ALI F. ABUTAHA

June 3, 1993

Dr. Stanislav Fabic

Gaithersburg, MD

Dear Dr. Fabic:

Reference to your letter of May 29, 1993, it concerns me a great deal that you could not recognize the enormity of the widespread error described in my write-ups. The safety, reliability and economy of important systems, including nuclear reactors, have been (and continue to be) severely compromised by the lack of understanding of transient loading conditions. This is not simply a matter of "a different opinion about causes-and-effects;" it is about a clear understanding of the causes and the effects, as they are. Since your views will be persuasive to the NRC, ASME, and others, I will clarify some matters and I hope that you will reconsider your earlier conclusion.

For "**forcing function**," you listed the "*Ignition of dynamite*," the "*Forward motion of the airfoil*," the "*Change in the reactor core's reactivity*," and so on. You then say that these are "*just a few of thousands of examples*" of forcing functions that you could quote from undergraduate classes! I doubt that you can do that. There are only a few standard inputs that are used as the "forcing function" in conducting correct transient analysis; i.e, **unit-step function, ramp function, impulse function, sinusoidal function, power-series function**, and at the most, a few more.

Next, a clear distinction must be made between the pressure (cause) in a vessel, and the stress (effect) in the materials that make up the vessel. If the pressure builds up infinitesimally slowly, then the stress build-up will be comparable to the pressure build-up. Here, the stress can be calculated directly from the pressure values. This is a pure static problem, where the general shape of the pressure-time and stress-time curves will be similar. This static condition is similar to applying one's weight on an old bathroom scale very very slowly, and watch the dial follow the applied load. The stress in the parts of the scale will correspond to the applied load, and the maximum stress will correspond to the actual weight.

If instead, you stepped suddenly on the weight scale, then the dial will overshoot your weight. To calculate the maximum stress in the parts of the scale (platform, spring, joints, etc.) due to the sudden load application requires correct transient analysis. The stress no longer corresponds to the applied load, or the actual weight. The force effect is magnified, strictly because of the sudden activity. This is a classical transient situation.

Mr. Intrater tells me that, in your conversation with him, you expressed the reservation that forces (because of some conservation reasons) do not magnify, except, when there is *resonance* or *shock wave reflection*; and that the force magnification I propose is like "*getting something for nothing*." I am including a couple of pages from Machine Design and Vibration textbooks, which show the doubling effect. In two simple steps, the equations simplify to: F = 2F!!

TEL-FAX (

There are two ingredients involved in the weight scale example; the person and the scale. The person's weight does not overshoot, but the parts of the scale experience the overshoot. The same is true of nuclear reactors' vessels. If a constant load (pressure or otherwise) is applied rapidly, there will surely be magnified forces in the parts of the vessel. It just happens that in *all* the technical papers and the panel discussions, in which you participated, on the safety of nuclear reactors in transient conditions, **the stress is derived directly from the pressure readouts**. The stress simply follows the pressure. There is no overshoot in the stress. This means that there were no transient analysis whatsoever, correct or otherwise; even though the word "transient" was widely used. The practice was done even when the pressure build-up occurred in less than 10 milliseconds. At this rate, Sir, the "forcing function" is nearly a unit-step-function; and correct transient analysis will show that the effect of the load on some parts of the system is nearly doubled. The stress in the parts of the system will also be nearly double. In all technical papers in the above and other Proceedings, the pressure-time curves are used as the transient response. The pressure-time curve is not the transient response.

The problem is trivial, but it is not obvious, though it is very important. By force magnification, I mean the amplified loads in the steel, aluminum, titanium, plastics and other materials that make up a pressure vessel, or a complete system. The magnified effect must be calculated correctly by separate transient analysis, and the maximum forces thus derived must then be used to design the parts of the nuclear reactor. The design stress must be derived from the magnified forces, and not directly from the maximum pressure.

You are thinking in terms of pressure fluctuations, which you call in your letter, "*pressure overshoot.*" This is a central part of the problem. The pressure does not overshoot. My weight does not magnify when I step suddenly on a weight scale. Similarly, the sudden pressure in a vessel does not overshoot.

You mention the "*pressure pulse*" that results from "*very high*" "*rate*" of vapor generation, and how the "*pulse*" "*could exceed the "equilibrium" pressure.*" And then you tell me, "***This is an example of the "pressure overshoot.***" This is not a "pressure overshoot." The "pulse" you refer to is strictly a "fluctuation." This pulse (or fluctuation), Sir, cannot exceed 50% of the maximum steady-state value! The overshoot can reach 100%. Look at attachment D (from the Specialist Meeting on Transients); when the pressure build-up happens in less than 1 (one) millisecond, the fluctuation is nearly 50%. This is almost a pure unit-step function; and the overshoot in the steel will be nearly 100%. The 50% limit on fluctuation is another long technical story, or another oversight, which I will be glad to discuss with you. For now, there is a distinct difference between the pressure fluctuation and the force overshoot. These differences have not been taught at the undergraduate or other levels.

I mentioned the two ingredients involved in the weight scale example: the person and the scale. When a person stands on a scale, the weight is represented by a force vector, $\mathbf{F}_0$, acting at a point (see my enclosed Figs. 5 and 6). The force, $\mathbf{F}_0$, acts through the area of the feet, thus producing a pressure, $\mathbf{P}_0$, on the platform. The pressure-time curve and the equivalent force-time curve for stepping suddenly on a weight scale are shown in Fig. 5d and e: A unit-step-function! When a jet is suddenly applied on the platform, the pressure builds up rapidly to a maximum value $\mathbf{P_0}$ (Fig. 5d). The equivalent force-time curve, Fig. 5e is strictly the forcing function in transient analysis. These examples show that the pressure does not overshoot. A person does not become instantly fat because he, or she, stepped suddenly on a weight scale. But, the parts of the scale will surely experience the magnified effect, or the dynamic overshoot. In order to do correct transient analysis (or any transient analysis), the pressure readouts must first be converted to force values; to be consistent with the other terms in the equation of motion. Transient analysis cannot be made directly with pressure-time curves or with pressure readouts. But this is the only kind of curves and data that have been used in the Transient Specialist Meetings, other conferences, technical papers, textbooks, etc.

Other **transient** experts recently dismissed my assertions out of hand because they say that modern pressure transducers are extremely sensitive and, hence, must pick up the transient response. Please refer to my enclosed figures (6a). **The pressure transducers do not, and cannot, measure nor detect the overshoot!** These experts consider my assertions idiotic. I repeat, the pressure transducers do not, and cannot, measure nor detect the overshoot!

Excerpt from a recent paper is enclosed (Page 4). I know that the analysis will seem trivial to you and other transient and dynamics experts. But let me point out that all vibration textbooks stop the analysis at Eq. 2. The displacement response, x(t), is hardly ever carried on to Eq. (4). Mr. James Intrater has examined my assertions for well over three years now. We have examined hundreds of textbooks and thousands of other technical sources, such as, the Transient Specialist Meeting, and my database is very extensive on the subject. I doubt that you allowed Jim to clarify matters, which by now, he is most capable of doing. This letter clarify some basic points.

There is nothing wrong with the existing transient analysis or the ability of the experts and others to use the analysis. Actually, transient analysis is highly developed mathematically. The problem lies in the clear and distinct recognition that the pressure build-up is itself NOT a transient response, as has been commonly used in your and other areas; nor does a pressure-time curve indicate the transient condition in the steel, aluminum, and other materials that make up the vessels, pipes, valves, etc. The neglected effect is of the order of 70% to 100%. This alone should prompt your very careful consideration.

Sincerely yours,

Ali F. AbuTaha

cc: Mr. James Intrater
Mr. Ronald Wray
Mr. Warren Minners

The transient problem can now be correctly formulated. In a typical combustion chamber, the pressure rises rapidly to the steady-state value, P_O. The pressure build-up, from zero to P_O, imposes equivalent forces, from zero to F_O, on the parts of the system. The rapid pressure build-up can be approximated by a unit-step function. It is the sudden application of a constant, or non-overshooting, pressure that produces the transient conditions, particularly, the force overshoot. The combustion chamber and the remainder of the system may be made up of hundreds, or tens of thousands, of structural, electrical, electronic, and other elements and parts. The transient analysis must be specifically aimed to find out the force overshoot in these elements, and not in the non-overshooting pressure. Because the equations of motion required for transient analysis contain only force terms, the forcing function must strictly conform to the units of force. This is why the pressure is converted to equivalent force. The transient problem can now be correctly formulated: The force on a particular component of a system rises rapidly to the steady-state value, F_O. What is the maximum overshoot? If the system is undamped, then the applicable equation of motion is simply:

$$m\ddot{x} + kx = F_o \quad (1)$$

The solution to Eq. (1) can be found in vibration and other textbooks and it represents the transient response:

$$x(t) = \frac{F_o}{k} (1 - \cos w_n t) \quad (2)$$

When $w_n t$ is equal to π, the cos term is -1, and,

$$x(t) = \frac{2F_o}{k} \quad (3)$$

Extending the above result one step further by relating Hooke's law, $F = kx$, to the time behavior of the system, or, $F(t) = kx(t)$, the maximum force overshoot is then found to be:

$$F(t) = kx(t) = 2F_o \quad (4)$$

Or, when the input is a unit-step-function and the system is undamped, the overshoot is 100%. In other words, the maximum force is $2F_O$, or twice the applied force, F_O. It must be clearly noted that the applied pressure, P_O, does not magnify, and that it is strictly the force effect of the pressure on a given part of the system that is magnified.

The maximum force overshoot can be calculated more accurately by including the damping effects. The response, x(t), for a damped case can be found in vibration or control textbooks, from which the following maximum force overshoot is obtained:

$$F(t) = F_o (1 + e^{-\xi\pi\sqrt{1 - \xi^2}}) \quad (5)$$

The damping ratio, ξ, for most modern structures, particularly aerospace systems, is generally in the range of 1% to 10% (0.01 to 0.10). For these values, the maximum force overshoot is 73% and 97%, respectively. A typical forcing function (or, input) and a transient response (or, output) are shown in Fig. 3. It is emphasized again that the maximum overshoot is the peak of the transient response, and not the small "fluctuation" peak of the transient input.

it is necessary to resort to short cuts. The method to be described next represents such a short cut. It has been used for a great many years and gives results which are on the conservative side.

We begin by making the following assumptions:

1. The inertia of the system is to be neglected. Note that this idealization reduces the problem to one involving only statics.
2. The deflection of the system is directly proportional to the force. Here note that if we were treating it as a problem in dynamics then the deflection would depend upon time as well as upon force.
3. The materials obey Hooke's law.
4. There is no loss in energy.

Figure 3-11 illustrates an energy load which is caused by the weight W falling through the distance h. Since the bar will elongate a distance δ, the work done is

$$U = W(h + \delta)$$

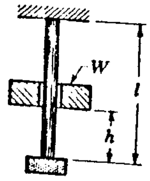


Fig. 3-11

Substituting this value of U in Eq. (3-6) and solving for σ,

$$\sigma = \sqrt{\frac{2W(h + \delta)E}{lA}} \qquad (3\text{-}7)$$

Equation (3-7) is difficult to handle in this form because the deformation δ is a function of the stress. Using the relation $\delta = \sigma l/E$, the equation can be solved for the stress to yield

$$\sigma = \frac{W}{A} + \frac{W}{A}\sqrt{1 + \frac{2hEA}{Wl}} \qquad (3\text{-}8)$$

The first term in the expression is the stress which would exist if the load were gradually applied. It is interesting to see that, if the term h is allowed to become zero, the expression reduces to

$$\sigma = \frac{2W}{A} \qquad (3\text{-}9)$$

This relation, therefore, represents the stress in the bar when the load is applied suddenly but without initial velocity. Referring to Fig. 3-11, this is the stress that would be produced in the bar if the weight W were held in contact with the stop, but without exerting any force upon it, and then suddenly released. The stress is twice as large as that caused by a gradually applied load.

Example 3-5. A steel bar 24 in. in length is to withstand a tensile impact load caused by a weight of 100 lb having a velocity on impact of 140 fpm. (*a*) Find the stress in the bar if the diameter is $1\frac{1}{2}$ in. (*b*) What diameter should be used if a stress of 32,000 psi is permitted? Assume a rigid support.

$$\sigma = \frac{2W}{A} \qquad \sigma = \frac{F}{A}$$

$$F = W$$

$$\frac{F}{A} = \frac{2F}{A}$$

$$F = 2F \;!!$$

$$\ddot{x} + 2\zeta\omega_n\dot{x} + \omega_n^2 x = \frac{F_0}{m} \qquad (\cdot$$

whose solution is the sum of the solutions to the homogeneous equatio

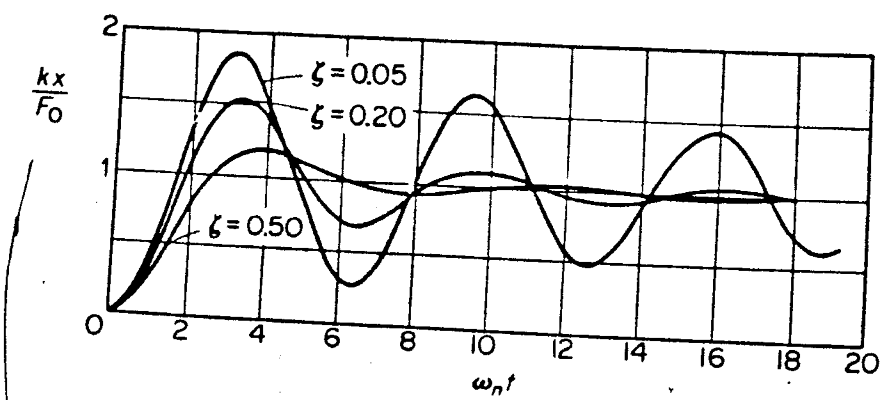


Fig. 4.3-2. Response to a unit step function.

$$\frac{k\,x(t)}{F_0} \simeq 2$$

$$k\;x(t) \simeq 2F_0$$

$$F(t) \simeq 2F_0$$

4.4 Implementation

The pseudo characteristic method has been implemented in a code [20] which runs at the Institute for Nuclear Research and the Chalk River Nuclear Laboratories. The code consists of a problem independent section, consisting of the FORSIM PDE package [13] and selected EISPACK eigensystem routines [21], and a problem oriented section. The latter includes modules specifying the particular model and application, and auxiliary routines to evaluate fluid properties, friction and heat transfer. The code has been run on a number of test problems. The EVET model performed very effectively on a reactor start up transient. The transient is specified and results are given in detail in reference [22]. The PC method has also been compared to the Lax Wendroff 2-step solution for this problem [23]. The reactor start up is a relatively smooth transient. Here we discuss application of the method to a well known benchmark problem involving fast transients.

Test Problem 2: This is standard flow-boiling problem 2, from reference [6]. Geometry and initial conditions are selected to agree with the experiment of Edwards and O'Brien [21]. Water at 243°C and 7 MPa is contained in a horizontal 4 meter pipe of diameter 0.032 m. At time t=0 one end is removed, resulting in a blowdown to atmosphere. Pressure wave propagation from the open to the closed end in the early stage of the transient is considered. During the first 3.5 ms of the transient there are regions of both subcooled water and two-phase mixture. The large discontinuous change in the sound speed, predicted by the EVET model at the boundaries between such regions, makes the computation difficult.

The problem specifications are as follows:

Initial Conditions [6]

Position	u(m/s)	H(MJ/kg)	ρ(kg/m³)	P(MPa)
z=0	70.1	1.03826	183.72	2.331
0<z<4	0	1.0459	815.09	7.0

Boundary Conditions

(1) z=0, u(0,t)=0

(2) z=4m, P(t)=100 kPa if u(t)<c(t) otherwise u(t)=c(t)

4.5 EVET Results

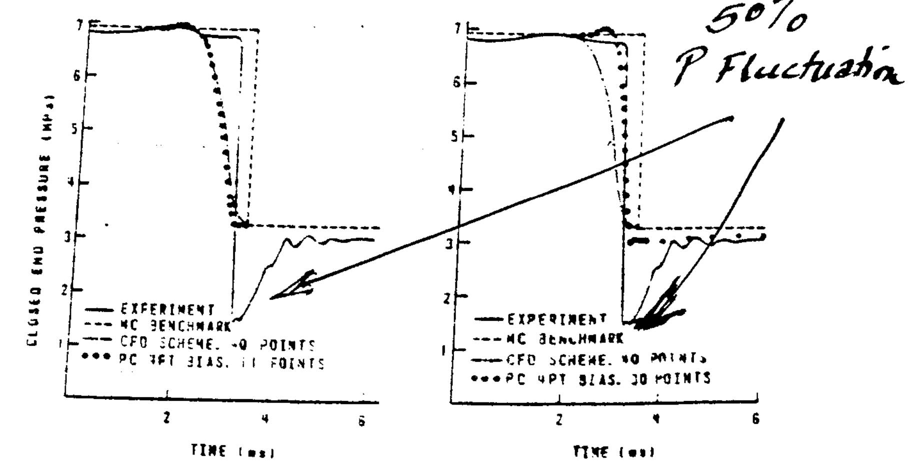
In order to make a comparison between the pseudo characteristic method and other methods reported in [17], the open end boundary condition U=C was imposed for the first several milliseconds of the transient. Figure 2 shows the results of the PC method using the four point upwind bias formula (11) on a grid of 11 and 21 points. The higher order PC solution obtains approximately the same accuracy with 11 points as the CFD did on a 40 point grid. When 30 points are used, the PC method much more closely approximates the benchmark solution. None of the EVET models predict the experimental pressure trough. This is attributed to departure from thermodynamic equilibrium, and can be predicted by the EVUT model.

Figure 2

Edwards Experiments, Two Phase Shock Tube

EVET Results

Comparison of Pseudo Characteristic Four Point Method with Method of Characteristics and Two Point CFD Method



(a) PC with 11 Points (b) PC with 30 Points

Figure 3

Progression of the Pressure Wave

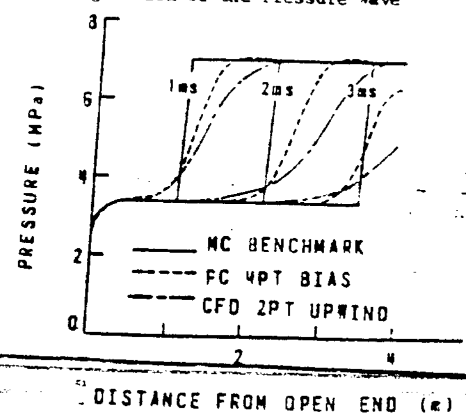
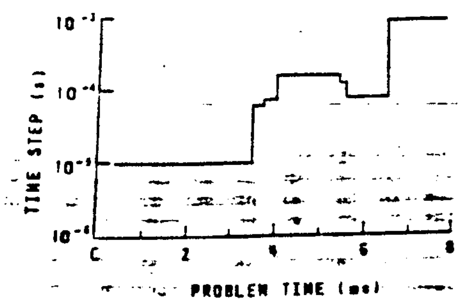


Figure 4

Variation in Integration Time Step



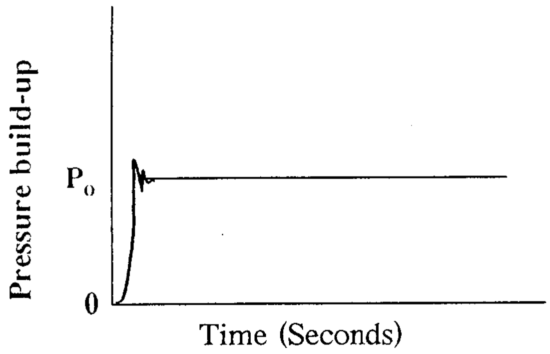


Fig. 1 Rapid pressure build-up. Note: ***pressure fluctuates during build-up, but, strictly, it does not overshoot***

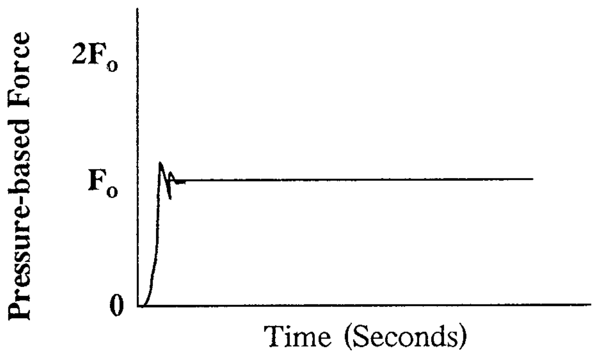


Fig. 2 Force derived directly from the pressure build-up in Fig. 1 is ***not a measure of the overshoot***

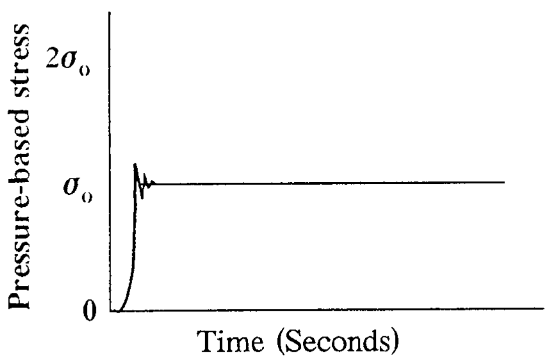


Fig. 3 The stress derived directly from the pressure build-up in Fig. 1 is not the maximum stress

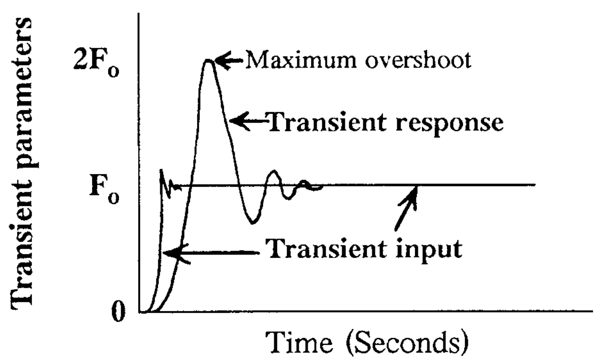


Fig. 4 Maximum design loads must be obtained from correct transient measurements or calculations

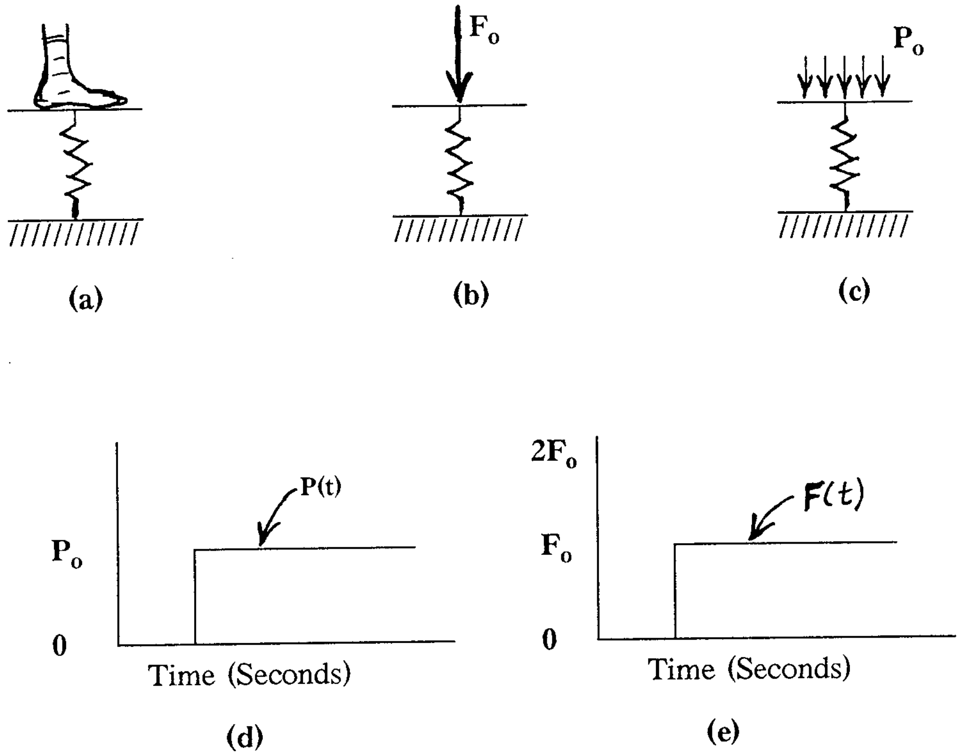


Fig. 5
(a) A weight applied suddenly on a scale
(b) Force vector, F_o, representation
(c) Constant pressure, P_o, representation
(d) Pressure build-up is the transient causal parameter
(e) The pressure-equivalent force is the transient forcing function required to derive the transient response.

$P_o = \frac{F_o}{A}$

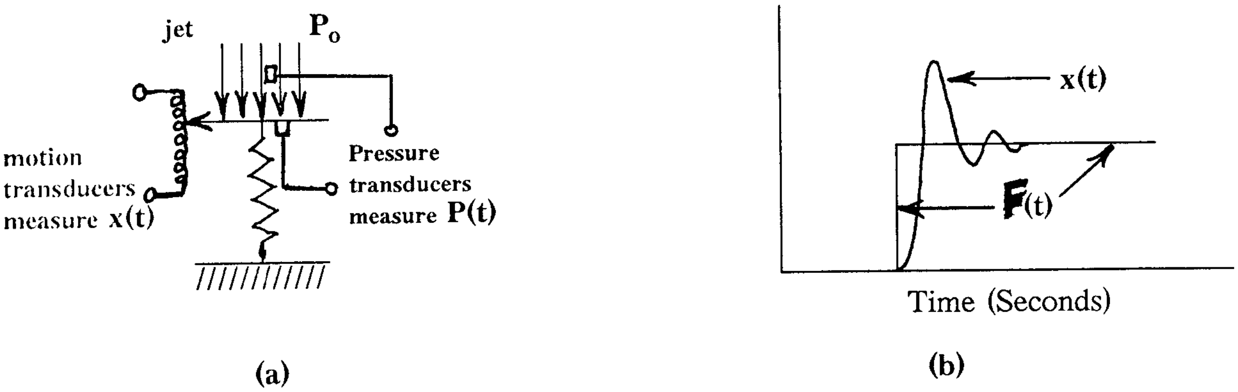


Fig. 6 A clear distinction must be made between **overshooting** and **non-overshooting** measurements. Whether a rocket engine or motor, or a nuclear reactor pressure vessel, the transient response is strictly described by **x(t)**, and not by **P(t)**.

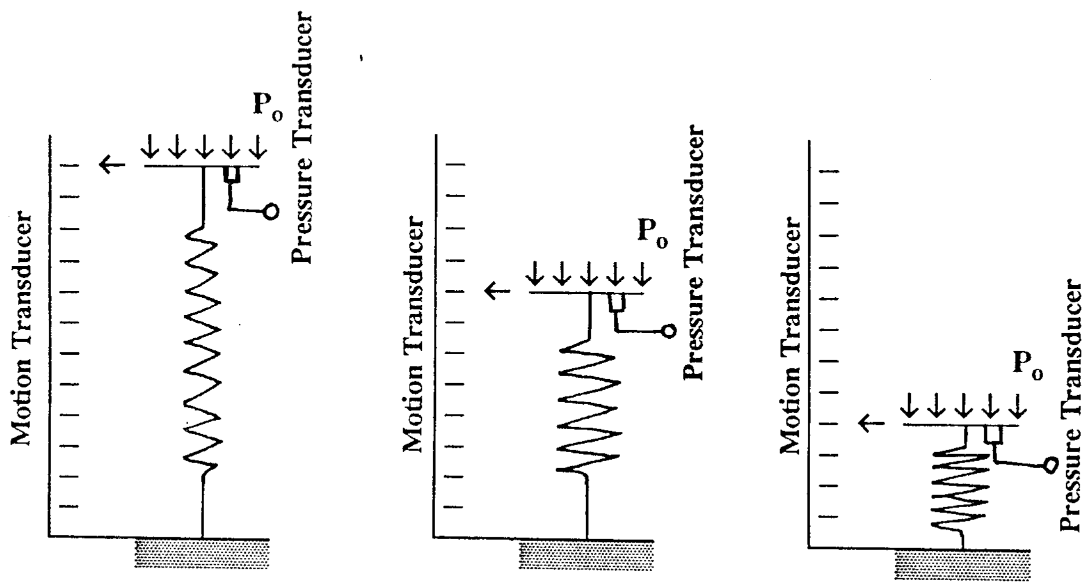


Fig. 6a While a motion transducer, such as an accelerometer or a strain gauge, can detect the transient overshoot; a pressure transducer does not, and cannot, measure or detect the overshoot.

[Substitute for original Fig. 6a]