# DEVELOPMENT & FLIGHT TESTING OF AN INTELLIGENT, AUTONOMOUS UAV CAPABILITY

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## INTRODUCTION

UAV/UCAV technology is at a key stage of its development with the introduction of truly autonomous operations. The DARPA/Air Force/Navy J-UCAS program is a joint effort to demonstrate the technical feasibility, military utility and operational value for a networked system of high performance, weaponized unmanned air vehicles. The first demonstration of this program promises truly autonomous operations, coordinated multi-vehicle operations and dynamic tasking. The DARPA/Army UCAR program will demonstrate the enabling technologies and system capabilities required to perform the mobile strike concept of operations within the Army's Objective Force system-of-systems environment. Specific objectives include autonomous multi-ship cooperation and collaboration, and autonomous low-altitude flight.

While many technologies for these programs can be adapted from manned aircraft technology, there is little experience and a small technology base upon which to develop autonomous systems, dynamic tasking and multi-ship operations. This paper reports on the progress of a current project to conduct flight-testing of an autonomous UAV capability, using teamed intelligent agents on board a small UAVs. This paper builds on previous projects and technology as described in last year's *Unmanned Unlimited* conference [Lucas et al, 2003].

## PROGRAM OUTLINE

The program is led by the Air Vehicles Division of the Australian Defence Science and Technology Organisation (DSTO), which was responsible for the aircraft, control system and integration with the autonomous controller. The Avatar aircraft, and pilot, were supplied by Codarra Advanced Systems, Agent Oriented Software provided its JACK Intelligent Agents software package, and DSTO's Air Operations Division together with the University of Melbourne developed the tactical aircraft behavior, represented as JACK plans. But the UAV development is positioned in the context of a broader research program.

### Research Program

As a part of an ongoing research program the Codarra Avatar is being provided with an autonomous operation capability. The goal is not to develop a mission-ready UAV but to provide DSTO scientists with a research test bed suitable for studying the impact of providing UAVs with autonomy. The research program driving the UAV development focuses on two distinct areas: aircraft platform management – which includes such things as air and flight worthiness, health monitoring and cost of ownership; and autonomous software development issues – including validation and verification, architectures for coordinated autonomous behavior, and autonomous controllers inspired by models of human cognition

## INTELLIGENT SOFTWARE AGENTS

The term 'software agent' is now in common usage, with a very broad definition covering a wide range of usage and levels of technological sophistication including:

- A term used simply to describe concurrent software processes in an information system;
- A piece of software (e.g. "Ask Jeeves" on the World Wide Web) that can respond to a user request to perform a task; and
- A far more sophisticated entity – an autonomous piece of software, capable of

simple rational reasoning, and capable of collaborating with other agents.

The technology being proposed is in accordance with the third description, and the technical terms used for such software include Rational Agents, Intentional Agents, and BDI (or Belief, Desire, Intentions) Agents. The term "Rational Agent" was coined as a result of work by Bratman[0] on rational reasoning in software systems embedded in environment. Subsequently, Bratman's work has been developed by others, including Rao[0] into the theory of Belief, Desire, Intentions, or BDI. One definition of an intelligent agent [Bratman, 1987] is an "encapsulated computer system, situated in some environment, and capable of flexible autonomous action in that environment in order to meet its design objectives".

## AVATAR AIRCRAFT AND CONTROL SYSTEM

The Codarra Avatar UAV is manufactured by Codarra Advanced Systems, Australia. It weighs approximately 10lbs and is propelled by a lithium polymer battery powered electric motor. The aircraft is supplied with a flight control system and on-board GPS. The flight control system can be updated (with speeds, altitudes, and waypoints) in-flight via a wireless modem. The aircraft is hand-launched and flown out via radio control and recovery is normally by parachute.

**Figure 1: From left to right: the payload bay containing the IPAQ; the notebook for loading the Intelligent Agent waypoints into the IPAQ; and the Avatar Ground Control Station (GCS).**

## JACK INTELLIGENT AGENTS™

The proposed teamed UAV control architecture will be built on a proven agent platform product, JACK Intelligent Agents™. JACK Intelligent Agents™ is a state-of-the-art agent infrastructure for building, running and integrating operational grade teamed-agent software, using a component-based approach. JACK supports the Belief, Desire, and Intention (BDI) model.

### JACKTeams™

JACKTeams is an integral part of the JACK product in its current release. JACKTeams is a team-modeling framework[0], developed initially for use in computer simulations of military tactics and equipment, in particular those of the Australian Army[0]. JACKTeams has been deployed in real-time control applications, most notably robotic assembly and the control of mobile robots[0]. A conclusion from the initial evaluation of existing team approaches was that teamwork (and support for teamwork) must be built into the modeling framework from inception; it cannot be 'bolted on' to a single agent or multi-agent architecture.

The JACKTeams framework introduces the notion of teams as separate reasoning entities. The behavior of a team, in particular the coordinated activity of the team members, is defined directly for the team entity. Thus, in the software model, each team exists as an entity with beliefs, desires and intentions separate from its members' beliefs, desires and intentions, and a team plan is distinctly a plan that the team entity performs.

## SINGLE VEHICLE CONTROL ARCHITECTURE

The primary driver for the architectural design for the first flight trial was ease of implementation. This led ultimately to the choice of the Hewlett Packard "IPAQ" personal digital assistant as the on-board computer and Jack as the agent platform. JACK will run on any platform with a Java Virtual Machine. An appropriate Java Virtual Machine was available for the IPAQ and the integration into the aircraft was straightforward. The reliability of the hardware/software combination was considered to be an acceptable risk and despite several failure modes that were identified as potentially mission critical none were actually observed in the extensive testing undertaken. The following section briefly describes the hardware architecture, the software architecture, and the internal design of the intelligent agent.

Hardware Architecture

The hardware architecture is as shown in Figure 1. The IPAQ was connected serially into the aircraft between the flight control system (FCS) and the Ground Control System (GCS). For the missions flown the GCS was not used and conceptually the intelligent agent can be considered as a replacement for the human controller on the ground. It is possible at any time to interrupt the FCS and switch the aircraft into radio control (RC) mode. This is standard for take-off and recovery and is a valuable safety feature that provides the capacity to isolate the intelligent agent and to fly the aircraft back should the software or hardware fail.

Software Architecture

The FCS provides data about the state of the environment and the platform at 1Hz. This data set includes GPS data, control deflections, and aircraft state parameters. The FCS accepts many commands that provide the capacity to control the aircraft through waypoint setting or by interacting directly with the control surfaces. For the first trial only the waypoint commands were used. Interface software running on the IPAQ provided an interface for the agent into the FCS. The agent written in JACK and hence running inside a JACK Kernel in a JVM runs asynchronously with respect to the interface.

Agent Architecture

The design of the agent is based on design pattern that has proven useful over more than a decade of simulation development within DSTO. Developed for simulating fighter pilots in air combat the basic agent design is based on Boyd's OODA* loop [ref]. The design has been used in several large simulations [ref] and forms the basis for a decade of modeling and simulation using intelligent agent languages.

## FLIGHT TRIALS PROGRAM

The flight trials program has been engineered to move in a controlled manner from a simple proof of concept demonstration into more sophisticated mission profiles. An important part of this process is the gaining of knowledge about the flight characteristics and performance capabilities of the Avatar. This knowledge will feed the development of on-board systems integral to health monitoring.

The first three flight trials are as follows: July 2004 (completed) – proof of concept shake-down and preliminary system testing; October 2004 (scheduled) – wireless modem mapping; January 2005 (planned) – preliminary operations with two UAVs operating as a team. It should be noted that this is not a "swarming" approach demonstrating emergent behavior, rather it demonstrates the power of a teamed approach, where each UAV performs its role in the team according to its capabilities to perform that role to achieve the overall team goal, or mission objective.

**Figure 2: The Codarra Avatar prior to assembly for launch. The cavity for the payload bay is visible on the underside of the aircraft and the wireless modem aerial can be seen standing vertically. The prop is fully folded, as it can be in flight, along the fuselage.**

Accompanying the flight trials program is the construction of a number complementary capabilities: a simulation capability and test harness for the agent software; and a hardware in the loop test facility.

Completed Flight Trial

The first flight trial was successfully conducted at the Graytown Army Experimental Facility in Victoria, Australia during the week of the 6th July 2004.

The first flight trial was a proof of concept and technology shakedown flight so the mission was kept simple and safety considerations paramount.

The Avatar was launched by radio control and flown to an altitude of 300 feet. Control was switched to the on-board software and a pre-briefed

* OODA is the shorthand for Observe-Orient-Decide-Act. In the context of the models described here these four activities are often transcribed as: Situation Awareness, Situation Assessment, Tactics Selection, and Standard Operating Procedures.

course was commenced. During the flight the JACK Intelligent Agent was monitoring the aircraft flight, specifically , the agent was estimating the wind speed and direction based on information from the air speed indicator and the GPS data. At a pre-determined point the agent assumed control of the aircraft and selected a new waypoint on the basis of its estimate of the wind speed and direction. This waypoint was sent as a command to the flight control system and mission continued.

Because the wind was variable and gusting up to about 10 knots it was difficult to be sure during the mission how the agent would respond to the wind conditions during the flight. Post mission evaluation of the flight logs indicated that the agent had indeed made the correct decision.

**Figure 3: The Avatar during parachute recovery from its first flight under autonomous control.**

Next Step in the Current Program

The development of the autonomous UAV capability described here is a part of an ongoing DSTO research program centred on issues related to platform management: flight worthiness, air worthiness and certification, health and situation monitoring. One possible investigation under consideration is the use of a Bayesian net based approach to health monitoring with the higher-level aspects related to mission management handled by agent technologies.

## SOFTWARE VALIDATION AND VERIFICATION

A five stage approach to validation and verification was adopted.

1. Design and Code Inspections. The software design was independently reviewed prior to commencing the coding. This review involved experts both in agent programming and UAV systems development. Code inspections and walk-throughs were employed throughout the software development.
2. Unit testing. The JACK agent, and every software component were thoroughly unit tested through a range of tests using both actual and simulated flight data.
3. System simulation testing (positive and negative). Once the software system integration was complete a suite of system simulation tests commenced. This included tests to check the performance capabilities of the hardware and to assess the likelihood and impact of various hardware failures.
4. Hardware in the loop testing – stimulation testing. The hardware and software was installed into the aircraft the complete system tested with stimulated inputs.
5. System walk-around. Immediately prior to the first flight the aircraft was literally *walked* around the course. Simulating a very low altitude, low speed flight in this manner was a simple means of effectively checking the software and hardware in an *approximately* real situation. Future tests might extend this idea to allow the aircraft to be driven around a course fixed to a vehicle.

## TEAMED INTELLIGENT, AUTONOMOUS VEHICLES

As the second step, the intelligent, autonomous approach can be extended to multiple UAVs operating autonomously and collaboratively in a highly flexible manner. This enables a number of vehicles to work together with humans as a single team. Such a team might include one or two aircraft, ground vehicles or surface vessels working with, say, three UAVs.

The power of robotic collectives, of which a team of UAVs is an instance of, has been well researched [Tucker et al., 2002]. Each individual UAV team member is capable of dynamically assuming various roles defined within the team hierarchy. The ability of team members to coordinate roles allows for a robust, efficient, and flexible team structure. A team of communicating homogeneous agents, such as a team of identical, communicating UAVs, can utilise dynamic role assignment and thus unleash the potential of the underlying configuration. For example, if a UAV fails during a mission, another UAV can assume the role of the failed UAV and maintain the team mission objectives.

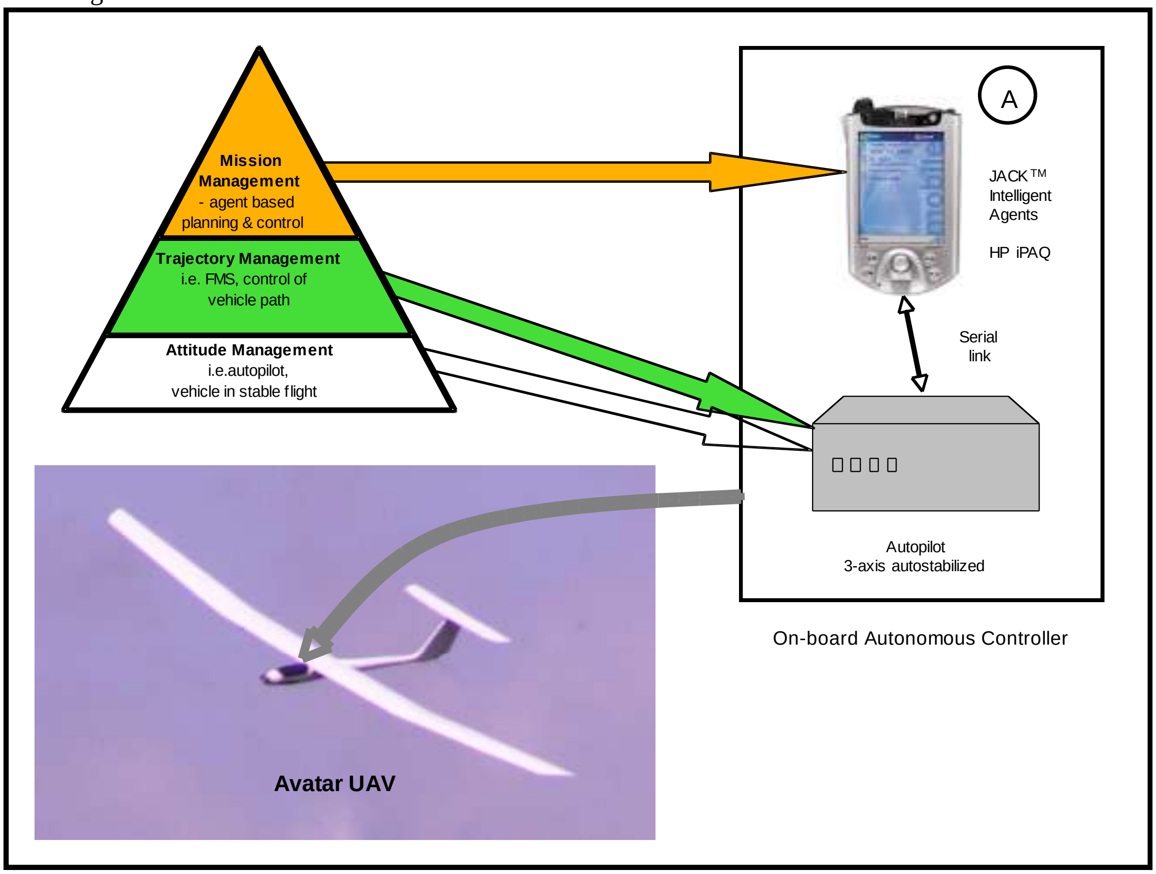


**Figure 4: The Hardware architecture for the first flight trial**

As shown in Figure 4, each vehicle has an agent on board, which communicates with a pilot-assistant agent on the manned vehicle.

## CONCLUSION

The addition of an autonomous flight capability to the Codarra Avatar UAV is part of an ongoing research program by DSTO concerned primarily with improving aircraft management functions on board UAVs.

JACK Intelligent Agents has proven an effective and elegant solution to the rapid development of this autonomous capability.

The advantages of JACK agent technologies are expected to be even more apparent in future stages of this program when teams of UAVs are to be flown.

The program drew together a broad grouping of Australian industry, academia, and defence to provide a rapid development. The elapsed time from commencing the software development to the first flight was less than 12 weeks.

Future flights will further enhance the autonomous capabilities but the emphasis will shift from simple platform manoeuvring to platform management.:developing agents that can take in data about its environment (one aspect of which is the aircraft state which includes state of health , energy state and estimates of the environment amongst others) and act appropriately (rationally) in the light of this understanding. This also translates well to teamed activities where the beliefs about the environment and the state of the team and the individuals within the team feed the agents' decision making processes.


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