MOSQUITO
KA114

DIGITAL
HOPLITE
A Flying Avionics Laboratory

REUNION OF
Obie O’Brien
The Corsair Guy

SWEDISH AIR FORCE
HISTORIC FLIGHT

GRUMMAN’S
UNFLAPPABLE
DUCK
WHERE DO YOU FIND an affordable helicopter for avionics research when you are on a budget? One idea is to check in a museum. This is exactly what Professor Tom “Mach” Schnell did when he was looking to add a rotorcraft to his fleet of avionics test beds. With the help of his friend, Zach McNell from Warbirds East, Mach found the Cold War Air Museum (CWAM), which has a fleet of actively flying Cold War era helicopters, including the venerable Mi-2 Hoplite built by the Mil Moscow Helicopter Plant. Through collaboration with CWAM, Mach procured N211PZ, a 1978 Hoplite that served with the Bulgarian Air Force prior to being brought to the USA by CWAM. So why does a university need a twin-turbine helicopter for research? Well, that is kind of a long story. The short answer is that Mach’s research group, Operator Performance Laboratory (OPL), collaborates with industry and government to develop and test systems that enhance warfighter readiness and capabilities in the digital battlespace. The longer answer follows.

Mach is the founder and director of the Operator Performance Laboratory (OPL) at the University of Iowa. The Operator Performance Laboratory conducts research on human-in-the-loop and intelligent autonomous systems to increase efficiency, interoperability, and safety. Systems of particular interest include aircraft, airborne sensor and data-link systems, Unmanned Aerial Systems (UAS), and surface mobility systems. Much of the work at OPL is geared toward optimizing technology for use by US warfighters so that they have the edge over adversaries. These systems include, but are not limited to, flight vision enhancing systems such as Synthetic Vision Systems (SVS), Enhanced Vision Systems (EVS), Head-Up Displays (HUDs), and Helmet Mounted Displays (HMD), along with optimized symbology sets. Many of these technologies require software integration of sensors such as Forward Looking Infrared (FLIR), Light Detection and Ranging (LIDAR), RADAR, and very accurate Time-Space-Position-Information (TSP) solutions. The engineering life-cycle of such advanced systems includes performance testing using model based simulation tools. This means that many systems are tested using computer programs and models, long before the systems themselves are built. However, model-based testing is still limited, as it cannot always accurately account for the variability seen in the real world. Therefore, there is still a need for hardware and human-in-the-loop testing as part of the development cycle. System testing in the real world allows engineers to update the system models for better prediction and it greatly reduces the risk that a completed system does not meet the performance requirements. The earlier in the engineering development spiral that a shortcoming can be identified, the smaller the impact will be on the completed operational system.

OPL has an established process that supports avionics and systems designers in testing hardware with humans in the loop at a very early stage in the development cycle. OPL can take breadboard designs from Technical Readiness Levels 3 (TRL 3) to system prototype Levels 3 (TRL 7). This reduces risk and enables unprecedented accuracy in system validation. OPL has two L-29 Fighter Jet Trainers, an A-36 Bonanza, and most recently they added...
an Mi-2 Hoplite to their fleet of test aircraft. Many engineers whose prototypes break down in flight testing will invariably claim that “it worked on the bench.” With the Mi-2, you can bring the prototype and the bench, thereby voiding that excuse. The OPL aircraft have been heavily modified to support their testing mission. It is easiest to think of these aircraft as networked “flying flight simulators.” This means that certain aspects of the environment are simulated and certain aspects are real. Some things such as weapons, their interactions (e.g. did the weapon kill or not), and enemy fighters are easier to simulate than to actually come by in a testing environment. Conversely some things, such as propagation of electromagnetic radiation through the atmosphere and its effect on optical media, are much harder to simulate and might be easier tested with actual hardware in the loop. Some effects of the flight environment on human performance such as g-loading, subtle vestibular, proprioceptive (seat of the pants) and visual cues can be generated with much higher fidelity in OPL’s test aircraft than in a simulated, ground-based environment. OPL has developed the Cognitive Assessment Tool Set (CATS), a system that measures many aspects of human performance, including brain wave activity, eye gaze behavior, electrocardiogram (ECG), and respiration amplitude and frequency. CATS also acquires information from the aircraft sensors, such as the GPS/Airdata/Attitude Heading Reference System (GADAHRS), flight control position, weapon deployment states, etc. CATS then combines the human and aircraft system state data to predict the pilot’s degree of cognitive loading in real-time during the mission. In fighter parlance, CATS can quantify, in real-time, the extent to which the pilot’s drool cup fills up. Using this powerful combination of test platform and data analysis software, OPL supports avionics systems designers in optimizing their technology throughout the development cycle. Many times, manufacturers can optimize their technology in affordable flight test spirals at OPL, immersed in the full-up target environment, long before the customer evaluates the system through their acceptance testing procedures. Ideally, from the customer’s perspective the systems will work as required, right out of the box.

A lot of progress has been made in net-centric airwarfare, but the type of connectivity between airborne assets we have recently seen is just beginning. More and more connectivity at higher bandwidth levels will be available to exchange information to sharpen the edge of the airborne warfighters in the digital battlespace. This net-centric method of airwarfare requires test environments that are on par, or better than the systems they test. In collaborations with Rockwell Collins, OPL is using very high bandwidth data radios that can connect the aircraft and ground based simulators and systems. The assets at OPL, including two L-29 jets, a piston-powered Bonanza, the Mi-2 helicopter, and ground based systems such as flight simulators, UAV control stations, and military surface vehicles, are connected with high-bandwidth datalinks to form a federation of entities. This framework led to the development of the Tactical Aircraft Online System (TAOS) at Rockwell Collins. TAOS offers Joint Terminal Attack Controllers (JTACs, see Figure 3) the ability to train live aircraft control without a training range but rather by performing that training with the tactical JTAC gear connected to the internet and through the digital datalinks to the aircraft that is prosecuting the air strike.

Over the past five years, OPL has been heavily involved in the design of Synthetic Vision Systems (SVS) and avionics display symbologies that prevent helicopter loss of control during conditions of brownout. Helicopter pilots have a great deal of respect for the dangers of brownout that may occur in dusty areas during the most critical phases of flight, when close to the ground at slow speeds. The danger arises during landing, when the dust engulfs the helicopter, robbing the pilot’s clear view of the ground and obstacles. The Rockwell Collins Common Avionics Architecture System (CAAS) system has a velocity vector, acceleration symbol, and a landing zone symbol (doghouse) that, in conjunction with vertical clearance information, guide the pilot to a safe landing, even in the Degraded Visual Environment (DVE). Synthetic Vision Systems (SVS) in military applications can render terrain at unprecedented high resolutions, giving the pilot a clear view of the landing zone (LZ). SVS draws pictures of the terrain on the Primary Flight Display (PFD) from an onboard database. To ensure that nothing has changed in the LZ when compared to the stored terrain data, the system uses other sensors such as onboard LIDAR and RADAR to update the terrain database on the fly. OPL is working with Rockwell Collins to develop the Human Machine Interface (HMI) of advanced helicopter SVS avionics. The Mi-2 platform is scheduled for avionics upgrades to support the military Synthetic Vision Avionics developments at Rockwell Collins. Additionally, the Mi-2 at OPL is being fitted with data link technology that will allow it to control air-launched micro UAVs as standoff sensors.

The Mil Moscow Mi-2 (NATO reporting name is Hoplite) twin-turbine transport helicopter was produced exclusively in Poland, in the WSK
“PZL-widnik” factory in widnik. Production ended in 1985 after a run of about 7,200 units. The helicopter was designed by the Moscow based Mil Bureau in the early ‘60s and production was established in Poland in 1964. The Mi-2 was designed around the 400 shp Isotov GTD-350 (series I through IV) gas turbine. The compressor is at the front of the engine and immediately behind is the turbine. The combustion chamber is at the back of the engine, making for a very short shaft that connects the compressor and turbine. The compressor features seven stages of axial compression, followed by a single centrifugal compressor. The engine has a two stage turbine. The first stage drives the compressor and the second stage powers the drive train and accessories. Each engine has its own separate oil system. The engines are automatically synchronized through a vacuum hose interconnection. The fuel control system is completely mechanical. The engines are identical for left and right side installation, only the exhaust stack is reversible with a cover plate in place to cover up the unused exhaust port. This setup simplifies the design and parts count, but has the drawback of leaving some items on the engine hard to access. In fact, when taken as a set of two engines, all parts such as the fuel control system, plumbing, and control linkages, are hard to get to. The power turbine speed is automatically governed within the range of 23,100-24,900 RPM with a 1:4 reduction driving the main gear box, which generates the nominal rotor RPM from 78-84%. The gas producer RPM can be controlled through the collective pitch lever (correlator), the twist grip (warning, opposite direction than US), and the single engine control levers.

The majority of Mi-2s were built for personnel transport (8 passengers, 2 crew), cargo operations, and medevac with a 4-stretcher configuration. The majority of units are also configured with the plumbing and controls for aerial spraying applications. A significant number of Mi-2s were armed with machine guns, rockets, and missiles.

For the test mission at OPL, the aft crew compartment has been modified with a rail structure that can accept floor mounted instrumentation racks. Ground-power for the rack is switchable on the fly to aircraft provided power. The Mi-2 has two 3KW starter generators, one for each engine, providing 28-Volts DC. Additionally, the rack can be supplied with 400cps 3-phase power, up to 16KW. Air data and inertial systems hookups are available on the equipment rack.

The Mi-2 operated by OPL has factory installed English placards for most switches. To high time US helicopter pilots, operation of the helicopter systems may appear scattered and counter to any sensible flow. To an engineer, it all makes perfect sense. All the stuff is located exactly where it is easiest to install, so that is where you need to look for it. It helps to have an advanced degree in engineering to fly the Mi-2. There are four board batteries at 12VDC each, arranged in banks of two. Each bank is installed in a box that has each battery individually wired to a master relay. All systems, except the starting cycle branch, use the two banks in parallel, thus providing 28VDC on the DC-bus.

All circuit breakers are of the toggle switch style. The check list has each circuit breaker turned off at the end of a flight, therefore, during startup, it is necessary to turn each circuit breaker on to power up the corresponding sub-systems. Banks of circuit breakers are ganged with a bar that allow turning the breakers on with one massive upward push. One might say, “Get to be ‘strong as the ox’ for this one.”

The batteries in their respective boxes can be pulled out like modules. To prevent battery depletion from the tiny vampire currents drawn by the master relay, it makes a lot of sense to pull the batteries out of their sockets when the helicopter is not in daily use. This only takes a couple of seconds and preserves the batteries.

During engine start using the board battery, the starting computer, which is actually just a box of switches and cams, connects all four batteries in series to the starter, thus running it at 48VDC. This high voltage makes quick work of the starting cycle. Most of the systems operate on the 28VDC bus. The pressure gauges use 36VAC in conjunction with their associated pressure transducers. The 36VAC instrument circuit is fed through a transformer connected to the 115VAC bus which in turn is fed by an electromechanical power inverter that converts 28VDC into single phase 115VAC. Another single phase 36VAC inverter provides power for the attitude and heading indicators. A three phase 36VAC generator that draws mechanical power from the main gear transmission and is used to power the anti-icing system of the blade and tail rotor heat elements. Speaking of anti-icing, the engine inlets are heated by virtue of the annular engine oil tanks. This is simply clever from an engineering point of view: cool the oil and heat the engine at the same time. Why not? It makes perfect sense to an engineer.

Another “oh-by-the-way” item is that it is very simple to drain the oil out of those tanks through a hose, into a bucket. Many pilots who operate Mi-2s in arctic climates drain the oil at the end of a day and take it inside to keep it warm. You just have to remember to pour it back in the
Mi-2 Specifications

Crew: One. Capacity: 8 passengers or 700 kg (1,540 lb), internal, 800 kg (1,760 lb) external cargo. Length: 11.40 m (37 ft 4¾ in). Rotor Diameter: 14.50 m (47 ft 6 in). Height: 3.75 m (12 ft 3¾ in). Disc Area: 166.4 m² (1,791 ft²). Empty Weight: 2,372 kg (5,218 lb), Loaded Weight: 3,550 kg (7,826 lb). Max. Takeoff Weight: 3,700 kg (8,157 lb). Powerplant: 2 x PZL GTD-350P turboshfts, 298 kW (400 shp) each. Maximum Speed: 200 km/h (108 knots, 124 mph). Range: 440 km (237 nmi, 273 ml), (max internal fuel, no reserves). Service Ceiling: 4,000 m (13,125 ft). Rate of Climb: 4.5 m/s (885 ft/min).
(below) Ice detector and "jacket shredder" on the pilot's door of the Mi-2. Photo: OPL
morning, through the large filler throats, and you are "good to go."

The hydraulic system, which is connected to the main transmission gearbox, boosts the collective and cyclic axes. The anti-torque pedals are connected to the teetering tail rotor with cables and pulleys and no boost is provided. The tail rotor centers by virtue of centrifugal force acting on weights attached to the blade rotation levers. The Mi-2 can be flown without hydraulic boost but it is quite a workout, especially in the collective axis. There are electric trimmers for the cyclic axes which can be controlled with a cockpit hat switch on the cyclic stick. Only one pilot can operate the trim at any given time. Trim control has to be passed back and forth between the pilots using a "gotcha" switch that is mounted out of the way, behind the pilot. Each trim axis has an indicator that lets the pilot see where the trim is set. Additionally, there is a blade pitch indicator that lets the pilot see how much pitch is being pulled. Like any good Soviet aircraft, the Mi-2 has a pneumatic system for no other purpose than the wheel brakes. At least it has the same wheels as the L-29, so there is a good place to use the worn out L-29 tires. An air reservoir is filled by a main gear box mounted compressor. The system can also be filled from a filler port under an access panel. Braking is applied with a cyclic stick mounted bicycle brake grip. The brake lever activates an air-valve under the floor which sends air pressure evenly to each wheel. The tiny nose-wheel is castering and directional control comes from lateral thrust generated by the tail rotor through its enormously long arm. Care must be taken when making sharp turns. The Mi-2 has a very high CG and the three point wheel setup lends itself to dynamic roll-over similar to Shermers on three-wheelers during a July 4th parade. The Mi-2 has a relatively elaborate system of fire detectors and fire suppression bottles. The system is largely automated but it can be operated manually.

It can get hot in a Mi-2 during the summer. The only technological provision for cooling is a trucker style electric fan on the instrument glare-shield. Care must be taken to ensure the blades are not scratching the windshield from the inside. To keep things cool in the warm summer months, it is possible to remove the front door and some of the windows. There are three doors and none of them work the same. The pilot on the left side has the only good door in that it is a sliding kind that can be opened in flight. The co-pilot door on the right is a hinged door, as is the only rear door, the large cargo door on the aft left side of the helicopter. As a reminder of the cold war, there is a placard above the right aft window that gives lead angles for Ak-47 fire. The placard also reminds the shooter to safety the weapon after use. The Mi-2 has parak style padding under the fiberglass interior covers. It is has excellent insulation, making it exceptionally well suited to arctic operations. Engine bleed air can be run through two heat exchangers that circulate forced air across. This allows for crisp roasting of the pilot and co-pilot while keeping everyone else comfortably warm.

A bladder style fuel tank is located under the mast in a box on the floor of the cabin. The bench seats are installed on top of that box. The internal fuel tank holds 600 liters. With a fuel burn of around 70 gph the math says you run out of fuel after 2.25 hrs. The fueling port is accessible at the right side of the fuselage. A small light is installed near the filler throat indicating when the tank is about full, a nice touch. The engines produce an excess amount of fuel during shut-down. This fuel is kept upstairs in the attic in a small holding tank. The discharge petcock is located under the fuel door right above the fuel throat, as if the designer implied it could be drained back to the fuel tank. This is not a good idea however, because the discharged fuel tends to be somewhat contaminated. Externally mounted fuel tanks holding an extra 400 liters can be installed. This extra fuel is quite nice to have for ferry flights but the tanks look bad and make ingress and egress from the pilot door difficult. When installing them the first time, there is a moment of doubt that it was done right because the tanks are not located at the same station forward-aft. The left tank is farther forward to allow the cargo door to be opened. As an engineering trade-off, the pilot door opens only half way, a "fat man's misery." Making the standard issue auxiliary tanks shorter was probably not an option back then. The external tanks simply drain into the main tank though hookups on each side. The pilot will notice that for about the first 1.5 hrs of flight, the fuel tank gauge will read 600 liters. The rotor turns in the clockwise direction, but who cares, as long as it is turning. So it takes right pedal when applying torque, no big deal. The collective grip has a flapper switch on its grip.

The flapper is depressed naturally when grabbing the collective grip. With the flapper depressed, the collective can be moved freely up and down. With the flapper released, the collective is held in any of the 32 detent teeth, freeing the left hand up to do other work without fear that the collective will slip. This seems to be a pretty nifty feature and during the approach, the pilot can "count down" the collective in one-tooth increments. Control forces are even and light and most pilots take to the Mi-2 flight characteristics very quickly. For night work there is a retractable
(left-top) The Mi-2 is quite hangar friendly for a three-bladed helicopter. Most other aircraft in the OPL hangar fit under the tail stance of the Mi-2. Photo: William Adams

(left-bottom) Ground handling of the Mi-2 is a breeze. You taxi it with a bit of trim and it can swivel on a point. Photo: William Adams

(right) Richard "Halon" Miller (right) is an EMS Medic and former Army helicopter pilot. Tom "Mach" Schnell (left) is a university engineering professor and research pilot. Both are rated in fixed wing and rotorcraft. Photo: William Adams

landing light that can be steered in the up-down axis with a coolie hat switch on the collective. To move the light left and right, the pilot has to yaw the light with the entire helicopter attached to it. A fixed cargo light is available under the belly of the aircraft; this is great during those night sling loading missions. Normal position lights are installed on the side and rear of the helicopter and the rotating beacon along with its invariably burned out bulb (lots of vibration) is mounted on top of the 90-degree gearbox of the tail rotor.

After brake release, the helicopter can be taxied by beeping in a bit of forward trim using the cyclic trimmer. Care must be taken in crosswind taxi conditions as the side of the fuselage can act as a large sail. If the helicopter starts to skid, it is essential to immediately move the twist grip to the left to pull power off the drive train and to counter the skid with cyclic. Under no circumstances should the pedals be used to counter a skid while taxiing due to the high location of the tail rotor. The Mi-2 is an easy helicopter to fly but due to its size and payload capability, it is essential to check available performance as there may not be enough to take off from a hover with a heavy load. The wheels make for easy running take-offs and landings. There is no torque limitation to watch during take-off. In fact the only real limitation is that of the gas generator not to exceed 985 C for 6 minutes.

With heated blades, heated tail rotor, heated windshield and pitot probe, the Mi-2 is certified for known icing (according to the flight manual) but it is not IFR certified. That makes one wonder where that ice would be coming from. The icing detector is low-tech. It is a metal device in the shape of an airfoil just outside the pilot window. A red stinger presumably picks up the ice, and when it has turned from red to white, the helicopter is considered iced. Outside of icing conditions, the stinger makes for a great pilot jacket shredder during ingress and egress from the pilot station.

The Mi-2 is not certified for aerobatics - bummer. In fact it is a really good idea to keep the bank angle to less than 30-degrees because the helicopter is so top heavy. The Mi-2 can be flown from both sides, but for whatever reason the right side crew station is farther back than the left one, giving the right side pilot very poor forward visibility, especially during the pitch-over on take-off. The way the right seat is located farther back makes one wonder if the designers had to do that to get the pedals not to touch each other in the middle. Be that as it may, the rearward seating position allows a flight instructor in the right seat to observe a student in the left seat without being noticed.

On the inside, the Mi-2 is a very loud helicopter. After all, each forward crew member has a turbine engine attached to their head. A good intercom at all crew stations is therefore a must. The Mi-2 is not a speed demon; at a power setting of 89% for the gas generators, it will reach about 97 knots. The three bladed, fully articulated rotor system makes for a relatively smooth flight. Slope landings are performed with the up-slope main wheel touching first and gentle (gentle) cyclic held into the slope and collective gradually let out until the down-slope wheel touches ground or cyclic control margins are reached. The maximum slope allowed (per flight manual) is a mere 5-degrees. Yikes. The rotor system has a lot of inertia thanks to the relatively heavy conventionally constructed blades. This helps a great deal in auto rotations that are performed conventionally. Collective can be used to control the rotor RPM to stay below 84%. Pitch should be set for speeds between 32 and 94 kts when operating below 3000 ft MSL with obvious concern given to preservation of energy in the speed bin.

Thanks to its wheels and high posture, the Mi-2 is surprisingly hangar friendly for a three bladed helicopter. Most other items in the OPL hangar live well below the rotor disk, and the fully castering nose wheel makes tow-bar work a breeze. It does take a good tug (or an ox) to move the helicopter around the tarmac and hangar area. Overall, the Mi-2 is an impressive machine that embodies the pragmatism and engineering savvy of the designers that created it. Engine vents and overflows generally just discharge over the side of the helicopter fuselage. Apparently, the extra five feet of plumbing and ducting was considered to be an unnecessary frill. Oh well, that’s what rags are for. If something could be designed in a simple way, it was done that way on the Mi-2. That causes the Mi-2 to perform a little worse than its western counterparts but it makes up for that through ruggedness, reliability, and simplicity of operation. ☹