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A Military Perspective

on Small Unmanned Aerial Vehicles

As the U.S. Army continues to deploy the most technologically advanced force in the world, the role of small unmanned aerial vehicles (UAVs) as a critical component for providing unprecedented situational awareness, is rapidly increasing. During the past several years, advances in microelectromechanical system (MEMS) sensors, miniature global position system (GPS) receivers, and microelectronics have allowed the development of avionics packages for small UAVs, appropriate for insertion into the military mainstream. I will provide a brief look at the history of small UAVs and how they fit into the military system and then describe a rather unique UAV under development by the U.S. Army Research Laboratory. I will also discuss several instrumentation and test challenges encountered during this development effort.

The U.S. Army is transforming itself in response to a new set of threats. For a number of decades, its primary mission was to defend against an onslaught of Soviet armor pouring through the Fulda Gap. The U.S. Army has developed a formidable array of weapon systems to achieve that mission, which include Abrams tanks, Bradley fighting vehicles, Apache attack helicopters, Paladin howitzers, and various other antiarmor weapons. Since the demise of the Soviet Union, the U.S. Army has found itself lacking such a clearly defined threat. However, it now faces an emerging collection of asymmetric threats that are, in many ways, more difficult to identify and even harder to deal with. Another paradigm shift for the U.S. Army is its new role as peacekeeper, as opposed to its traditional mission of war fighter.

Throughout these changes, one thing has become clear: the U.S. Army can no longer afford the time and resources required to mass heavy vehicles prior to execution of an attack, as past doctrine dictated. Instead, the U.S. Army will consist of a collection of smaller, rapidly transportable units with the ultimate goal of deploying anywhere on the globe

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within 72 hours. This necessitates several fundamental changes. First, the extremely formidable and massive, main battle tanks are not able to be deployed in the numbers necessary to support such a quick-reaction response. Therefore, the future U.S. Army will comprise much lighter (20-ton)

vehicles that are required to contain the same levels of survivability and lethality as the current 70-ton behemoths. Even with advanced technologies and highly engineered materials, the only way to achieve success in such an environment is to possess an unprecedented level of battlefield situational awareness. This will allow the U.S. Army systems to locate and engage targets at distances that far exceed enemy capabilities, such that significant attrition will cripple the enemy's ability to fight effectively, long before closing within traditional engagement ranges.

Establishing and maintaining this level of situational awareness is a formidable task to say the least. It requires an unparalleled level of data collection, transport, and fusion between multitudes of assets; everything from satellites to scattered ground sensors. Assuring the timely movement of this unprocessed data, combined with the bandwidth necessary for secure operational communications across a hostile battlefield, dictates a highly sophisticated and robust tactical network. This network will include multiple levels of node functionality, from low capacity devices that might reside within tiny ground sensors, to highly functional hubs that would enable command and control elements to absorb and transmit information at extreme throughputs.

The collection of raw battlefield intelligence is carried out by an assemblage of diverse sensors, spanning the gambit of capabilities. In combination, these assets will provide the situational awareness necessary to plan and execute tactical operations with a high probability of achieving success. One type of asset that continues to prove its merit as a collection device is the small UAV. Typically defined as apparatus that is man portable and deployed in direct support of small units, these UAVs have recently experienced a surge in popularity and are quickly becoming "got to have" organic assets. The real-time overhead imagery that they provide is valuable to field commanders during operational planning, as well as providing the all-important "look before you leap" bird's eye view over an area of concern.

Although the U.S. Army has been experimenting with small UAVs for many years, their military acceptance was not immediate or universal. Early attempts involved modifying remote control model aircraft. As such, they suffered from a lack of reliability, required piloting skills, and were extremely fragile. Many of these aircraft employed two-stroke model engines that, while efficient, required special fuel and were in constant need of adjustment to function over the spectrum of operational conditions.

In the past, a daunting combination of limited volume, low mass, and reasonable cost drove small UAV solutions to either pilot-in-the-loop or rudimentary autopilots that were difficult to operate and quite limited in capability. The basic avionics sensors available at that time were relatively large, power hungry, and very costly; state-of-the-art components such as ring laser gyros and piezo accelerometers fell into this category. In tandem, the microelectronics revolution, along with the development of MEMS sensors, began providing the components necessary for miniature, high perfor-

Fig. 1. (a) Pointer, (b) Raven, and (c) Dragon Eye UAVs.

mance avionics packages. In addition, small GPS receivers, also facilitated by advancements in microelectronics, were becoming available. Finally, an explosion in miniature imaging components, such as video cameras and megapixel still imagers, provided low cost, highly capable payload sensors for small UAVs. Without the developments that each of these enabling technologies have experienced, small UAVs would not be the capable and practical devices that they are today.

As a result, the small UAV is gaining an unprecedented level of acceptance as a military tool. The future U.S. Army is positioned to exploit UAVs and plans to deeply integrate their functionality. In fact, the U.S. Army Future Combat Force calls for four distinct classes of UAVs, ranging from micro (6–9 in scale) up to Predator sized aircraft.

A snapshot of the U.S. Army's current small UAV inventory includes a number of Pointer and Raven systems, while the Marines have deployed the Dragon Eye (Figure 1) (see the AeroVironment Web site: www.aerovironment.com). Each of these exhibits slightly different performance characteristics, but all are similar in basic capability. These three aircraft were designed with the military user in mind and are a true departure from remote control models of the past. However, they remain fragile when subjected to a tactical military environment. This includes a propensity to incur damage, sometimes in flight, but more likely during storage, transport, and handling. Another major detraction is the simple fact that soldiers must carry these devices into combat, concern themselves with recovery following a mission, and then carry them back out. Finally, the time and exposure required to assemble and launch these small UAVs, although not involved, can be critical to the operational tempo of a mission.

A Unique Approach to Small UAVs

To overcome the shortcomings mentioned previously, the U.S. Army Research Laboratory, teamed with AeroVironment Inc., has pursued the demonstration of a gun-launched UAV and development of the technologies required to realize such a unique approach. The collection of these technologies into a

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demonstration vehicle is called silent operating aerial reconnaissance (SOAR). The SOAR concept employs an existing cargo delivery projectile that has been modified to contain a folding airframe (Figure 2). This projectile is launched from an existing gun system; in this case a 120-mm mortar. Following launch, the projectile flies a ballistic trajectory, then, just past apogee, a timed fuse functions to pyrotechnically separate the projectile and

expel the UAV. The SOAR is entirely encased within the projectile body, affording it robust protection until the instant of deployment. Its parent cartridge is stored, transported, and fired similarly to conventional ammunition, easing logistical and training issues. By using the ballistic energy of the launch system to quickly achieve initial altitude and range, valuable on-board power can be conserved, thereby extending the operational envelope. This approach also allows SOAR, with a near supersonic muzzle velocity, to arrive on station in seconds, as opposed to the minutes required for a conventional small UAV to be assembled, launched, and fly to the area of operation.

The most significant technological hurdle is achieving a design that is capable of surviving the extreme rigors of gun-launch and UAV expulsion, where accelerations are 20,000 and 3,000 g, respectively. Typical structural and electronic assemblies are reduced to shattered bits when subjected to forces of this magnitude. Therefore, an approach using extensive structural analysis, combined with numerous validation experiments, was used to confirm survival under these severe constraints.

To arrive at an optimal airframe configuration, a series of detailed trade studies were conducted. The parameter space included factors such as flight performance, a cylindrical packaging envelope, reliable function, simple construction, and high-shock survival. Extensive investigation of this trade space revealed that a tandem wing configuration proved the most attractive. This airframe consists of a base plate, payload tube with fairings, four pivoting wings, two hinged rudders, and a fixed ventral fin on the bottom (Figure 3).

The primary on-board functions for a UAV can be separated into the following categories: avionics, sensors, communications, propulsion, power source, and actuators. A modular approach allowed each major function to be contained within a cylindrical package. Each of these modules would consist of components on round printed circuit boards arranged perpendicular to the body axis and connected using solid wire pins around the circumference (Figure 4). Individual modules would then be fully potted in epoxy, resembling a hockey puck. This method of protecting electronic assemblies from gun-launch forces, in combination with the proper orientation of discrete components, has been used with much success [1].

Fig. 2. SOAR airframe in modified 120-mm mortar projectile.

The experimental methodology typically employed to validate the high-shock survival of the electronics starts at the individual component level and involves the use of a shock table capable of producing peak accelerations similar to the gun environment. Following this screening process, successful individual components are assembled into sub-

Fig. 3. Exploded view of tandem wing airframe.

Fig. 4. (a) Unpotted avionics module. (b) Potted sensor module.

component assemblies and shock tested again. Finally, complete modules are fabricated and evaluated in a similar fashion. Modules are readied for actual gun-fired experiments only after completing this thorough evaluation process. In parallel, the airframe and structural components are also evaluated using an iterative process that employs dynamic finite element analysis in conjunction with shock table experiments and finally with gun-fired validations.

The SOAR avionics package contains the most comprehensive set of components and proves the most challenging. The sensor inputs required for SOAR to function in a fully autonomous mode include: rate gyros (three axis), accelerometers (three axis), magnetometers (three axis), static and dynamic pressure, ambient temperature, GPS receiver, servo drivers, and a microcontroller. All the inertial devices and pressure sensors are MEMS based, while the other components are solid state. Design challenges for the inertial sensors included the selection of commercial off the shelf (COTS) components capable of surviving and functioning after high-shock exposure, while not experiencing a significant shift in scale factor or offset (bias). A series of evaluation experiments, conducted over the expected range of operating temperatures, provided critical data on these devices. The result is an avionics module that can both survive and function subsequent to the rigors of gun launch and UAV expulsion.

Other notable development issues included the need to ruggedize the single-board COTS video camera and electric motor. In addition to selecting a small pinhole lens and fully potting the discrete components, the crystal oscillator had to be replaced with one that was designed specifically for high-shock applications. An electric motor designed for remote control models was found to function after repeated shocks, given minor bushing modifications. Finally, Lithium-ion polymer cells appear to be quite resistant to high shock and, given their high power density, were sufficient for integration into the tight confines of the SOAR airframe. The radio frequency communication links used for initial flights were COTS devices not capable of withstanding gun-launch, however, a set of high-shock qualified components, developed under a hardened telemetry program, is being integrated to bridge this deficiency.

Besides the obvious challenges associated with a gun-launched device, is the requirement to provide high confidence “ground truth” measurements for independent verification of individual sensor outputs up to higher-level avionics functions. The general rule of thumb is to employ test instrumentation with an order of magnitude more accurate than the device that is under test. Combining this constraint with a test article (UAV) so highly integrated that every cubic centimeter is already occupied presents a real challenge concerning test instrumentation. To address this issue, a series of captive carry flights were executed where the SOAR was carried under a larger aircraft that was capable of supporting a more accurate set of avionics and diagnostic sensors. Although not optimal, it was felt to be an acceptable solution, given the severe system constraints.

Summary

In recent years, advancements in three technology areas, microelectronics, MEMS sensors, and GPS receivers, have allowed small UAVs to overcome critical deficiencies and become practical for insertion into the military mainstream. The maturation and commercialization of these technologies have resulted in readily available components that have decreased in both size and cost, to the point where truly low-cost, highly capable, small UAVs are possible. In particular, inertial devices such as MEMS accelerometers and angular rate sensors, pressure sensors, and magnetometers have reached the point where they are reliable, accurate, and affordable. These devices allow the determination of vehicle state with the precision required to enable autonomous flight. In addition, advanced microelectronic devices, such as digital signal processors, field programmable gate arrays, and microcontrollers have enabled sophisticated flight control functions, including fully autonomous flight using GPS waypoints. In combination, these advances have allowed small UAVs such as Pointer, Raven, and Dragon Eye to move into full-scale production and continue to allow the progression of UAVs into smaller and smaller packages. To address several of the deployment issues connected with small UAVs, a gun-launched version, along with the underpinning technologies, is

under development. This device represents a clear departure from conventional UAVs with several clear advantages; however, it also contains severe design challenges, as well as test and evaluation dilemmas. An option of this type is envisioned not as a replacement for conventional small UAVs but rather as an augmenting capability.

References

- [1] J.A. Condon, J.T. McLaughlin, and C.E. Mitchell, "Shock hardening and testing of munition-deployed video imager subassembly components," *U.S. Army Res. Laboratory Tech. Rep.*, p. 510, 2001.

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