International Journal of
Flow Control

Volume 1 · Number 3 · September 2009

Multi-Science Publishing
ISSN 1756-8250

International Journal of **Flow Control**

Volume 1 · Number 3 · September 2009

Flow Control and the Energy Crisis

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Abstract
Energy and global warming are two of the most pressing quandaries facing humanity in the twenty-first century. Flow control can help in both fronts. This brief describes how, but is mostly a bird-eye's view of the energy crisis.

1. FLOW CONTROL

Flow control is the attempt to favorably alter the character or disposition of an internal or external flow field. The ability to manipulate a fluid flow actively or passively to effect a desired change is of immense technological importance. The potential benefits of realizing efficient flow-control systems range from saving billions of dollars in annual fuel costs for land, air and sea vehicles, to reducing the pumping costs in thousands of long-haul pipelines, to achieving economically and environmentally more competitive industrial processes involving fluid flows.

Drag is the force by which a fluid resists the relative motion of a solid. An equal and opposite reaction force acts on the body surface as a result of the fluid deformation, and drag is the component of this force parallel to the direction of the relative velocity vector. Likewise, a lifting surface in relative motion with a fluid experience an additional force perpendicular to the flow direction called the lift force.

The fluid can be external or internal to the solid boundaries, and the solid surface can be rigid or compliant. Drag can be divided into skin-friction drag and pressure drag, and the ratio of those two components depends on the shape and the Reynolds and Mach numbers. For example, approximately 90% of the total drag encountered by a well-designed cruising nuclear submarine is in the form of skin friction. On the other hand, on a cruising wide-body commercial aircraft, the drag force is equally divided between skin friction and pressure drag. The latter has more significant contribution mostly because of the additional induced and wave drag, two elements that are not as dominant in the case of the submarine.

For the most part, flow control is about drag reduction and lift enhancement. If done right, control of separation, laminar-to-turbulence transition, turbulence intensity and mixing all lead to the desired drag reduction and lift enhancement. An ideal method of flow control that is simple, inexpensive to build and operate, and does not have any tradeoffs does not exist, and the skilled engineer has to make several compromises to achieve a particular design goal. The book by Gad-el-Hak [1] extensively covers the broad subject of flow control.

Both drag reduction and lift enhancement lead to energy conservation. Fuel needs to be burned to provide the thrust necessary to overcome drag forces. Less skin-friction and pressure drags mean less energy consumption in transportation systems and pipelines. Enhanced lift means that an airplane, say, can fly at lower speeds and still be able to carry the same weight, which again means energy saving. Since most transportation and power generation systems utilize fossil fuels, drag reduction and lift enhancement lead to not only energy conservation but also to the production of less global-warming gases. For the benefit of the readers of the *International Journal of Flow Control*, the rest of this brief provides a bird-eye's view of the energy crisis.

2. ENERGY

Nothing can move let alone survive without it. Yet, until a gallon of gas hit $4, the word was rarely uttered during the 2008 presidential campaign. Promises to effect somehow a lower price of gas at the pump, or of a Federal gas tax break during last summer, are at best a short-term band-aid to what should be a much broader and longer-term national debate. During two visits to Saudi Arabia that took place 15 January 2008 and 16 May 2008, President Bush pleaded with King Abdullah to open the oil spigots, while the Royal told his eminent visitor how worried he was about the impact of oil prices on the world economy. The spigots did not open; and even if they were, such pleas and worries are not going to solve the energy problem or its intimately linked global warming crisis.

Much like company executives, politicians mind, envision and articulate issues in terms of years, not decades. A four-year horizon is about right, as this is the term for a president, twice that for a representative, and two-third of a senate term. The tenure of a typical CEO is even shorter than that for a senator. But the debate on energy should ideally be framed in terms of a human lifespan, currently about 75 years. The reason is two fold. First, fossil fuel, such as oil, gas and coal, is being consumed at a much faster rate than nature can make it. These are not renewable resources. Considering the anticipated population growth (with a conservative albeit unrealistic assumption of no increase in the per capita demand) and the known reserves of this type of energy sources, the world supply of oil is estimated to be exhausted in 0.5 lifespan, of gas in one lifespan, and of coal in 1.5 lifespan [2]. Second, alternative energy sources must be developed to prevent a colossal disruption of our way of life. But, barring miracles, those cannot be found overnight, but rather over several decades of intensive research and development. The clock is ticking, and few people seem to be listening to the current whisper and, inevitably, the future thunder.

Uranium fission power plants currently supply about 8% of the U.S. total energy need, which is about 100 Quad/year or 10^{20} Joule/year [3, 4]. (Total energy consumed is in the form of electricity, 40%, the burning of fossil fuel to directly generate heat for buildings and industrial processes, 30%, and mechanical energy for transportation systems, 30%.) Coal, natural gas and nuclear power plants respectively generate 50, 20 and 20% of our electricity need. The corresponding numbers in France are 4, 4 and 80%. Even at that modest rate of consumption and with current nuclear reactor technology, the United States will exhaust its supply of uranium in about two lifespan. Real and imagined concerns about the safety of nuclear energy and depositions of their spent fuel have brought to a halt all new constructions since the mid 1970s. Happily, 2007 breezed new life into the nuclear issue. There are now 7 new nuclear reactors in the early planning stages for the U.S. market, and over 65 more for China, Japan, India, Russia and South Korea.

Fission-based power generation not only can reduce the country's insatiable appetite for fossil fuel but also no carbon dioxide or any other heat-trapping gases is generated as a result of nuclear power generation. Along with other pollutants, a coal-fired power plant, in contrast, annually releases 10 billion kg of carbon dioxide into the atmosphere for each 1,000 MW of (fully utilized) electric capacity. Nuclear power generation must be part of the solution to both the energy and global warming crises.

Controlled nuclear fusion, also a non-polluting source of energy, has the potential to supply inexhaustibly all of our energy need, but, even in the laboratory, we are far from achieving the breakeven point (i.e., getting more energy from the reactor than needed to sustain the reaction).

3. THE ENERGY CRISIS

With 5% of the world population, the United States consumes 25% of the world annual energy usage, generating in the process a proportional amount of greenhouse gases. Conservation alone is not going to solve the problem; it will merely relegate the anticipated crises to a later date. A whopping 20% conservation effort this year will be wiped out by a 1% annual population increase over the next 20 years. But that does not mean it shouldn't be done. Without conservation, the situation will be that much worse.

The energy crises exemplified by the 1973 Arab oil embargo brought about a noticeable shift of attitudes toward energy conservation. During the 1970s and 1980s, governments, corporations and citizens around the world but particularly in the industrialized countries invested valuable resources searching for methods to conserve energy. Dwellings and other buildings became better insulated, and automobiles and other modes of transportation became more energy efficient. Plentiful fossil fuel supplies during the 1990s and the typical short memory of the long gas lines during 1973 have, unfortunately, somewhat dulled the urgency and enthusiasm for energy conservation research as well as practice. Witness—at least in the United States—the awakening of the long-hibernated gas-guzzler automobile and the recent run on house-size sport utility vehicles, a.k.a. land barges. The $140 plus barrel of crude oil last year has reignited interest in conservation. But in my opinion, the gas at the pump needs to skyrocket to a painful $10 per gallon to have the required shock value. The cost is close to that much in Europe, and the difference in attitudes between the two continents is apparent.

Conservation or not, talk of energy independence is just that, unless alternative energy sources are developed. The United States simply does not have traditional energy sources in sufficient quantities to become independent. In fact, our energy dependence has increased steadily since the 1973 oil crisis. The nontraditional sources are currently either nonexistent or too expensive to compete even with the $4 per gallon at the pump. But a $10 price tag will do the trick, one day.

4. THE SOLUTION

How do we go from here to there? We need to work on both the supply side and the demand side. On the latter, consumers need to moderate their insatiable appetite for energy. Homes do not have to be as warm in the winter as a crowded bus, or as cold in the summer as a refrigerator. A car with a 300-horsepower engine (equivalent to 300 live horses, really) is not needed to take one person to work via congested city roads. Additionally, new technology can provide even more efficient air, land and sea vehicles than exist today. The art and science of flow control can play a significant role in this noble task [1]. Better-insulated buildings, less wasteful energy conversion, storage and transmission systems, and many other measures save energy; every bit helps.

On the supply side, we need to develop the technology to deliver nontraditional energy sources inexpensively, safely and with minimum impact on the environment. The U.S. and many other countries are already searching for those alternative energy sources. But are we searching with sufficient intensity? Enough urgency? I think not, simply because the problem does not affect, with sufficient pain, this or the next presidential election, but rather the 5^{th} or 10^{th} one down the road. Who is willing to pay more taxes now for something that will benefit the next generation? Witness the unceremonious demise of former President Carter's Energy Security Corporation, which was supposed to kick off with the issuance of $5 billion energy bonds. One way to assuage the energy problem is to increase usage taxes, thus help curb demands, and to use the proceeds to develop new supplies.

Let us briefly appraise the nontraditional sources known or even (sparingly) used today. The listing herein is not exhaustive, and other technologies unforeseen today may be developed in the future. Shale oil comes from sedimentary rock containing dilute amounts of near-solid fossil fuel. The cost, in dollar as well as in energy, of extracting and refining that last drop of oil is currently prohibitive. Moreover, the resulting fuel is not any less polluting than other fossil fuels. There are also the so-called renewable energy sources. Though the term is a misnomer because once energy is used it is gone forever [2], those sources are inexhaustible in the sense that they cannot be used faster than nature makes them. The Sun is the source of all energy on Earth, providing heat, light, photosynthesis, winds, waves, life and its eventual albeit very slow decay into fossil fuel, etc. Renewable energy sources will always be here as long as the Sun stays alight, hopefully for a few more billion years.

Using the Sun radiation, when available, to generate either heat or electricity is limited by the available area, the cost of the heat collector or the photovoltaic cell, and the number of years of operation it takes the particular device to recover the energy used in its manufacturing. The U.S. is blessed with its enormous land, and can in principle generate all of its energy need via solar cells utilizing less than 3% of available land area. Belgium, in contrast, requires an unrealistic 25% of its land area to supply its energy need using the same technology. Solar cells are presently inefficient as well as expensive. They also require about 5 years of constant operation just to recover the energy spent on their manufacturing. Extensive R&D is needed to improve on all those fronts.

Wind energy though not constant is also inexhaustible, but has similar limitations to those of solar cells. Without tax subsidies, generating electricity via windmills currently cannot compete with fossil fuel or even nuclear power generation. Other types of renewable energy sources include hydroelectric power; biomass; geophysical and oceanic thermal energy; and ocean waves and tides. Food-based biomass is a low-carbon fuel when compared to fossil oil. Depending on how they are produced, however, biofuels may or may not offer net reduction of carbon dioxide emissions [5]. Hydrogen provides clean energy, but has to be made using a different source of energy, for example photovoltaic cells. Despite all the hype, the hydrogen economy is not a net energy saver, but has other advantages nevertheless. Even such noble cause as hydrogen-fueled or battery-powered automobiles will reduce pollution and dependence on fossil fuel only if nuclear power or other non-fossil, non-polluting energy sources are used to produce the hydrogen or to generate the electricity needed to charge the batteries.

5. THE INVESTMENT

Are we investing enough to solve the energy crisis? We recite some alarming statistics provided in a recent article by the then chair of the U.S. Senate Energy and Natural Resources Committee, Pete V. Domenici [6]. Federal funding for energy Research and Development has been declining for years, and it is not being made up by increased private-sector R&D expenditure. Over the 25-year period from 1978 to 2004, federal appropriations fell from $6.4 billion to $2.75 billion in constant 2000 dollars, nearly 60% reduction. Private sector investment fell from about $4 billion to $2 billion during the period from 1990 to 2006. Compared to high-technology industries, energy R&D expenditure is the least intensive. For example, the private sector R&D investment is about 12% of sales in the pharmaceuticals industry and 15% in the airline industry, while the combined federal and private-sector energy R&D expenditure is less than 1% of total energy sales.

6. WHAT IS NEEDED

What is now needed is a visionary leader that will inspire the nation to accept the pain necessary to solve its energy problems and in the process help the world slow down global warming. The goal is to reduce significantly the country's dependence on foreign and domestic fossil fuel, replenishing the deficit with renewable, non-polluting sources of energy. The scale of the challenge is likely to be substantially larger than that of the 1940s Manhattan Project or the 1960s Apollo program. In his 'malaise' speech of July 15, 1979, Jimmy Carter lamented, "Why have we not been able to get together as a nation to resolve our serious energy problem?" Why not indeed Mr. President.

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