally homogeneous because parameter symbols in equations *must* represent *only* numerical value.
- Modern engineering laws should be replaced by analogs of Eq. (32) in which y and x are the *numerical values* of primary parameters such as stress and strain, or heat flux and temperature difference, etc.

$$y = f\{x\} \quad (32)$$

- Laws that are analogs of Eq. (32) are true laws because they have parameter symbols that represent *only* numerical value, they identify the primary parameters, they describe *exactly* the same behavior described by data, and they *always* apply.
- Equation (33) should replace Eq. (34), and Eq. (35) should replace Eq. (36).

$$\sigma = f\{\varepsilon\} \quad (33)$$

$$\sigma = E\varepsilon \equiv (\sigma/\varepsilon)\varepsilon \quad (34)$$

$$q = f\{\Delta T\} \quad (35)$$

$$q = h\Delta T \equiv (q/\Delta T)\Delta T \quad (36)$$

- Parameters such as $q/\Delta T$ (*ie* h) and σ/ε (*ie* E) should be abandoned because they are *unnecessary* and *undesirable*. They are unnecessary because problems are readily solved without them. They are undesirable because, when dealing with problems that concern nonlinear behavior, they are extraneous variables that greatly complicate solutions.
- The engineering science that results from abandoning parameters such as h (*ie* $q/\Delta T$) and E (*ie* σ/ε) is *much* easier to learn because there are fewer parameters that must be understood and applied, and because the primary parameters are *not* combined in ratios such as $(q/\Delta T)$ and (σ/ε) that greatly complicate the solution of nonlinear problems by making it *impossible* to solve them with the primary variables *separated*, the methodology learned and preferred in mathematics.

Nomenclature

Symbols

Note: The symbols may represent numerical value *and* dimension, or numerical value alone.

a	acceleration
c	arbitrary number
D	diameter
E	modulus, symbol for σ/ε , kg/cm ²
F	force
h	heat transfer coefficient, symbol for $q/\Delta T$, W/m ² K
k	thermal conductivity, symbol for $q/(dT/dx)$, W/mK
m	mass
Nu	Nusselt number
Pr	Prandtl number
q	heat flux, W/m ²
Re	Reynolds number
T	temperature, C
t	thickness, m
U	overall heat transfer coefficient, symbol for $q/\Delta T_{total}$, W/m ² K
ε	strain
σ	stress, kg/cm ²

Subscripts

1	refers to Fluid 1
2	“ Fluid 2
<i>elastic</i>	“ elastic region
<i>wall</i>	“ wall

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There are no competing interests.

Figures

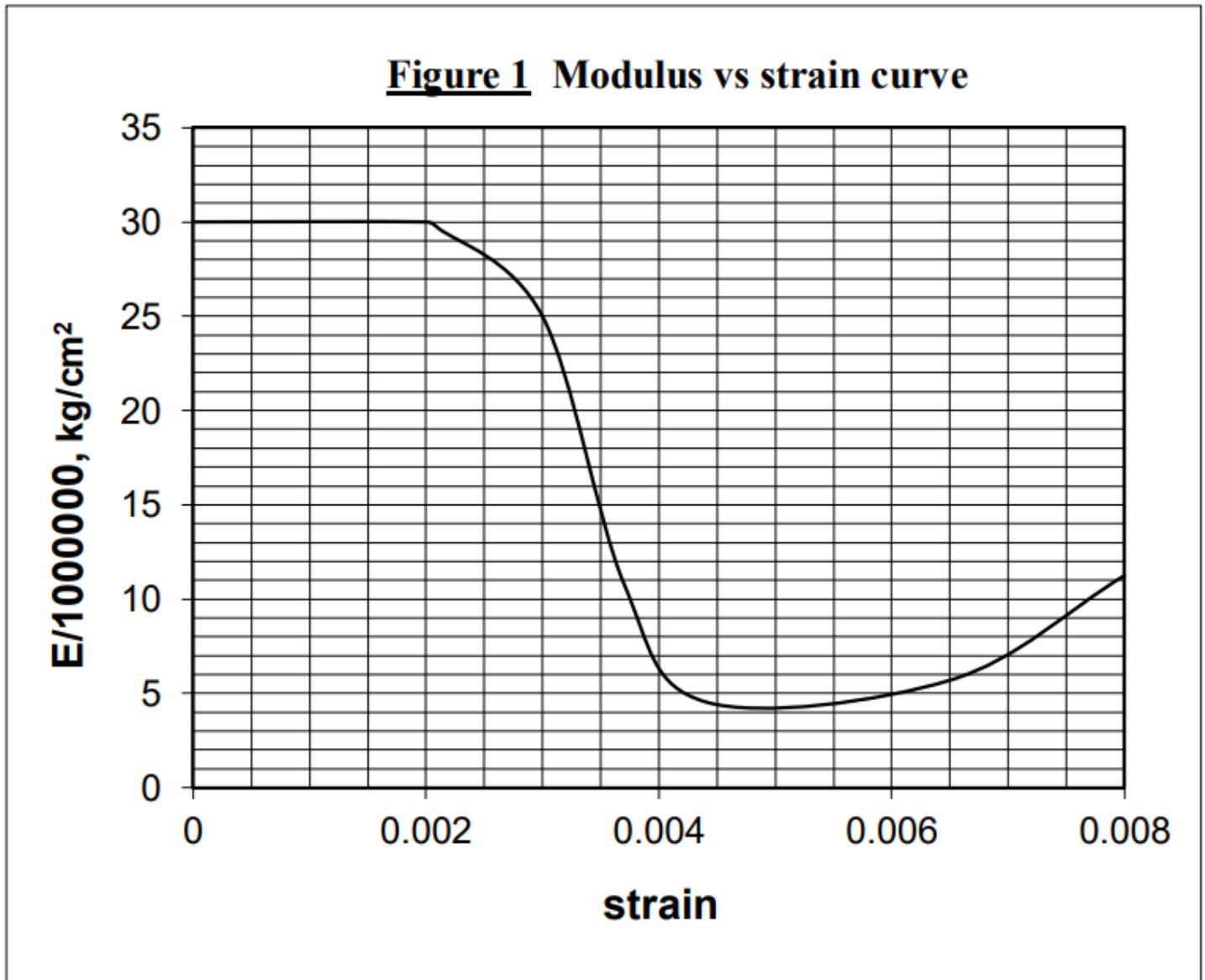


Figure 1

Modulus vs strain curve

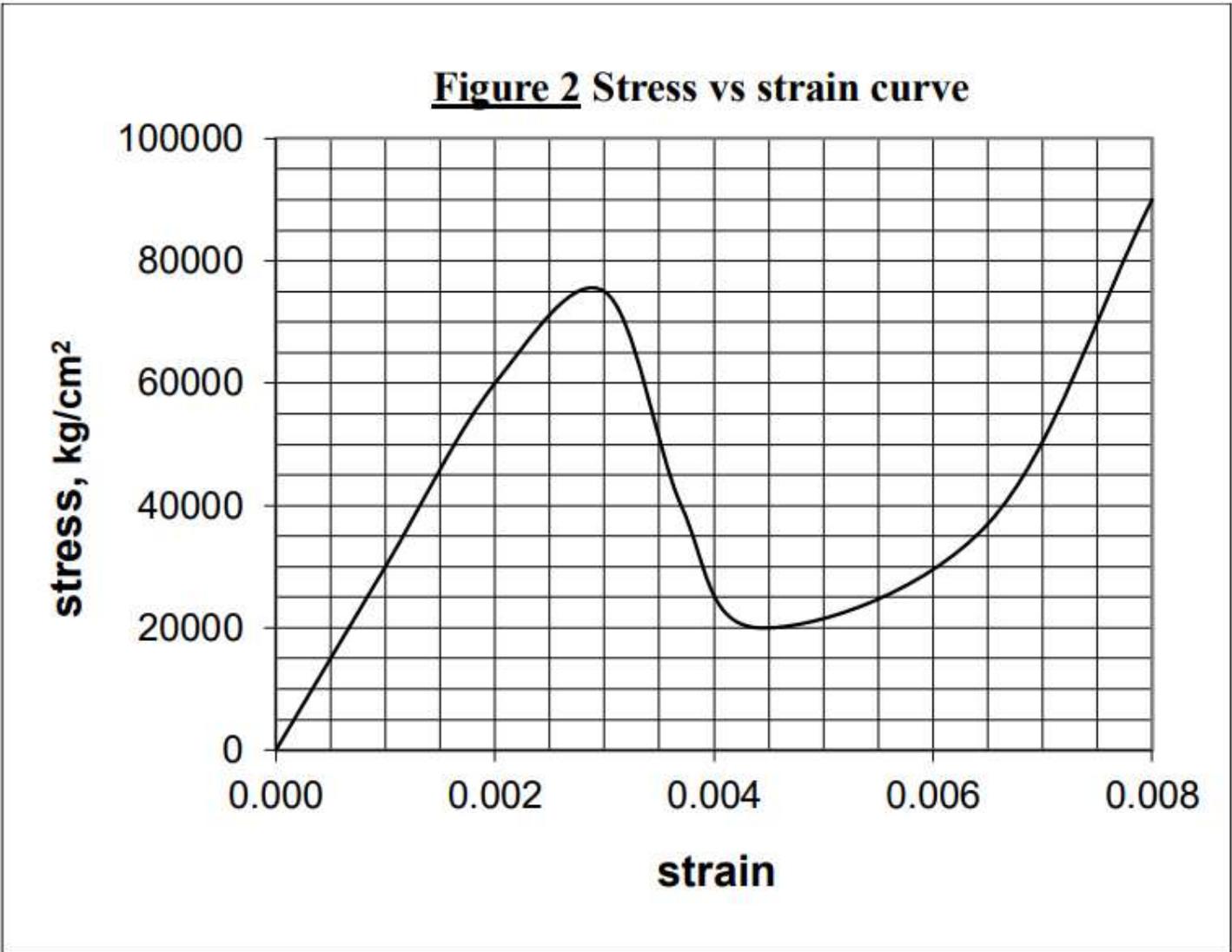


Figure 2

Stress vs strain curve