Vladimir Rombakh, NASGRO EQUATION, AND ITS ERRORS

Physics has always been the basis of technology. Particular success in using a natural phenomenon is achieved when a physical law can be expressed as a mathematical equation expressing a quantitative relationship between cause and effect. The uniqueness of this connection in nature leads to the simplicity of physical equations. The basis of mechanics is Newton's laws, the foundation of electrodynamics is down in Maxwell's equations, the basis of nuclear energy is the Einstein formula, connecting energy E and mass m with a constant factor, which is the speed of light c ($E = mc^2$).

NASGRO is a suite of *computer programs used to analyze fracture and fatigue crack growth (FCG) in structures and mechanical components*. The software is developed jointly by *Southwest Research Institute* (SwRI) and the *National Aeronautics and Space Administration* (NASA) under a Space Act Agreement, with additional support from the NASGRO Consortium and the *Federal Aviation Administration* (FAA). NASGRO is the most widely used fracture mechanics and FCG software in the *world* today, including many applications for aircraft, spacecraft, rotorcraft, gas turbine engines, pressure vessels, and other structural components.

Application of the NASGRO equation, derived by Forman and Newman from NASA, de Koning from NLR and Henriksen from ESA, of the general form (AFGROW, 2002; NASGRO, 2006):

$$\frac{dl}{dN} = C \cdot \left[\frac{(1-f)}{(1-R)} \cdot \Delta K\right]^n \cdot \frac{\left(1-\frac{\Delta K_{th}}{\Delta K}\right)^p}{\left(1-\frac{K_{max}}{K_c}\right)^q} \quad (1)^1$$

Today one can find many works whose authors propose NASGRO equations, with various options for parameters and computer programs. One of them is considering.

The equation (1) as significantly extended possibilities of distributing the crack growth rate tested according to the standard (ASTM E647). The coefficients stand for:

l – crack length [mm],
N- number of load cycles,
C, n, p, q -empirical coefficients,
R – stress ratio,
ΔK – the stress-intensity-factor (SIF) range that depends on the size of the specimen, applied loads, crack length, $\Delta K = K_{max} — K_{min}$ [MPa$\sqrt{m}$],
ΔK_{th}-the SIF threshold, i.e., a minimum value of ΔK, from which the crack starts to propagate:

$$\Delta K_{th} = \left(\Delta K_1 \cdot \left(\frac{a}{a+a_0}\right)^{1/2}\right) \cdot \frac{\left[\frac{1-R}{1-f}\right]^{(1+RC_{th})}}{(1-A_0)^{(1-R)C_{th}}} \quad (2)$$

$$f = \begin{cases} \max(R_1 A_0 + A_1 R + A_2 R^2 + A_3 R^3) \; for \; R \geq 0 \\ A_0 + A_1 R \;\; for \;\; -2 \leq R < 0 \end{cases} \quad (3)$$

where A_1, A_2, A_3, A_4 coefficients are equal:

$$A_0 = (0.825 - 0.34 \cdot a + 0.05 \cdot a^2)\left[cos\left(\frac{\pi}{2} \cdot \frac{S_{max}}{\sigma_0}\right)\right]^{\frac{1}{a}}, \quad (4)$$

$$A_1 = (0.415 - 0.071 \cdot a) \cdot \frac{S_{max}}{a}, \quad (5)$$

$$A_2 = 1 - A_0 - A_1 - A_3, \quad (6)$$

[1] It is generally accepting that the crack length is denoted by the letter a, but Newman used it as another parameter.

Formatted: Font: (Default) Times New Roman

$$A_3 = 2A_0 + A_1 - 1 \qquad (7)$$

$a, \frac{S_{max}}{\sigma_0}$ – Newman′s empirical coefficients.

Let's analyze this equation.

1. A branch of science using stress intensity factors is called linear fracture mechanics. Such a name is contradictory, because with linear deformation, i.e., the fulfillment of Hooke's law, cracks do not form. The formation of cracks is spasmodic, i.e., non-linear, in nature.
   The dimension of stress intensity factors (SIF) is Pa·$m^{1/2}$. The starting point is the tip of the crack. The fact that location spaced apart from the crack tip by a distance *m* has the pressure changed √m times is only a hypothesis because the pressure in the region located in front of the tip of the crack tip has not been measured. It's only a hypothesis that the area spaced apart from the crack tip by a distance *m* has the pressure changed √m times since the pressure in the region located in front of the tip of the crack tip has not been measured.
2. Therefore, there are no measurable parameters on the right side of the equation. It means that the functional relationship between the crack growth rate and stress intensity factors is not proven, and the equation cannot be used.
3. The linear mechanics of destruction proceeds from the hypothesis that cracking and destruction are caused by the emission of elastic energy, which accumulates in stress concentrators. An experiment refutes this hypothesis.
4. The coefficients $A_0 - A_7$ are dimensionless. Therefore, they are in no way connected with the parameters of the material and external influences. Their use in equation (1) is meaningless.
5. So, we see that the number of dimensionless parameters doubled, depriving the equation of physical meaning.

As A. Einstein warned:

"*The laws of mathematics that have anything to do with the real world are unreliable, and reliable mathematical laws are not related to the real world*."