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The Amazing Bird Design – Heart-Lung System, the Information of Navigation, and Flight Stability

by Michael S. Shelton

In his excellent textbook "*Flight Stability and Automatic Control*" {McGraw-Hill, 1989}, Dr. Robert Nelson states,

> "The goal of this book is to present an integrated treatment of the basic elements of aircraft stability, flight control, and autopilot design. An understanding of flight stability and control played an important role in the ultimate success of the earliest aircraft designs."

I used this text in my graduate studies at the Naval Postgraduate School in Monterey, CA, where I earned my MS in Aeronautical Engineering (Avionics). My defended thesis included the completion and flight of a 1/7th-scale F/A-18 Hornet ducted-fan remote-controlled (RC) model kit, designed by Yellow Aircraft, an RC kit company formerly of Puyallup, WA, and now located in Massachusetts (http://www.yellowaircraft.com). This Hornet model was intended to be a multi-student project to investigate very high angle-of-attack (AOA) flight research using non-conventional yaw control methods. Similar research was later conducted with a full-scale NASA F/A-18.

The biggest lesson I learned from the research was the substantial time investment needed to ensure that a new or modified aircraft design will be not only be stable both in static and dynamic environments, but will have desirable handling characteristics for a pilot to both effectively and safely fly it. There's little value of an aircraft having amazing performance, such as superior thrust-to-weight ratios or turning maneuverability, if it requires excessive workload or it scares the daylights out of the operator!

Included in my thesis work was the implementation of scaling factors and a suite of mathematical equations / algorithms, special functions, equations of motion, and various verification / validation approaches. These were to ensure that the model's mass, static and dynamic calculations, and its stability derivatives, could be accurately correlated to those same attributes of the real full-scale Hornet. The final results showed the methodologies and calculations to be close. We were confident that further flight testing would yield useful data that would correlate to nonconventional yaw control research of the real airplane.

We have the early pioneers in flight to thank for these elegant solutions and methodologies to evaluate the performance of aircraft designs – such names as Otto Lilienthal, the Wright brothers, Henri Coanda (discovered the air flow phenomenon that was named for him – beyond the scope of this discussion), Anthony Fokker (remember the Red Baron's airplane?), Bellanca, Langley, and many others.

Specialization

The above technical summary is used merely to demonstrate to the reader that birds already possess the flight stability attributes that allows each species to operate in its design specialty. I say "design" because there are many species and sub-species of birds, and each one has specialized skills in its particular environment of the wonder of life. We see birds that specialize in soaring, such as eagles, hawks, vultures, and condors. We see birds with short-range extreme maneuverability such as hummingbirds and sparrows. We see birds with keen eyesight needed to spot its prey and close in for the capture and kill. Some of these are done at night, where low-light eyesight attributes are required. A bird-killing raptor is the Peregrine Falcon, also known as Hayabusa in Japan, which swoops from above on its unsuspecting feathered victim, such as rock pigeons, ducks, hummingbirds, and the like. It is the fastest known animal on the planet, routinely diving at 200+ mph and one has supposedly been clocked at 242 mph.

Each species of bird requires a total System of Systems (SoS), intimately integrated and orchestrated, to enable it to function as designed. Some birds eat only insects and below-ground creatures (the early bird gets the worm, but the second mouse gets the cheese). Some birds are restricted only to plant foods. Some birds subsist primarily on dead / decayed animals, and some birds require the capture and kill of live prey. Each of these diet requirements require specialized flight requirement attributes.

Commonalities

But there are common traits among birds – such as light, yet strong, skeletal frames. Good eyesight to allow for spatial orientation and the approach to landing, or to evade danger. Wing-flapping that still results in a stable platform to climb in altitude, maintain an approach path or glideslope, to maneuver in dynamic situations such as windy conditions or maintain formation in large groups or another single bird. Flight machines also need efficient power and energy mechanisms to minimize weight. The lighter the overall structural and propulsive weight, the more payload and / or better flight performance. This is particularly key for long-range flight, such as the Golden Plover and other migratory birds, or for snatching a massive prey out of the water or off the ground, such as the requirements for eagles, hawks, and owls.

One of the most unique but common amongst bird's traits is the heart-lung system. Unique, because the avian cardio-lung system is drastically different than that of mammals, including the only known flying mammal, the bat species. Before I cover this, I need to discuss information theory.

Information Is Key

Creationist Dr. Werner Gitt authored a book by the title "*In The Beginning Was Information*." Dr. Gitt makes the compelling case that everything that shows design, that involves a plan or code, requires information. Referring to his book and a 2005 presentation at the Creation SuperConference at Liberty University, I can summarize some information characteristics.

"A definition in science must be precise and very clear. It must have sharp, distinct borders that include only the subjects of the definition and exclude everything else." (Gitt, 2005) According to Gitt, Information must comprise:

Apobetics: Purpose, result

Pragmatics: Action

Semantics: Meaning

Syntax: Sets of Symbols, Grammar

Statistics: Signal, Number of Symbols

Only if we find all five levels of information then it is information. (Gitt, 2005)

Four possible definition *domains* for information:

A: Coded Systems With Semantics (systems with statistics, syntax, semantics, pragmatics, apobetics)

B: Artificial Systems (systems with apobetics only)

C: Coded Systems without Semantics (systems with statistics and syntax but without semantics, pragmatics, apobetics)

D: Arbitrary Structures without Code (systems with apobetics only)

Information is information, neither matter nor energy. Why is information a non-material entity?

- Information is an idea
- Information has no mass
- Information is not a property of matter
- Information is not correlated to matter

Why are energy, impulse, viscosity, electricity . . . . material entities?

- they aren't ideas
- they are properties of matter
- they are correlated with matter

Ten Laws of Nature about Information (Gitt, 2005):

1. Anything *material,* such as physical/chemical processes, cannot create something *non-material*
2. Information is a *non-material* fundamental entity and not a property of matter
3. Information requires a material medium for storage and transmission
4. Information cannot originate in statistical processes
5. There can be *no* information without a code
6. All codes result from an intentional choice and agreement between sender and recipient
7. The determination of meaning for and from a set of symbols is a mental process that requires intelligence
8. There can be no *new* information without an intelligent, purposeful sender
9. Any given chain of information can be traced back to an intelligent source
10. Information comprises the nonmaterial foundation for all:
    - technological systems
    - works of art
    - biological systems

An Information Example – Bird Navigation

The Golden Plover – These birds forage for food on tundra, fields, beaches and tidal flats, usually by sight. They eat insects and crustaceans, also berries. The breeding habitat of the American Golden Plover is Arctic tundra from northern Canada and Alaska. They nest on the ground in a dry open area. They are migratory, with three major groups. One large group migrates to and from wintering grounds in southern South America. Much of the southbound route is over the Atlantic off the east coast of North America. Another large and different family actually migrates across the northern Pacific to Hawaii, over open water the entire time without stopping. In the Fall, the American migratory group takes an easterly route, flying mostly over the western Atlantic and Caribbean Sea to the wintering grounds in Patagonia. The bird has one of the longest known migratory routes of over 25,000 miles. Of this, 2,400 miles is open ocean where it cannot stop to feed or drink. It does this from body fat stores that it stocks up on prior to the flight. Another, smaller group, is a regular vagrant to western Europe. (*Wikipedia and Gitt*)

The Hawaiian group makes a 2,800-mile one-way nonstop migration between Hawaii and Alaska, and back again. They make the flight in about three and a-half days (about 80 hours), averaging about 35 miles per hour. When the three-month old golden plovers make their first migration to Hawaii, they do so with no adult leaders! These birds have inherited the amazing instinct to find their wintering grounds, across thousands of miles of ocean.

At launch, the typical Golden Plover weighs at least 200 grams (just shy of a half-pound). The migration to Hawaii consumes about 65-70 grams. Much more, and the bird runs out of fat reserves and will tire and have to land in the ocean – with nothing to eat. The ocean surface is not its feeding habitat. Somehow, the Golden Plover is able to consistently find Hawaii for the winter, then fly back to Alaska, and is able to find Hawaii even on its first trip. No maps (maps would be no good – they would all show blue!), no GPS, no fancy ring-laser gyro inertial navigation reference system.

Where did this come from? Pure evolution? I don't think so. The birds' DNA is pre-programmed from heredity with the navigational codes to make the migration. This is information. Like embedded firmware or flash BIOS computer instructions, the Golden Plover's brain has the timers and routes already coded with the information necessary to make these herculean trips.

The Bird Heart-Lung Layout

In mammals, the air is breathed in because of diaphragm bellows actions. The fresh air comes in, and air molecule transfer across the lung-blood capillaries boundary occurs. Excess carbon dioxide and other waste gases are transferred from the blood and into the tiny air sacs of the lung. Oppositely, oxygen molecules, along with nitrogen and the other tiny gas percentages in the fresh air, are transferred across the interface into the blood capillaries and then pumped throughout the body to service the body's cells. Mammal's lungs are relatively fragile and quite pliable. Additionally, the waste air is never 100% exhausted from the lungs. Each new fresh breath of air mixes with some of the leftover stale air of the previous breathing cycle.

Not so the bird lung system – the actual lungs are much more rigid. The bird's blood flow through the lung's capillaries is opposite of the one-way (unidirectional) air flow. Via a unique set of air sacs, hollow bones, and check valves, the bird's breathing cycle consists of a double inhalation and double exhalation. The bird's trachea and mouth have the same in and out pattern as mammals, but the internal ducting and valve system results in air flow ONLY one way through the lungs. Although the bird's lungs are relatively much stiffer than those of a mammal, the blood / air exchange boundary interface is thinner, which promotes a faster exchange rate.

With the blood flow opposite that of the air flow, the entry into the lungs of the blood provides the freshest air immediately, with the quickest possible oxygen and carbon dioxide exchange rate. As the blood flow continues toward the front of the bird's lungs, it continues to encounter fresh air that has never mixed with stale exhalation gases. This maximizes the oxygenation of the blood.

Because flying machines need an efficient power system and energy source, balanced with a light-weight design, the avian cardio-lung design provides, in a relatively short exchange path, the most efficient gases transfer. This allows a steady supply of richly-oxygenated blood to service the many cells of the bird in flight, particularly the flapping muscles.

This particular system, so extraordinarily different than that of mammals, defies the evolutionary just-so stories that slight variations and mutations were responsible to morph the heart-lung design from dinosaurs to the supposedly-evolved bird. Not only this, but the adaptation of feathers and control systems defy mutative design processes. Three-dimensional non-buoyant operation through the atmosphere requires a specialized body plan, propulsion techniques, and stability and control. Unlike a helium or hot air balloon that floats in the gaseous atmosphere and does not necessarily require specialized control or maneuvering equipment, all heavier-than-air flight machines (birds included) require some locomotive / propulsive device to drive airflow across lifting devices (wings, rotor blades, etc.), and to control maneuvering and direction while in flight, including safe landings when the need for flight has ended. It is extremely improbable that birds evolved from a previous non-flight capable animal with all the above attributes required to operate in three-dimensions as opposed to only two-dimensional ground operation.

More Information – Colors

Some birds have ordinary, even bland colors. Other birds have bright flamboyant colors that are often important in attracting a mate or to use as camouflage. The color of the beak, the legs, the plume, the tail, the breast and neck and wings, are all coded by information in the DNA genome of the bird

And More Information – Flight Stability and Control

As I conclude this article, I will purposely avoid going too deep in the technical aspects of stability and control. I will cover the basics, and leave the reader with some additional references that one can pursue.

As was shown earlier with the long-range navigation capabilities of birds, information is needed to employ such extraordinary navigation over long distances, open water, with no landing for food. All aspects of flight require the applicable information to acquire a target, fly to it, execute a capture or landing or avoidance of danger, to land, to rendezvous with like-minded creatures, to gather food, and so forth. Some birds are extremely agile and can turn on a dime. Hummingbirds can hover like a helicopter, with similar maneuvering aspects of backward and sideways flight. Small birds can make extreme turns so quickly that they're difficult to follow. Other birds like high-flying hawks and vultures can use thermals and upslope winds to glide and soar for hours while looking for food. All these aspects require stability and control.

Static Stability – this is a trait or measure of how an object, if disturbed, wants to return to its previously undisturbed condition. Positive static stability means that the vehicle tends to return back to its original condition, like a weather vane or arrow wants to align with the wind. Negative stability means that the vehicle tends to diverge to a more disturbed condition, and implies that if left unchecked, the vehicle will depart controlled flight and become dangerously out of control and will crash if not addressed. Neutral stability means that, within limits, the vehicle will remain at the new perturbed condition.

Pulling a rope results in a natural trailing motion and the rope is considered statically stable. Same for hanging a rod from a string. However, pushing a rope or balancing a rod or ruler on the tip of a finger is negative static stability. A small disturbance only wants to get worse.

Dynamic stability – positive, neutral, and negative dynamic stability have similar meanings as static stability, but now in a dynamic motion sense. Positive dynamic stability means that the motions are damped and tend to return to stable non-disturbed motion. Negative dynamic stability means that once disturbed, the vehicle or body tends to return to the previous condition but overshoots worse in the other direction. It again comes back but even worse and more displaced, and so on and so on till it diverges so badly that the vehicle loses control.

Examples: Positive dynamic stability is like good shocks on a car. Go through a series of bumps or "whoop-de-dos" and the suspension is damped sufficiently that the vehicle remains under control and keeps the ride manageable. Negative dynamic stability is like the old '72 Buick bouncing down the road with worn shocks, with the car doing excessive boing-boing-boing motions as it hits every bump or pothole. If this occurs excessively in a corner, the car is a handful for the driver and loss of control and departing the road is a possibility.

Some airplanes are designed for a great ride and strong static and dynamic stability. An airliner or smaller general aviation passenger aircraft are good examples. The passengers want a smooth ride with assurance that the airplane won't be easily upset and lose control.

The opposite would be aircraft that require good maneuverability and agile flight conditions. Sport aerobatic aircraft and military fighters fit this design need. The pilot needs an airplane that he can throw around and put it where it needs to be, such as behind another airplane to shoot it down, or to make last-second fine correctives to win a competition. The pilot can often fly right on the edge of the loss-of-control envelope.

Birds are no different. I mentioned at the beginning that I had learned of the "substantial time investment needed to ensure that a new or modified aircraft design will be not only be stable both in static and dynamic environments, but will have desirable handling characteristics for a pilot to both effectively and safely fly it." The flight performance and design engineers do this through investigative and painstaking development of stability derivatives.

> **Stability Derivatives**, and also **Control Derivatives**, are measures of how particular forces and moments on an aircraft change as other parameters related to stability change (parameters such as airspeed, altitude, angle of attack, etc.). For a defined "trim" flight condition, changes and oscillations occur in these parameters. Equations of motion are used to analyze these changes and oscillations. Stability and control derivatives are used to linearize (simplify) these equations of motion so the stability of the vehicle can be more readily analyzed.
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> Stability and control derivatives change as flight conditions change. The collection of stability and control derivatives as they change over a range of flight conditions is called an Aero Model. Aero models are used in engineering flight simulators to analyze stability, and in real-time flight simulators for training and entertainment.
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> **Stability derivatives and Control derivatives** are related because they both are measures of forces and moments on a vehicle as other parameters change. Often the words are used together and abbreviated in the term "S&C derivatives." They differ in that stability derivatives measure the effects of changes in flight conditions while control derivatives measure effects of changes in the control surface positions:
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> - A **stability derivative** measures how much change occurs in a force or moment acting on the vehicle when there is a small change in a flight condition parameter such as angle of attack, airspeed, altitude, etc. (Such parameters are called "states.")

- A **control derivative** measures how much change occurs in a force or moment acting on the vehicle when there is a small change in the deflection of a control surface such as the ailerons, elevator, and rudder.

There are three methods to find the stability derivatives. The first one is of course by performing flight tests or wind tunnel tests. But these tests are quite expensive. A second method is using computational fluid dynamics (CDF). This is usually less expensive, but it still requires considerable production. Finally, simple analytic expressions can be used. They are usually not very accurate (especially not for strange aircraft configurations). However, they don't require as much work.

(source: "*Longitudinal stability derivatives*," courtesy of the Aerostudents website (http://www.aerostudents.com) at **TU Delft** near Rotterdam, Netherlands, with its text resources for Stability and Control. (http://www.aerostudents.com/thirdyear/flightDynamics.php)

There is much more to all this – the airplane must be evaluated on all three axes of pitch, roll, and yaw. But the deeper technical aspects are outside the scope of this article. The bottom line is that when a design team is going to build the next jumbo jetliner or the next world-class top-line fighter jet, that team will devote thousands upon thousands of manhours to determine initial operational parameters, then devote even more time to computer fine-tuning of the design, followed by thousands of hours of wind tunnel model testing and developmental flight testing. The man-machine and human systems / computer systems interfaces must be exhaustively tested. Finally, the world sees the manufacturer deploy the F-22 or the new F/A-18 or the new F-35 Joint Strike Fighter or the new Airbus A380 or the new Boeing 787 or the new King Air 300 variant.

Yet birds are born with such information and stability derivatives already built in. Some birds are destined to remain local in summer and winter. Some birds nest on the ground, others in cliffs, others in trees. Some birds will display majestic grace as they soar, others will show incredible speed and maneuverability as they swoop to pick up the fish or the small ground squirrel. Others will be life-long migratory creatures, picking up many frequent-flyer miles as they go back and forth between the northern and southern hemispheres.

This cannot be the result of evolution, of mindless, purposeless, time-plus-chance-plus-opportunity-plus-mutative forces. Birds are just one aspect of biological life forms that are "wonderfully and fearfully made" as King David the Psalmist described humans in Psalm 139.

Birds are the result of design by the Intelligent Designer Who also made the stars, Who made the solar system, and Who has compassion and zeal and a love for His creatures, particularly Man.

For further reference:

1. *Flight Stability and Automatic Control*" by Robert C. Nelson {hardcover, 150 pages, McGraw-Hill, 1989}
2. Delft University of Technology (Dutch: *Technische Universiteit Delft*), Delft, the Netherlands, text resource for Stability and Control (http://www.aerostudents.com/thirdyear/flightDynamics.php)