“INTELLIGENT” TEST AIRCRAFT THAT LEARNS BY DOING

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About five years ago National Aeronautics and Space Administration (NASA) in cooperation with United Stated Air Force (USAF) unveiled a new kind of test aircraft that is able to control itself while flying in the air. This jet-powered aircraft is equipped with flight control technologies that demonstrate a computerized flight control system that learns as it flies – especially important for the demands of ultra high-speed flight.

The test aircraft named Low-Observable Flight Test Experiment (LoFLYTE) is designed to demonstrate the use of neural network technique which is implemented into the aircraft control system to learn by mimicking the pilot. The neural network is used on the “worst-case scenario” situation that possibly happens when handling the aircraft. The scenario means that the neural network can help pilots of future aircraft to fly in quick-decision situation and help damaged aircraft land safely even when aircraft controls such as aileron, elevator or rudder is partially damaged.

Three main institutions, while not neglecting commercial sources, were involved in this precious work. They are NASA Langley Research Center (LaRC) of Hampton, Virginia led by James L. Hunt; Air Force Wright Laboratory in Dayton, Ohio led by DR. Kervyn Mach and Accurate Automation Corp. of Chattanooga, Tennessee led by Bob Pap that work under the Small Business Innovation Research (SBIR) program. The test flight was done at Edwards Air Force Base, California under the direction of the 445th Flight Test Squadron with the support of NASA Dryden Flight Research Center. The 8-foot-4 inch jet-powered LoFLYTE Remotely-Piloted Vehicle (RPV) was developed by Accurate Automation Corporation.

“Waverider” Aircraft

Besides designed to provide a technology test-bed for the emerging aerospace technology emphasizing on the advantage of using the neural network technology as the aircraft control system, the LoFLYTE prototype was also designed to demonstrate the subsonic airworthiness of the “waverider” shape aircraft. The term "waverider" refers to the fact that aircraft of this type ride on the shock waves that they create as they fly above the speed of sound. The “waverider” shape improves fuel consumption by decreasing air resistance at speeds greater than mach one. Other supersonic and hypersonic aircraft suffer reduced performance because they fight against the shock waves rather than riding them. This “waverider” configuration was also chosen because it allows for long hypersonic cruise ranges to 8,000 miles. At an altitude of 90,000 feet the Mach 5 “waverider” would be able to fly at a rate of one mile per second.

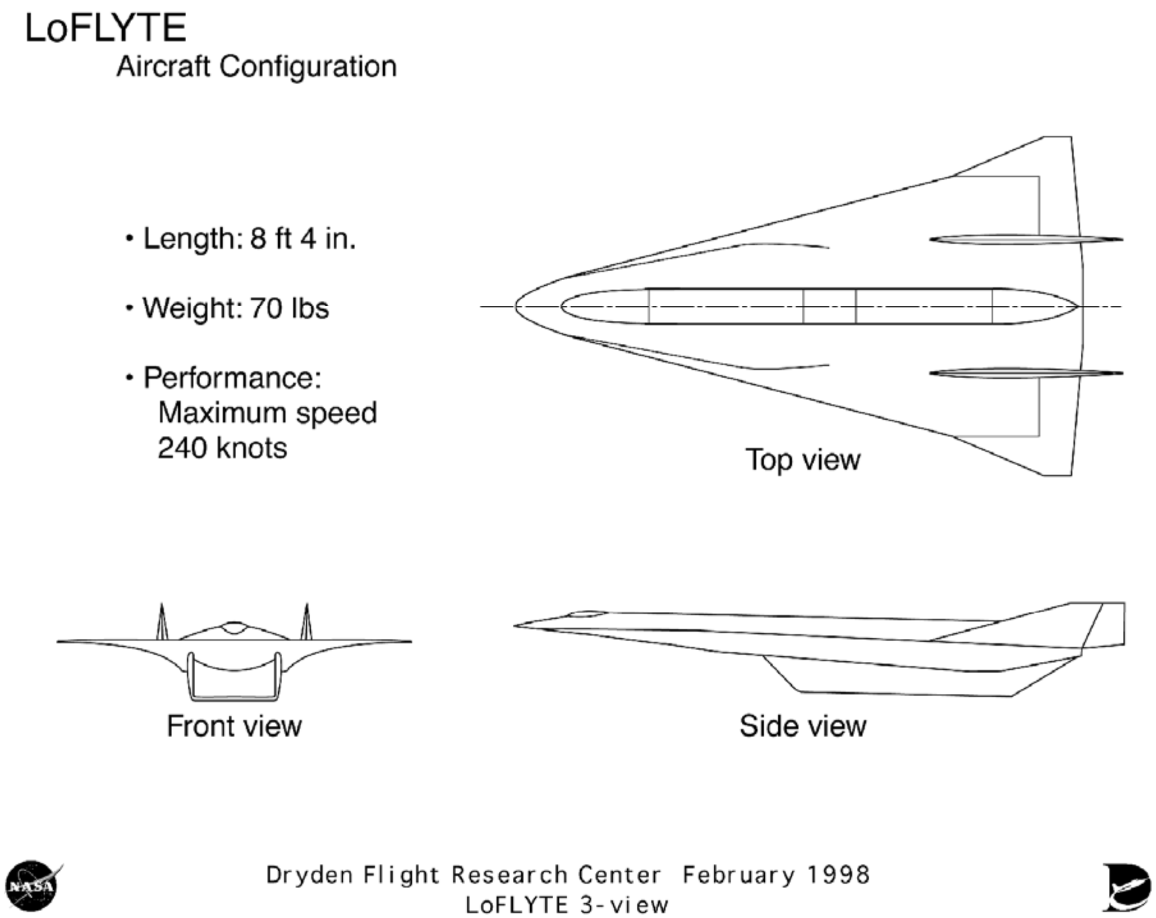

Figure 1. The “waverider” shape LoFLYTE configuration.

The initial configuration for the aircraft was developed at NASA Langley Research Center and then Accurate Automation Corporation integrated the neural network technology into it. The construction of the aircraft was completed at SWB Turbines of Appleton, Wisconsin. This company provided the small hypersonic air breathing turbine engine that powers the aircraft. The aircraft's shell was made at Mississippi State's Raspet Flight Research Laboratory and then shipped to SWB Turbines so that the radio control gear and the engine could be installed.

Figure 2. LoFLYTE.

The "waverider" shape is based upon a high lift/drag Mach 5 and a futuristic hypersonic aircraft configuration that could cruise on top of its own shockwave if powered to hypersonic speeds. It takes advantage of engine/body integration and was derived from a Mach 5 conical flowfield – the cone-shaped shockwave generated by a supersonic or hypersonic vehicle. This 72-pound "waverider" aircraft, powered by a 38-pound air breathing hypersonic engine built by SWB Turbines, would fly at speed above Mach 4. Mach 4 is much faster than any aircraft with air breathing engines has ever flown. The famous SR-71 "Blackbird" has a top speed that is only slightly over Mach three. LoFLYTE represents the first known flying "waverider" air breathing vehicle configuration in the world.

Figure 3. LoFLYTE banks after take-off.

Figure 4. LoFLYTE flies during Landing Approach.

The LoFLYTE first flight test was carried out on 6th December 1996 at Mojave Airport. After completing design, airworthiness and flight safety reviews required by NASA and U.S. Air Force, it was flown again at Edwards AFB, California and accomplished successfully. Flight testing using neural network controls was begun in late 1997. This flight test could not be successful without the help from NASA Langley Research Center that did a wind tunnel test to the LoFLYTE article as many as 191 runs in both the 12-foot Low Speed Tunnel and 30 x 60 foot wind tunnels. In addition, the Naval Postgraduate School in Monterey, California also did water tunnel flow visualization tests on a 72-inch long drop model. During the week of 23rd June 1997, LoFLYTE had made three successful flights at Edwards AFB under the direction of the U.S. Air Force 445th Flight Test Squadron.

Figure 5. LoFLYTE's Wind Tunnel Test.

Figure 6. A front view from a camera installed on LoFLYTE.

Figure 7. The LoFLYTE Mobile Ground Control Station.

Neural Network Flight Control

The LoFLYTE Neural Network Flight Control System is an important advance in aerospace technology because of the adaptive nature of the control system. Neural network is a computer system that learns by doing. The computer network consists of many interconnected control systems or nodes, similar to neurons in the brain. Each node assigns a value to the input from each of its counterparts then as these values are changed, the network can adjust the way it responds. Based on the neural network controller nature, the control system, not the pilot, determines the most effective commands to give the aircraft for a particular situation.

The neural network control system, also designed and manufactured by Accurate Automation Corporation, is based on the company's successful Neural Network Processor (NNP®), also funded under the SBIR program. The NNP® is a multiple instruction/multiple data (MIMD) system that can be used in personal computers as well as aircraft. With this advantage, the neural network controller will be able to continually alter the aircraft's control laws in order to optimize flight performance and take the pilot's response into consideration. Over the time, the neural network controller can be trained to control the aircraft. It will learn to get the most optimized result from every situation it gets – can be said as learn from experience. So in the future, it can apply the most precise control action when a certain situation occurs during the flight.

Figure 8. Neural Network Processor (NNP®).

During normal flight, the neural network controller will use the data it receives from the telemetry system to compute the most efficient flight characteristics and adjust the control surfaces accordingly. However, where the neural network control system has an enormous advantage over traditional control systems is during a “worst-case scenario” situation such as abnormal or unexpected flight conditions. For example, if the control system determines that the rudder is not responding, it will adjust quickly to control the aircraft using the remaining flight surfaces. Neural network control system is necessary in hypersonic vehicles where the center of gravity of the vehicle can change significantly throughout the flight. The neural network can adjust to changing flight conditions faster than a human pilot, greatly enhancing the safety of the aircraft.

Figure 9. LoFLYTE is flying at Mach speed (Artist’s rendition).

The speed of neural network controller’s data processing becomes much better because the communications inside LoFLYTE is done by fiber optic “Fly-by Light”. The use of fiber optic offers lighter weight, increased transmission capability and safety from electrical short circuits and also Electromagnetic Interference (EMI). The telemetry captures the data from the instrumentation in real-time and displays it for operational decisions – used to train the neural network controller – during the flight and transmission to a remote site. The remote site is a Mobile Ground Control Station (MGCS) that provides the flight test team with all of the facilities needed to conduct flight testing, including all aircraft maintenance and safety equipment, computers for telemetry and data recording, and a weather station.

Here is the list some of the technologies that were tested with the LoFLYTE aircraft:

- Rapid Aircraft Prototyping and Design Concepts.
- Aircraft Instrumentation.
- Fault Diagnosis and Isolation Techniques.
- Real-time Airborne Data Acquisition, Control System and Video.
- Miniature Spread Spectrum Telemetry.
- Antenna Placement.
- EMI Minimization.
- Tiperons.
- Neural Network Flight Controls.
- Interface for the Neurocontrol with Flight and Propulsion Control.
- Neural Air Data Subsystem for Determining Angle of Attack, Sideslip, and Velocity.
- Advanced Nozzle Concepts.
- Various TitaniumAlloy Parts with Subsequent Non-destructive Evaluation.
- Adaptive Compensation for "Pilot-induced Oscillations".
- Trajectory Control.
- Advanced Landing Concepts.

"Pilot-induced Oscillations" is a condition of aircraft uncontrollability caused when pilot’s intent and the control system get out of sequence, forcing the plane to swing back and forth, often with disastrous results.

The Future

The NASA’s LoFLYTE program has proven two things. First, it shows that the “waverider” shape was successfully applied to an aircraft model and the model could demonstrate what an aircraft normally does from take-off, flying in the air and return to the land. There were no difficulties for LoFLYTE to do those tasks. Second, application the neural network technology as “intelligent” aircraft control system is feasible for this kind of aircraft configuration and the neural network controller had shown its capability to control the aircraft.

The longer version of LoFLYTE, 100-inch long, had also been tested successfully at Edwards AFB. Following this success, the larger transonic version was planned to be developed to explore supersonic flight characteristics of the "waverider" shape. This larger version will include a unique hypersonic flow path configuration. An advanced engine controller was also developed for ramjets under NASA Lewis Research Center SBIR program and would be tested on the LoFLYTE aircraft.

Even though this aircraft model was designed for a Mach 5 conical flowfield, the LoFLYTE, at that time, was not actually capable of flying at hypersonic speeds. It has instead been tested for basic handling characteristics at low-speeds such as take-off and landing. But with this successful result, the team sees a big advantage to using this type of control system in a hypersonic aircraft because at that high speeds things happen so quickly that the pilot cannot control the aircraft as easily as at subsonic speeds. Anyway, the technologies that were successfully implemented in the LoFLYTE program can eventually find their way into commercial, general aviation and military aircraft.

The successful result of NASA's LoFLYTE program arises a question such as "*Do we still need pilots for future aircrafts ?*" The answer will vary. It depends on where we view the question. Back to the nature of the neural network that needs "thing" to be mimicked means that the pilot is still needed. His experience in handling an aircraft in every situation including unexpected situations can be used as inputs to train the neural network and as comparison to the neural network's output when learning the inputs. How smart a neural network cannot be compared to how intelligent the human brains. But, once it "graduates" from training scheme and is ready to be used, its processing speed is much faster than the human brains. So, there is a possibility to reduce new pilots recruitment for the future aircraft. Who knows ?