A bird? A plane?

It's all evolution

The paper, "The evolution of airplanes," created a media stir earlier this year when it was published online by the Journal of Applied Physics. The authors contend that the similarities seen across aircraft designs are a manifestation of the same law that drives the evolution of biological creatures and terrain features like river basins. Lead author Adrian Bejan of Duke University describes the methodology behind the paper and the predictive value of the constructal law, the theory he developed 19 years ago to explain the "oneness" he sees in the evolution of living and non-living systems.

VIEWPOINT
BY ADRIAN BEJAN

What is evolution and why does it exist in the biological, geophysical and technological realms — in short, everywhere? Why is there a time direction — a time arrow — in the changes we know are happening every moment and everywhere?

I have been theorizing about these questions for two decades as an offshoot of my specialty in thermodynamics. Most recently, I and two colleagues — Boeing engineer Jordan Charles and civil engineer Sylvie Lorente of the Université de Toulouse — collected dimension and performance data on 100 different models of airplanes. When we plotted the data, we observed common relationships just as we predicted would be the case under the constructal law, a law of physics I conceived in 1995 to account for design evolution in biology, geophysics and technology. No matter the model of the plane, engine mass should be proportional to body mass, for example, and the data in "The evolution of airplanes" reflect this.

The value of the constructal law is this predictive capability. This was not an empirical data-mining experiment. We expected the data to line up as it did. Aircraft are flow systems: Mass is carried over the Earth within them; air rushes around them and currents course through them in the form of electricity to drive motors that move flight control surfaces. Fuel and air combine to produce combustion gases that turn turbines or drive pistons. A


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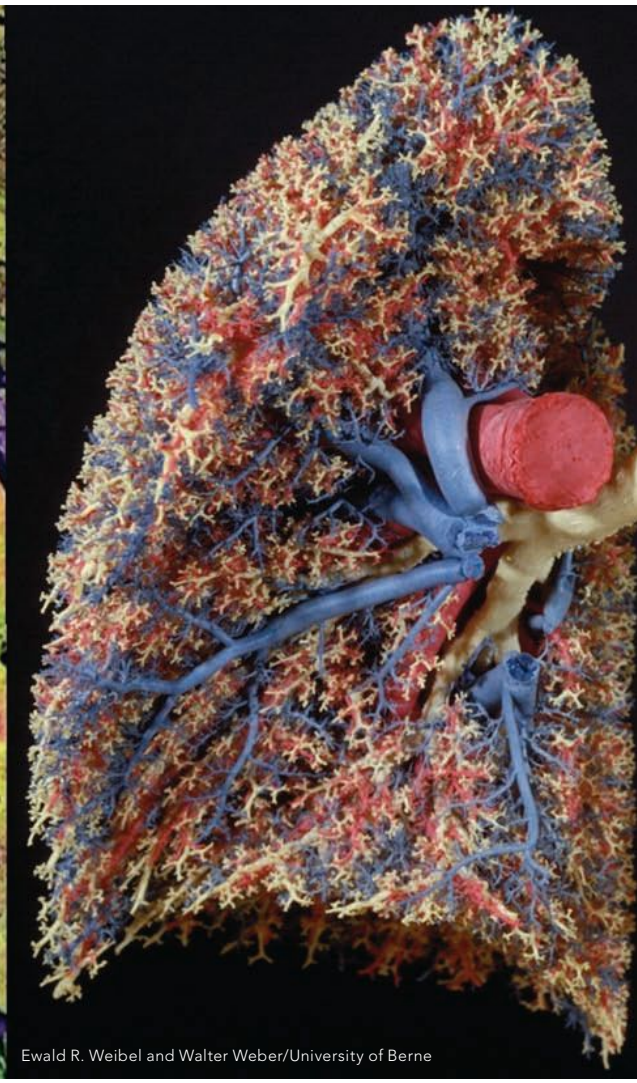
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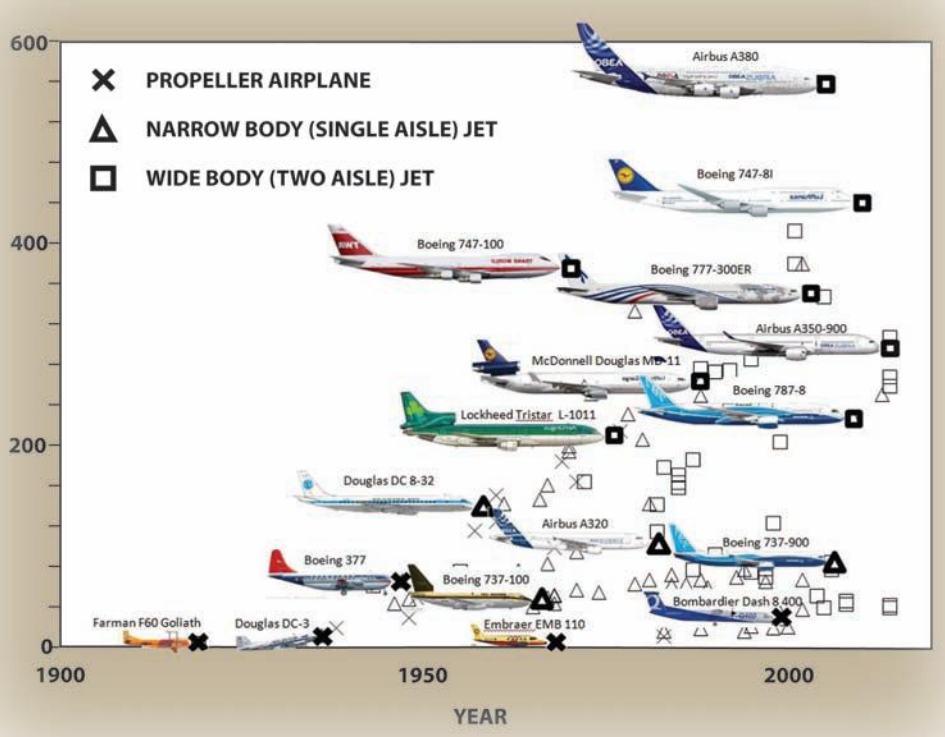
Coincidence or a law of physics?
Siberia's Lena River delta, left, shown in a Landsat 7 image, suggests design similarities to a plastic model of a human lung.

river is a flow system, too, consisting of water and sediments that can, over time, produce a delta whose branches deliver water, nutrients and life to the sea. Our lungs are a flow system of chemical energy exchange between air and blood. The visible design similarities among flow systems are not a product of chance. They arise from distinct mechanisms, including genetic mutations, geophysical interactions and technological experimentation by humans. But the solutions exhibit a design oneness toward improving the flow of currents within these systems.

Consider the wording of the constructal law:

For a finite-size flow system to persist in time (to live), its configuration must evolve (freely) in such a way that it provides easier access to the currents that flow through it.

Without power, nothing moves. There is a unifying tendency across all domains to produce and use power more efficiently, to overcome friction and other forms of resistance. My experience as an engineer in the thermodynamics discipline helped me recognize this unifying fact in 1995 during a flight back from Europe. With the constructal law, researchers worldwide are now showing that evolutionary flow architectures are present and predictable throughout nature, whether animate, inanimate or human-made. Constructal Law Conferences have been organized every two years. The 2011 event was held in Brazil; the 2013 conference was in China; and the ninth Constructal Law Conference is scheduled to be held in Parma, Italy, in May. We can see the constructal law in snowflakes, Earth's climate, lungs, body insulation, breathing rhythm, city traffic, the shape of the pyramids and many more.



Airliner evolution
New airliners come in a variety of sizes, but "the biggest airplanes of one decade are joined by even bigger models in the next decade," according to the paper, "The evolution of airplanes."

A better airliner

The pace of technology allows us to witness our own evolution in our lifetimes in the following sense: We are attached to and empowered by our contrivances, including historical artifacts, new machines, and our social organizations and the rule of law. We are what I call the *human & machine species*, and we are evolving with each improvement to aircraft and other machines. In the biological realm, evolution occurs on a timescale immensely longer than our lifetimes. We, the observers, are latecomers to the movie of animal evolution, and we are challenged to imagine the plot. But in the "The evolution of airplanes" we take a bird's-eye view of evolution, and we see that the dimensions and performance of aircraft dating back to the Farman F.60 Goliath of 1919 are as predicted by the constructal law. There is a unity with the animal and geophysical worlds:

- Speeds should be proportional to body mass raised to the fractional exponent 1/6, and this is just like the speeds of all animals (fliers, runners, swimmers).
- Engine mass should be proportional to body mass, just like the proportionality between muscle mass and body mass in all animals, and between motor mass and body mass in road vehicles.
- Fuel load should be proportional to body mass and engine mass, just like the proportionality between food intake and animal body mass.
- Distance traveled (the range) should be proportional to body mass, just as with animals, rivers, atmospheric currents and rolling stones. The bigger travel farther and live or last longer.
- The fuselage length and the wing span should be almost equal, which is also exhibited by flying animals.
- There should be a geometric similarity between the fuselage profile and the wing profile. Both profiles should fit in slender rectangles with the aspect ratio 10:1.

Organ size

Key is the question of why an organ (engine, fuel or wing, for example) should have a characteristic size. The answer, it turns out, is at the heart of why humans are attracted to technology, and why they have the instinct to change it, to improve it, which means to evolve it.

Think of an aircraft or ground vehicle

that consumes fuel and moves across the world map, and ask how large one of the organs of this vehicle should be, for example, the engine, or a duct with fluid flowing through it, or the heat exchanger surface of the environmental control system. Because the size of the organ is finite, the vehicle is penalized in fuel terms by the component in two ways:

First, the organ is alive with currents that flow by overcoming resistances of many kinds. In thermodynamics, this universal phenomenon is called irreversibility, entropy generation or destruction of useful energy (exergy). This fuel penalty is smaller when the organ is larger, because larger means wider ducts and larger heat transfer surfaces. In this limit, larger is better.

Second, the vehicle must burn fuel and destroy more exergy in order to transport the organ. The fuel penalty for carrying the organ is proportional to the weight of the organ. This second penalty suggests that smaller is better, and it comes in conflict with the first penalty. From this conflict emerges the purely theoretical discovery that the organ should have a characteristic size that is finite, not too large, not too small, but just right for that particular vehicle. The organ size recommended by this trade-off is such that large organs (engines, fuel loads) belong on proportionally large vehicles and small organs belong on small vehicles.

The need to move

Air and land vehicle evolution is about the evolving design of human movement from one place to the next. People, goods, materials, construction and mining equipment must all be moved. As the whole vehicle or animal evolves toward becoming better at moving mass on or over the landscape, the organs remain imperfect, because each organ has a finite size. The whole vehicle or animal is a construct of organs that are imperfect only when examined in isolation. The vehicle design evolves over time and becomes a more efficient construct for moving the vehicle mass on the world map.

The history of commercial air travel confirms this trend. Over the last half century, aircraft have become an order of magnitude more efficient measured by the liters of fuel required to carry one person 100 kilometers. There has been a 1.2 percent annual decrease in fuel burn per seat on average. Commercial airplanes satisfy an insatiable need of the human & machine species to move as many people as possible a specified distance while using as little fuel as possible.

The arrow of time

New technologies emerge so that they offer greater access to what flows — greater access to the available space, areas and volumes, and persistence in time. As a special class of evolving designs, humanity today is kept moving sustainably by the power and movement produced in our contrivances: engines and vehicles. The designs morph with us.

Design change keeps spreading across the human landscape in the form of better science, cognition, knowledge, security, technology, health care and much more. Knowledge means flow-design change that is useful and the ability to make the change happen. Knowledge spreads through a territory naturally. The boundary between those who know more and those who know less is shifting in the direction of more knowledge. Knowledge (the ability to make useful design changes) is penetrating the low, because knowledgeable people are more mobile than the low. Technology evolution is about us, about the evolutionary design of all the flows and movements that facilitate human flow, which means life on the Earth's surface (people, goods, etc.). The evolution of airplanes illustrates this convincingly. What works is kept. Flow architectures that offer greater access persist and are joined by even better ones. Together, the vascular tapestry of old and new carries the human flow easier and farther than the old alone. Air mass transport by new and old airplane models mixes the global sphere more effectively than would be the case in the absence of new models.

Flow architectures are evolving right now, throughout nature and in our technologies. The legacy of all animate and inanimate flow systems is this: They have moved mass — they have mixed the Earth's crust — to a greater degree because of design evolution.

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