# Population implosion and the model of cavitation applied to demography

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*Based on the hypothesis that in all states of flux (including demographic flux), as in all liquids, the phenomenon of cavitation appears when the local (or demographic) pressure decreases below the vaporization value (the demographic point of survival) respectively, under the saturation pressure (defined by the fertility rate), at the given temperature of gases (general demographic conditions), dissolved in the liquid. This paper presents and analyses cavitation phenomenon as a powerful, rather than merely a potential, demographic model. The structure of this paper could be considered as a succinct three-section solution to describe the evolution from the demographical explosion of the entire world to the demographical implosion of the whole of Europe during the next three or four decades, in a number of population trends. Some final remarks underline the importance of cavitation model and its applied version in demographic implosion, as well as evaluation of the risk of cavitation and computation of cavitation coefficients in demography.*

**Keywords:** Cavitation phenomenon, risk of cavitation, cavitation coefficients, implosion, demography.

DESPITE the *relative gnoseological, experimental* and *predictive immaturity* in relation to other millennia-old sciences like philosophy, logic, mathematics or physics, the importance of demography as a science has increased significantly and permanently, and some models of the sciences considered as *superb*[1] tend to transit, for their predictive qualities, into the space of demographic research.

This is what the practical approach of this paper is: modelling population implosion or initiating a challenge concerning trans-disciplinary application of the model of cavitation, thus facilitating the description of the new phenomenon called demographic implosion.

Under natural conditions, the population of any type of an area or site, be it local, regional, national, continental or international, fluctuates between two values, a lower one, below which the human species disappears, and a higher one, above which individuals die owing to lack of space and food. In the evolution of demographic phenomena, three elements have been recognized that generate a set of profoundly bleak visions of and approaches to the future, namely population explosion (initially generalized in developing countries, in Robert Cook's view, then specific to the 'poor worlds of the globe'), the long-term decrease in fertility, with a generalized impact in the so-called implosive trend of population and accelerated population aging in the economically developed countries. Referring to a new process of demographic change, and defining population decline through the concept of demographic implosion, Philip Longman remarked in amazement, as early as 2004, that the battle to feed humanity was over, since the seventies, when hundreds of millions of people should have died of starvation, despite all the humanitarian programmes launched till then; hence, Ehrlich's 1968 prediction ('the population bomb') proved to be erroneous[2]. Thus, simultaneously threatened by both the spectre of overpopulation to the level of 10.9 billion in 2100, and by the issues of aging and declining population (Elon Musk's forecast: 2015), contemporary humankind remains exposed to world explosion and tendency implosion, especially in Europe.

## Demographic arguments of the presence of the phenomena of explosion and implosion

The evolution of planet Earth's population remains the mere result of long-term economic and social transformations[3]. The last two and a half millennia, until the end of the nineteenth century, have been the expression of different dynamics of world population[4]. After 1600 the first world demographic 'boom' occurred. In only two centuries, around 1800, the world population doubled, reaching, about one billion people. According to the UN Statistical Commission Secretariat's assessments, within a range of over four fifths of a century, from 1927 to 2010, the world's total population increased about 3.5 times, from 2 billion, gradually going up to 2.5 billion in 1950, then to

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3 billion in 1960, to reach 6.9 billion in 2010, and exceeded 7 billion in 2012.

The world population estimate made by the UN demography division is realistic in terms of an accepted error for 2050, with the median value of 9.3 billion people. The twentieth century historically marked the advent of opposing continental trends, as well as the concept of *demographic explosion*, unparalleled in point of impact in previous centuries, an explosion especially connected with the lack of economic development of the countries and regions of the world, in the so-called south pole of global underdevelopment, and also the emergence of a growing heterogeneity of evolution, with implosion or downward trends, specific to Europe. At the end of last century, the concept of *demographic implosion*, specific to developed countries and eastern European countries, and surprisingly, even to those nations in transition or real convergence towards the model of market economy of the European Union, has become dominant for the old continent[4]. Estimates for 2100 are alarming as global alternatives are explosive. While the medium fertility projection for the years 2025, 2050 and 2075 has high global population values, of 8.1 billion, 9.6 billion and 10.4 billion, respectively, and the 2100 estimate of approximately 10.9 billion inhabitants, or a secular growth by nearly 57% of the globe's population, the same population forecast variant in Europe for the 21st century shows a population decrease across the old continent by more than 12.3%, i.e. a population of only 0.6 billion.

At the beginning of the new century, the world population manifests ever more clear trends of sharp demographic oscillation. For the next forty years, the trends of demographic projections in many economically developed countries are downward, which means that these countries, and even the entire European continent, will severely reduce their populations, while in nearly all developing countries, or economically weaker nations, population will increase at an accelerating rate. Some experts believe that over 97% of population growth occurs exclusively in developing countries or economically weaker countries after 2010, and foresee that the population of African countries, for example, can multiply more than three times, while Europe could lose more than 10% of its citizens.

The new 'top hierarchy' will probably have India in top position, with a population of about 1.7 billion people, surpassing China by 0.4 billion in 2050, the two countries accumulating in this situation nearly one third of the world population (in this respect, the projections of the bureau of documentation in Washington are nearly identical to the statistics of demographers at the UN Department of Economic and Social Statistics). Discrimination by revenue, marked by an average ratio of 40/1 and a difference in life expectancy at birth of about 30–35 years, between the populations of developed and underdeveloped nations, generates migrations and even subsequent conflicts, which are important enough for transdisciplinary-oriented modelling solutions[5]. An immediate consequence of observing the fundamental human rights of free communication and freedom of movement, migration, regardless of its legal or illegal character, is the expression of a significant correlation between economic development and demographics, and manifests itself in one major respect, as migration of people in the underdeveloped world towards the economically developed areas[6]. Over the past 10 years, the number of migrants was close to 214 million people, increasing by 20% and becoming comparable to the pace of demographic surplus in that period. Qualitative changes, however, are very interesting and useful for modelling disciplines.

## Cavitation – general theoretical considerations and specific concepts

Cavitation is a dynamic process whereby bubbles or cavities filled with vapour and gas form, develop and implode in a liquid, and is basically caused by a transient decrease in local pressure below critical thresholds.

The factors favouring the emergence and development of cavitation bubbles, or the cavitation germs, are represented by impurities in the liquid, the cracks, the nicks, the flaws or imperfections in the form of solid bodies in contact with the fluid or the moving flow, and they promote retention of microscopic volumes of non-dissolved gas in the liquid, thus creating nuclei or cores of cavitation[7]. If pressure drops, locally and transitorily, to the level of critical values such as vaporization values, these cavitation nuclei having a free surface, will engender the vaporization phenomenon, and because of the gases sent off from the liquid and the evaporation of the liquid, they will develop, turning into bubbles or cavities (filled with a mixture of dissolved gas and/or liquid vapour), and may sometimes contain solid particles that accommodated the cavitation germs.

Cavitation bubbles, once formed in the low pressure areas, are taken over by the fluid current and transported into high pressure regions, where there occurs a sudden condensation of vapour in the cavity, that is, their sudden collapse. They are taken to the inside of cavity walls. This 'crash' occurs from the wall subjected to greater pressure to the opposite wall, and the presence of a solid wall near the bubble leads to its asymmetric collapse, with the emergence of a micro jet that crosses the cavity[8,9].

The impact of the cavitation bubble wall and the liquid jet, having a diameter of the order of 10–100 μm and the speed of the order of several hundreds of meters per second, give rise to acoustic waves and light emissions that occur in the middle of the bubble. Additionally, pressure waves are produced in the amplitude of 100 MPa.

The extremely high values of ambient pressure and the speeds generated around the bubble during implosion, the shock waves emitted at the end point of the collapse and the impact of the liquid micro-jets that cross the inside of the bubble upon the adjacent surfaces, when the bubble moves next to them, are the primary cause of cavitation damage.

To estimate the risk of developing cavitation, it is necessary to follow the evolution of static pressure in the range of flows caused by a fluid in its movement[10]. To illustrate this, the flow of an ideal fluid, incompressible by the Venturi-type bottleneck, is considered, which consists of a bottlenecked converging frusto-conical core, and a diverging frusto-conical core at the exit, where two different points are defined along the current line, with different static pressures, and the difference between pressures 1 and 2 is known and accessible through two open piezometric pipes, or determined with a pressure gauge (Figure 1).

In keeping with a natural relation of continuity in the laminar flow between two sections, before and after the bottleneck, velocities ($V_1$ and $V_2$), multiplied by the surfaces ($S_1$ and $S_2$) should be equal to the flow of the fluid $Q$, and between them ($Q = V_1 \times S_1 = V_2 \times S_2$), generating a significant increase in the speed in the bottleneck area[11]. Simultaneously, a drop in static pressure occurs, from $P_1$ to $P_2$. The two piezometric heights are determined by the values $h_1 = (P_1 : \gamma)$, and $h_2 = (P_2 : \gamma)$, and according to Bernoulli's relationship, relative to the tube axis, as a reference point, the state of equilibrium generates the equality

$$(V_1)^2 : 2g + (P_1 : \gamma) = (V_2)^2 : 2g + (P_2 : \gamma), \qquad (1)$$

where $g$ is the value of acceleration in the gravitational field, for vertical tubes.

Figure 1 shows that the difference between $h_1 = (P_1 : \gamma)$ and $h_2 = (P_2 : \gamma)$ is given as $\Delta h = [(P_1 - P_2) : \gamma]$, and hence the pressure drop between the points of the two piezometric heights is directly proportional to the square of the fluid flow $Q^2 = S^2 V^2$ and

$$(Q^2 : 2g) \times \{[1 : (S_2)^2] - [1 : (S_1)^2]\} = (P_1 - P_2) : \gamma. \qquad (2)$$

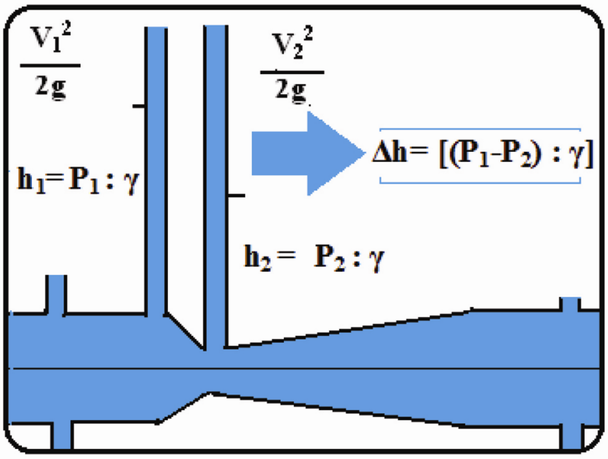

**Figure 1.** The risk of developing cavitation. The static pressures are $P_1$ and $P_2$ (measured by vertical piezometric tubes), the velocities are $V_1$ and $V_2$, of the fluid (supposed constant on the whole section of the tubes), the piezometric heights $h_1 = (P_1 : \gamma)$ and $h_2 = (P_2 : \gamma)$, and their difference $\Delta h = [(P_1 - P_2) : \gamma]$, where $\gamma$ (N/m$^3$) represents the specific weight of the liquid generating the flow and $g$ acceleration of gravity.

The pressure drop ($P_1 - P_2$), between the input section and the section placed after the bottleneck, is relatively low, and the value of minimum pressure remains above the evaporating pressure, and thus it does not generate favourable conditions for cavitation occurring in relatively small fluid flows, or at the most for average flows[12]. For high and very high flow rates, the piezometric line falls below the bottleneck axis, to values below atmospheric pressure, and the risk of cavitation is imminent (static pressure falls to the vapour pressure value corresponding to fluid temperature, and thus creates the condition for initiating cavitation). The occurrence of vapour- and gas-filled cavities virtually prevents pressure values from falling to values lower than evaporation pressure, as the limit value of the static pressure in the bottleneck area cannot be exceeded, even by increasing the flow of fluid passing through the bottleneck, when only that area extends where cavitation bubbles are visualized, and therefore the risk of cavitation or implosion area[13].

Assessment of occurrence of cavitation risk is practically made by determining the deviation of a number of cavitations ($\sigma_{\text{cavitation}}$) when a minimum value indicates a major risk

$$\sigma_{\text{cavitation}} = (P_0 - P_{\text{vaporization}}) : [(\rho V^2) : 2], \qquad (3)$$

or as a general solution

$$\sigma_{\text{cavitation}} = f[(P_0 - P_{\text{vaporization}}), \rho, V], \qquad (4)$$

where $\rho$ is density (in the case of a Venturi-type bottleneck, and in keeping with Bernoulli's relationship $P_0$ is the static pressure upstream of the bottleneck or in an undisturbed flow of a fluid with velocity $V$, and $P_{\text{vaporization}}$ is the minimum value of static pressure in the bottleneck area, or the cavitation threshold).

The probability for the phenomenon of cavitation to occur in the bottleneck area is proportionally lower as $\sigma$ assumes higher values. The solutions for diminishing cavitation risk are provided by the suitable increase in static pressure $P_0$ and slowing velocity $V$ upstream of the bottleneck or strangulation. In giving the technical definition of cavitation coefficients, a specific paradigmatic or notional set is resorted to the degree up to which the cavitation phenomenon develops in different situations is given by cavitation criteria; the composition of such a criterion will comprise the following types of quantities or values (where $P$ = pressure, $V$ = volume, $Z = h_1 - h_2$); (a) quantities describing the cavitation behaviour of the fluid used, namely the values of the pressure of saturating vapour of the fluid and the density of the work fluid

($P_v$, $\rho$); (b) quantities describing the behaviour of the pressure field and velocities within the flow range under study, mainly dependent on the geometry of the hydraulic path, or the shape of the device or body studied ($V_{max}$, $P_{min}$); (c) other quantities[11], describing the energy characteristics of technical installations.

The equation of energy transfer between the two points (one before the bottleneck, and the other interior to the strangulation) allows evaluation of relevant values for a generalized cavitation modelling. Starting from the deviation of a number of cavitations ($\sigma_{cavitation}$), several specific cavitation coefficients can be detailed, called coefficients of incipient cavitation, which result from exclusive comparison to pressure, the installation, etc. and also a set of coefficients of cavitation reserve ($\sigma_{res}$)

$$\sigma_{res} = (P_{min} - P_{vaporization}): [\rho(V_0)^2: 2], \tag{5}$$

where $P_{min}$ is the threshold $P_0$, in fact, from relation (3).

The cavitation stages[12,13] can be defined as follows: (a) $\sigma_{res} > 0$ or $P_{min} > P_{vaporization}$ – absence of cavitation, normal, non-cavitational operation; (b) $\sigma_{res} = 0$ or incipient cavitation at the minimum pressure point; (c) $\sigma_{res} < 0$ or cavitation phenomenon present, slightly developed cavitation, relatively developed, relatively acceptable; (d) $\sigma_{res} \ll 0$ or developed cavitation, with risk of imploding; (e) $\sigma_{res} \lll 0$ or super-cavitation, with high risk of implosion.

## Concrete hypotheses of cavitation modelling for demographic implosion

In demography two variables are identified with a major evolution impact – explosive, but especially implosive: pressure of fertility and migration speed, which virtually offers immediate solutions to cavitation modelling of demographic processes. Demographic pressure can be defined unilaterally by the pressure of births, and it will affect only part of the population, namely the female sub-population of child-bearing age, also known as the population at the age of reproduction, composed of 35 annual cohorts.

The fertile contingent conventionally includes the male sub-population in the [18–52]-year age group, and the female sub-population in the [15–49]-year group fertility. Demographic pressure may also be determined as the result of the simultaneous action of fertility, birth rate and death rate (total and infantile), in which case the model becomes more complicated. Instrumentally, demography provides a variety of assessment tools for fertility pressure. Fertility rates are used when the denominator of a birth rate fraction is limited to a group of individuals of the same sex at the age of procreation (conventional women)[14]. That denominator is usually the sub-population in the mid-year in the middle of the period established, but it may also be the number of years of age completed, or even the average size of the group during the study period.

General or gross fertility rate could be expressed as number or as probability

$$R_{BF} = (\text{live births: } P^F_{mean15–49}) \times 1000, \tag{6}$$

where $P^F_{mean15–49}$ = female population of fertile age.

Total reproduction rate, as deeper analysis variant of the degree of detail of fertility pressure, based on fertility rate per specific age groups ($X_i$), as $R_i = (L_i: P^F_{meanXi}) \times 1000$, where $L_i$ stands for live births of $X_i$ age group in a year and $P^F_{meanXi}$ = female population of $X_i$ age group, is aggregated as follows

$$R_{Total\,F} = \sum_{i=15}^{49} (R_i). \tag{7}$$

The downward trend of one female generation describes the most important population renewal process or the number of live births per 1000 women by the end of the fertile period

$$D = \sum_{i=15}^{49} R_i \times 1000. \tag{8}$$

The gross reproduction rate in women is determined as

$$RGR = 0.48 \times D, \tag{9}$$

and stands for the average number of girls that one woman in a generation has given birth to, during her fertile period, where 0.48 is the coefficient expressing the number of female children at birth (48.2%) as in the demographic law originally formulated by John Graunt, who demonstrated the existence of a relatively constant ratio between the number of male and female children, i.e. about 14/13.

If we considered the probability of survival ($S_i$) at age $i$, determined according to the most recent death rate table, as the ratio of surviving women at age $i$ and women surviving at birth or at age 0, the net reproductive rate in women would result, which is quantified as follows

$$\text{RNR} = 0.48 \times \sum_{i=15}^{49} (R_i \times S_i). \tag{10}$$

Any of the fertility indicators from eqs (6) to (10) can generate alternative models for analysing demographic implosion from relations (3) or (4) of the phenomenon of cavitation, relations in which pressure could be income, $\rho$ the density of fertile female contingent, $g$ the fertility threshold specific to a constant development (value 2.3 is the characteristic feature of simple reproduction), and $V_m$ a specific migration velocity.

Such a migration rate ($\lambda_1$ or $\lambda_2$) is defined by income multipliers of the type GDP/inhabitant, or elasticity coefficients of the type migration/income, obviously at different values depending on the significant factor of the model

$$\lambda_1 = [\,\partial(\text{GDP/inhabitant})_X : \partial(\text{GDP})_X] : [\partial(\text{GDP/inhabitant})_Y : \partial(\text{GDP})_Y], \qquad (11)$$

or

$$\lambda_2 = [\Delta\text{migration} : \text{migration}] : [\Delta\text{income} : \text{income}] = \text{RMigration} : \text{RIncome}. \qquad (12)$$

Migration, whether of a spatial type (from the origin area to the destination area), of a temporal type (temporary and indefinite), of a residential type (change of residence and change of legal address), or of the economic type, means change or relocation of permanent residence within the destination community, and is described by demographic phenomena and events specific to external and internal migration. Migration, analysed as a ratio in the model, could take account of dominant migration flows (internal or external, based on domicile or residence, economic or of any other nature), or of all types of migration flows.

## Conclusion

The practice of predicting and improving demographic implosion can resort to the phenomenon of cavitation, but also to the main coefficients of incipient cavitation, with which migration speeds can thus be modelled through relations (11) and (12), also capitalizing on pressures connected with fertility, or in an even simpler manner, to the family size.

If explosion represents a phenomenon extensively studied and based on a predictable energy dynamics or evolution, implosion involves major risks and energy imbalances difficult to estimate in point of impact, and this paper tried to generate the premises for a fruitful dialogue on the topic of demographic implosion. Hence, two major issues arise, and they provide at least two models as a real challenge for contemporary demography: (a) determining the occurrence of cavitation risk (implicitly, the introduction of a standard deviation σ, or a number of cavitation into contemporary demography, mainly continental Europe), and (b) evaluation, using a number of cavitation coefficients, of incipient cavitation or demographic implosion (including 'technical' solutions to mitigate its impact).

Will the evolution of science, presented above by the name of demography, change so radically, as shown by the demographic explosions and implosions that threaten it?

On a long and very long term, two terrifying, fully contrasting demographic projections stand out, both conceived by François Héran, head of the French National Institute for Demographic Studies (INED). They are focussed on a diminished upward or sharp downward trend. The first describes a positive rate of demographic surplus, which is however declining, which will lead, in the year 2300, to a global population in a state of explosion, of about 36.4 billion people, and the second has a pessimistic level, almost stationary around the year 2075, the year when a historic threshold of 9.2 billion people would occur, a projection probably characterized by incipient decreasing trends after the year 2100, and installed severely after the year 2300, when the Earth's population is estimated to be less than 2.3 billion people. A polarized demographic century, whose echo-projections for the next centuries describe trends as alarming and uncertain, if there is no trans-disciplinary and inter-disciplinary demography.

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