



INSTITUTE FOR DEFENSE ANALYSES

**Terrorist Use of Improvised or
Commercially Available Precision-Guided
UAVs at Stand-Off Ranges: An Approach
for Formulating Mitigation Considerations**

Jay Mandelbaum and James Ralston, Project Leaders
Ivars Gutmanis
Andrew Hull
Christopher Martin

October 2005

Approved for public release;
distribution unlimited.

IDA Document D-3199

Log: H 05-002008

This work was conducted under IDA's independent research program. The publication of this IDA document does not indicate endorsement by the Department of Defense, nor should the contents be construed as reflecting the official position of that Agency.

© 2005 Institute for Defense Analyses, 4850 Mark Center Drive, Alexandria, Virginia 22311-1882 • (703) 845-2000.

This material may be reproduced by or for the U.S. Government.

INSTITUTE FOR DEFENSE ANALYSES

IDA Document D-3199

**Terrorist Use of Improvised or
Commercially Available Precision-Guided
UAVs at Stand-Off Ranges: An Approach
for Formulating Mitigation Considerations**

Jay Mandelbaum and James Ralston, Project Leaders

Ivars Gutmanis

Andrew Hull

Christopher Martin

PREFACE

The work detailed in this document was carried out in two separate Independent Research Projects—one entitled “Commercial PGMs as Weapons” led by Jay Mandelbaum of the Strategy, Forces and Resources Division (SF&RD) and the other entitled “Commercial PGMs ” led by James Ralston of the Science and Technology Division (STD). The technical reviewer was Christina Patterson of SFRD.

CONTENTS

Preface.....	iii
Summary	S-1
Background assumptions and Motivation.....	1
The Premise	2
The Proposition.....	3
Some Supporting Evidence.....	4
Summing It Up.....	10
Initial Research Objectives	11
Assumptions/Scope.....	12
What We Learned Early	13
Initial Findings	14
Threat of Terrorism Using UAVs - Technical Aspects	15
Remotely Piloted Vehicle Threat.....	16
What We Can Add.....	17
Updated Research Objectives	18
An Approach for Analyzing Terrorist Options.....	19
Scenarios of Interest Will Exhibit Certain Criteria.....	20
Selected Key UAV Attributes Relatable to Terrorist Criteria	21
Exploring the Payload Delivery Mechanism: Fully Assembled System Basis.....	22
Spraying-Capable UAVs: RMAX	23
Spraying-Capable UAVs: RPH-2	24
Spraying-Capable UAVs: C50/C80/C100/CT100.....	25
Spraying-Capable UAVs: Mitigation Considerations	26
Exploring Payload Capacity: Fully assembled System Basis.....	27
Large Model Airplanes: Swordfish.....	28
Large Model Airplanes: Passenger Jet Model – Dehaviland Comet	29
Large Model Airplanes: RAF Vulcan.....	30
Large Model Airplanes: Other Examples	31
Many Available Models Are Fully Flight Ready	32

Large Model Airplanes: Mitigation Considerations	33
Exploring the Propulsion Subsystem	34
A Wide Variety of Small Engines	35
Microturbo Turbojet Engines for Missiles, Target and Reconnaissance Drones	36
Engine-Related Mitigation Considerations	37
Exploring the Autopilot Subsystem	38
Autopilots	39
Autopilot-Related Mitigation Considerations	40
Conclusions.....	41
Follow-on	44

SUMMARY

The research documented in this report was conducted under the premise that terrorist activities will evolve in unexpected directions. As some strategies become more difficult to execute, other strategies that once may have been rejected as too difficult become more attractive.

Before 9-11, it was far easier to bring agents into the United States. Suicide attackers could be replaced relatively easily. As security tightens, getting agents into this country is increasingly difficult. Availability of people with the specialized skill of living undetected in the US society is very rare. It takes a long time to train such operatives. Therefore, human assets that can function in the US society are of great value today. It follows that such assets probably will not be “wasted” in suicide attacks or used in plans where there is a high likelihood of capture. Using those assets in situations where they can attack, escape, and attack again is far preferable.

The specific situation examined in this report was terrorist use of improvised or commercially available precision-guided unmanned aerial vehicles (UAVs) at a stand-off range from the target. As effective guidance and control technologies become available as consumer items, the needed payload for effectiveness becomes smaller. The idea is that a small team could launch a UAV from hiding, with a relatively small launch footprint, and make their escape before impact. Even if the UAV were spotted, it would be difficult to shoot it down unless the target had either a very elaborate anti-missile capability or could jam the guidance system. Once the materials for the weapon have been assembled, the scenario is not complex. There would be little danger of detection in transportation, launch, or escape assuming that everything was planned in advance. In addition, multiple teams could act independently or repeatedly so there could be numerous attacks over a long period of time.

After providing some supporting evidence for terrorist use of UAVs, the report suggests an approach for analyzing terrorist options. While a wide range of scenarios using improvised or commercially available precision-guided UAVs at stand-off ranges are possible, this research demonstrated that many of the more interesting ones can be analyzed through their effectiveness in achieving terrorist objectives. Attributes associated with effectiveness were determined and then used to identify warning

indicators that in turn implied preliminary preparedness and mitigation considerations as follows:

- Monitoring purchases of individual components does not appear to offer much potential although correlating purchases with known threats may help.
- Monitoring suppliers of fully assembled special purpose UAVs may be viable and worthwhile.
- Monitoring trainers has promise; there are a limited number of providers of training and simulation devices for sensory UAVs.
- Some out-of-the-box ideas such as establishing a watch center for stolen UAVs, the use of locator chips, and regulations on UAV operations and/or security may be worthwhile.

The report concludes by identifying some places where further effort is needed to flesh out both terrorist options and their implications in order to develop recommendations for specific actions.

Outline

- **Background assumptions and motivation**
- What we learned early (we aren't the first...)
- What we can add
- Conclusions

We begin with our premise of how terrorist activity may evolve and then provide some supporting evidence for these beliefs. We will also show our initial research objectives and assumptions.

The Premise

Terrorist Activities will Evolve in Unexpected Directions

- **To enhance their probability of success, terrorists will plan scenarios where extensive mitigation activities have not been undertaken**
- **As the difficulty of successfully integrating people into US society continues to increase, terrorists will plan scenarios that minimize the vulnerability of their agents**
- **Demonstrating new threat dimensions fits the terrorist agenda of continually increasing fear and uncertainty**

Activities will follow the path of least resistance. As some strategies become more difficult to execute, other strategies that once may have been rejected as too difficult become more attractive.

Before 9-11, it was far easier to bring agents into the United States. Suicide attackers could be replaced relatively easily. As security tightens, getting agents into this country is increasingly difficult. Availability of people with the specialized skill of living undetected in the US society is very rare. It takes a long time to train such operatives. Therefore, human assets that can function in the US society are of great value today. It follows that such assets probably will not be “wasted” in suicide attacks or used in plans where there is a high likelihood of capture. Using those assets in situations where they can attack, escape, and attack again is far preferable.

New threat dimensions include new targets, new delivery mechanisms, and/or new tactics.

The Proposition

The Unexpected Direction We Chose to Consider Was Use of Improvised or Commercially Available Precision-Guided UAVs at Stand-Off Range

- As effective guidance and control technologies become available as consumer items, the needed payload for effectiveness becomes smaller
 - Same rationale for military precision-guided munitions (PGMs)
- Advantages of PGMs include:
 - Low probability of apprehending agents who launch them
 - They are difficult to counter, once launched
 - Scenarios for obtaining and using them are not complex
 - **Consequently, there is a high probability of successful execution**

The idea is that a small team could launch an unmanned aerial vehicle (UAV) from hiding, with a relatively small launch footprint. Such a UAV could be fired from beyond visual range at a target while the terrorists make their escape before impact. Even if the UAV were spotted, it would be difficult to shoot it down unless the target had either a very elaborate anti-missile capability or could jam the guidance system.

Once the materials for the weapon have been assembled, the scenario is not complex. There would be little danger of detection in transportation, launch, or escape assuming that everything was planned in advance.

In addition, multiple teams could act independently or repeatedly so there could be numerous attacks over a long period of time.

Some Supporting Evidence (1 of 6)

There are Documented Examples of Terrorist Experiments with UAVs

- Colombian FARC insurgent group has weaponized a model aircraft
- Palestinian Fatah militiamen have conducted model airplane flight tests
- Osama Bin Laden alleged threat to use a remote-controlled airplane to kill George Bush at the G-8 summit in Genoa, Italy

The Revolutionary Armed Forces of Colombia, or FARC, was discovered in possession of nine remote-controlled unmanned aircraft when a Colombian army unit overran one of their remote camps in August 2002. “Colombia – FARC Drones Discovered,” *EFE News Service*, August 28, 2002.

Model airplanes were purchased in Europe and sent to Palestinian shopkeepers as part of an alleged humanitarian effort. They were sent to workshops for conversion into miniature air bombers with explosive payloads.

Bin Laden allegation was reported by Michael Gips, “A Remote Threat,” *Security Management Online*, October 2002.

There have been other unsubstantiated reports:

- In June 2002 Reuters reported that Al Queda might be planning to use model airplanes to attack passenger aircraft.
- *The Independent* (London) reported that a British national detainee at Guantanamo confessed to being part of a plot to acquire a drone to attack the House of Commons with anthrax.
- According to Reuters, in March 2004, Israeli intelligence prevented a terrorist attack on a settlement in Gaza using a UAV loaded with explosives.

Some Supporting Evidence (2 of 6)

Atlantic Monthly Article Headline: “Allah is My Co-Pilot”

- Hezbollah UAV Flown Over Israel on Nov 7, 2004



Mersad-1 UAV
(40-50 kg Payload)



Flight Path of Mersad-1

Unmanned aerial vehicle (UAV) of Lebanese extremist organization Hezbollah intruded into Israeli airspace on November 7, 2004, at approximately 10:30 a.m. local time. It flew at a low altitude over a town of Nahariya, turned to the Mediterranean Sea, turned again to the north, and fell down at sea near the Lebanese shore. According to information published in the press, the UAV spent nearly half an hour over territory of Israel. The *Atlantic Monthly* wrote about this incident in an article entitled “Allah is My Co-Pilot.” On April 11, 2005, a second drone flew over Israeli communities all the way to the area of the coastal city of Acre in northern Israel “in response to the enemy’s continuous and repeated violations of Lebanese airspace.”

Some Supporting Evidence (3 of 6)

A Drone Was Seized from an Al-Queda Stronghold It Sure Looks Like a Model Airplane

- Pakistani forces recovered an unmanned drone aircraft • • •
- Militants used the Chinese-made vehicle to spy on security forces • • • Lieutenant General Safdar Hussain told reporters.
- The find in North Waziristan, believed to be the first of its kind in Pakistan, • • •
- "The terrorists used the RPV (remotely-piloted vehicle) to check the position of security forces and attack them," the general said, adding that the drone was capable of carrying weapons.



This was reported in Yahoo news on Tuesday, September 13.

The militants were from Al Qaeda according to the article.

Some Supporting Evidence (4 of 6)

Commercial UAV Trends Enhance Attractiveness to Terrorists

- Increased payload capacity
- Improved in-flight communications
- Extended operational endurance
- Increased maneuverability
- Operations at lower/higher ceilings
- Decreased weight
- Proliferation of uses

and there currently are 157 manufacturers of commercial UAVs worldwide

UAVs are being used for reconnaissance and surveillance in a large number of commercial and public safety applications. They are suitable to various terrains.



8

Some Supporting Evidence (6 of 6) ... sort of

You Can Even Build a Do-It-Yourself Cruise Missile in your Garage for less than \$5,000

- Proposed specifications
 - Range at lease 650 km
 - Payload at least 22 kg
 - Accuracy at least 100 m
- Required elements
 - Engine
 - Navigation unit
 - Flight controls & auto guidance
 - Launcher
 - Payload



This claim needs to be heavily caveated. Until a Do-It-Yourself (DIY) cruise missile flies, no one will be confident that it will.

However, to make a flight-capable vehicle is not out of the question. The autopilots and 6-DOF simulators that exist now can predict flight qualities and fly aircraft to GPS waypoints (they even are Differential GPS capable). The issue will be take-off, since wing loading is high and that requires high speed to maintain flight. Current military cruise missiles use rockets to push aircraft to flight speed, but this type of system would be too complex for a home-built vehicle.

The following material was extracted from the DIY website:

Welcome to the DIY Cruise Missile construction diary.

Regular visitors to this area of the website will be able to see:

- How and where materials and components were sourced and how much was paid.
- How the airframe is designed and constructed (with full working plans)
- How the engine (a conventional pulsejet) is designed and constructed (with full working plans)
- How the guidance system is designed, built and programmed
- How the launch system is designed, built and tested (with full working plans)
- How the various subsystems are tested
- The final assembly and testing of all major subsystems
- Flight-testing and deployment (under controlled conditions with a dummy payload)

Summing It Up ...

“UAVs can become a very attractive option for terrorists anxious to deliver a covert attack with the use of chemical or biological weapons. Even armed with conventional explosives, a UAV can become more efficient than so-called “shaheed’s belt” frequently used by suicide terrorists. ... UAVs can penetrate to the areas where suicide terrorists have almost no chance to get to.”

*Center for Arms Control, Energy and Environment
Studies at the Moscow Institute of Physics and
Technology*

This quote is extracted from a commentary written about the November 7, 2004, Hezbollah UAV flight over Israel. The commentary was prepared by the Center for Arms Control, Energy and Environment Studies at the Moscow Institute of Physics and Technology.

Initial Research Objectives

- **Analyze terrorist options that have not been previously considered**
- **Evaluate the danger posed**
- **Formulate defense options as a basis for further research**

Thinking that we were the first ones to investigate this topic, we initially formulated our research objectives as above. Our plan was to show something about the threat and give some mitigation considerations. This would become the basis for generating sponsor interest in the Department of Homeland Security or elsewhere.

Assumptions/Scope

- Terrorists will be adequately financed
- Supporting infrastructure for building or buying commercially available precision-guided UAVs is in place
- Small mobile delivery teams exist
- Payloads are obtainable
- Exclude military UAVs
- Exclude ground-based and sea-based unmanned vehicles
 - Lack range, speed, and access to targets

Terrorists will have access to the funding needed to execute the scenario.

Terrorists will have the infrastructure in place to buy the UAVs either produced in the US or produced abroad and imported (either assembled or disassembled). They will have planned in advance the targets and escape routes.

There will be teams available to launch the weapons.

Our quick study did not delve into payload availability. We assume that payloads may be biological, chemical, radiological, or explosive and of sufficient size to cause the desired impact.

We are excluding military-grade UAVs although there is no reason to believe they are unobtainable in this country. Improvised or commercially available precision-guided UAVs are available in quantity.

We are excluding ground-based and sea-based because:

- They can be more easily blocked
- Much more damage can be inflicted from the air

Outline

- Background assumptions and motivation
- What we learned early (we aren't the first...)
- What we can add
- Conclusions

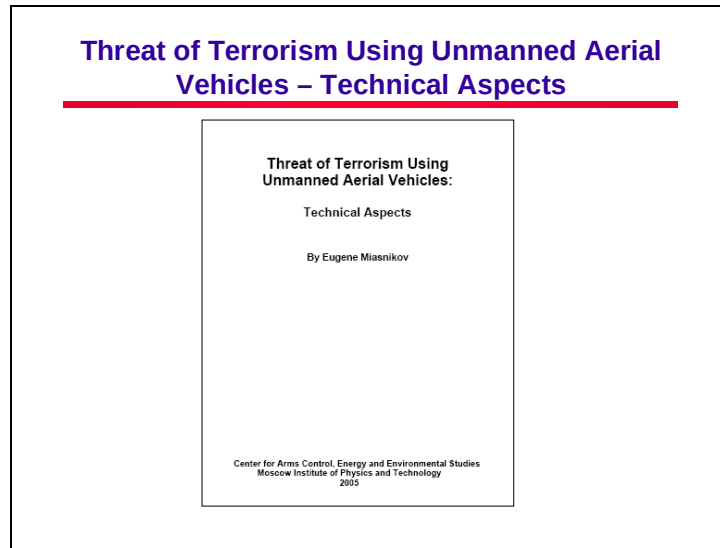
Our assumption that this subject had not been explored proved to be incorrect.

Initial Findings



- We weren't the first to get this far
- Some thought-provoking work had already been done

Photo shows Roald Amundsen's camp at the South Pole, but the photo was taken by Robert Scott. Amundsen's expedition left covertly 8 weeks later than Scott's.



Prepared in 2005 by the Center for Arms Control, Energy and Environmental Studies at the Moscow Institute of Physics and Technology. 26 pages. Numerous references.

This paper discusses potential targets and possible damage. It describes how damage is increased with an air detonation for explosives, chemical, biological, and radiological payloads.

The paper describes how terrorists may acquire UAVs. It includes modifying model airplanes, making a purely commercial purchase, converting airplanes, and building from scratch.

The paper also describes the technical characteristics of a number of UAVs. It discusses how they may be controlled – line of sight through radio controls or autopilots for beyond visual range.

The paper also describes defense against UAVs, including both detection and destruction.

Remotely Piloted Vehicle Threat



Information Bulletin
Title: Remotely Piloted Vehicle Threat
Date: June 7, 2004

It defines remotely piloted vehicles as either military grade UAVs or remote controlled aircraft either for hobbyists or commercial. The Bulletin also (1) briefly characterizes (range, payload, accuracy and availability) hobby remotely piloted vehicles (RPVs); (2) gives an indication about how they may be used; and (3) mentions some actual terrorist uses.

Finally some protective measures are suggested:

- Contact trainers and ask them to report suspicious activity
- Contact hobby shop owners and ask them to report suspicious purchases
- Contact autopilot suppliers and ask them to report suspicious purchases
- Be on the lookout for people taking GPS measurements

Outline

- Background assumptions and motivation
- What we learned early (we aren't the first...)
- What we can add
- Conclusions

Updated Research Objectives

Original

- Analyze terrorist options that have not been seriously considered
- Evaluate the danger posed
- Formulate defensive considerations as a basis for further research

Revised

- Develop an approach for analyzing terrorist options
- Demonstrate how the approach may be used to:
 - Point out terrorist options that may not have been sufficiently scrutinized
 - Formulate some considerations for improving preparedness and for mitigating such threats
- Identify potential topics for further research

Given our early findings, we adapted our research objectives as shown above.

An Approach for Analyzing Terrorist Options

Develop and Test a Framework for Examining a Range of Potential Scenarios such that Mitigation Activities Become More Manageable



Rather than postulate different scenarios (which would be a very long and arbitrary list), we decided to first look at those criteria that scenarios of interest would have in common – i.e., those things that terrorists would like to accomplish. Once those criteria were established, we would look at UAV attributes needed to achieve the criteria. Finally, we thought about mitigation considerations related to the identified UAV attributes.

On the next two pages we expand on:

- Criteria for scenarios of interest
- UAV attributes

The remainder of this section of the briefing explores mitigation considerations for four such attributes.

Scenarios of Interest Will Exhibit Certain Criteria

The “Ideal” Terrorist Scenario Will Exhibit One or More of These Criteria:

- **Large area affected**
 - Long-term contamination
 - Precludes access
- **Many people affected**
 - Not necessarily killed or even obviously injured
- **Large aftereffect on society**
 - Impact lingers long after the event(s)

These criteria are important for accomplishing terrorist objectives:

- Create atmosphere of fear and panic
- Disrupt the American way of life
- Create economic havoc in the US – affect the value of the stock market / retirement savings; make all businesses spend more on security; force even greater deficit spending in Federal budget; disrupt consumer spending
- Undermine confidence in the government
- Generate publicity
- Divert government attention to domestic matters

Selected Key UAV Attributes Relatable to Terrorist Criteria

**May be Analyzed from a Fully Assembled
System Basis or by Major Subsystem**

- **Propulsion**
 - Range
 - Endurance
- **Payload**
 - Capacity
 - Delivery mechanism
- **Guidance and control**

We briefly explored four subsets of these attribute areas to see what we could learn about the utility of this approach.

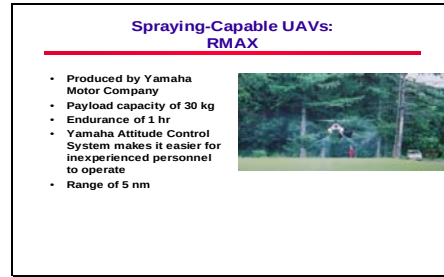
Two of the subsets were approached on a fully assembled system basis.

Two of the subsets are major subsystems.

Exploring the Payload Delivery Mechanism: Fully Assembled System Basis

Spraying-Capable UAVs Can Be Used To Achieve Terrorist Objectives

- **Spraying is far more effective than direct explosive impact as a method of dispensing chemical payloads**
- **Depending on the target, the use of UAVs with spraying capability can encompass a very large area and/or many people with lingering effects**



In 1990 Yamaha Motor Company introduced the R-50 as the world's first commercial use unmanned helicopter capable of carrying payloads up to 20 kilograms. Yamaha in 1997 introduced the RMAX, which was powered by a specially developed horizontally opposed liquid cooled two-stroke engine. This more powerful engine increased the maximum payload to 30 kilograms. The primary mission of these UAV helicopters is crop dusting and crop spraying. The granular dispenser can hold 24 kilograms of solid material with a diameter of 0.7 millimeters. The liquid dispenser holds a maximum of 24 liters and sprays that liquid at rates of 1.3 liters or 2.0 liters per minute. The operator can select to distribute produce in a radius of 7.5 or 5 meters. Both the liquid and granular dispensers would be used to distribute other kinds of lethal or non-lethal agents in addition to agricultural chemicals.

The main features of the RMAX include: A new 246 cubic centimeter, liquid-cooled two-stroke horizontal opposed-type engine; Two cassette-type payload tanks (one on each side) that can be filled on the ground for immediate replacement thereby increasing the amount of spraying that can be done in a given amount of time; Yamaha Attitude Control System making it easier for inexperienced personnel to operate the UAV; Selectable 7.5 or 5 meter distribution radius; Wheels are attached to the front of the landing skids to make it easier for one person to move the RMAX on the ground.

In 1995, the company introduced the Yamaha Attitude Control System that greatly increases flight stability and operation by means of flight pattern control models based upon extensive flight analysis. This Attitude Control System has a computer make constant adjustments in direction, speed, and altitude based on how the UAV mission. The introduction of the Yamaha Attitude Control System meant that what had previously been a very difficult skill to master could now be mastered by new operators in just a short time.

Spraying-Capable UAVs: RPH-2

- Produced by Fuji Heavy Industries
- Payload capacity of 175 lb
- Endurance of 1 hr
- Range of 5 nm



RPH-2 VTOL UAV (Japan)

Fuji Heavy Industries also makes an unmanned rotary wing UAV for use in the agricultural sector. The UAV, called the RPH-2, carries crop-spraying apparatus that extends from either side of the body of the UAV.

Technical Characteristics of the RHP-2 VTOL UAV

Gross weight	673 lb
Payload	175 lb
Rotor radius	16 ft
Endurance	1 hr
Range	5 nm
Ceiling	2,000 ft

Spraying-Capable UAVs: C50/C80/C100/CT100

- Produced by Tactical Aerospace Group in the US
- Payload capacity in excess of 40 lb
- Can be programmed to dispense payload in a precise pattern
- GPS based flight navigation system



Tactical Aerospace Group (TAG) produces “high performance UAV VTOL technology for advanced applications and payloads.” The company advertises its C50, C80, C100, and CT100 models as capable of performing a wide variety of scientific, commercial, and civilian missions, including agricultural spraying. The company’s Internet website describes the “flexible and precise spraying” capabilities of its UAVs as follows:

With a payload capability in excess of 40 lb and a GPS-based flight navigation system, TAG UAVs can take on the role of ‘Crop Duster’ when fitted with tanks of liquid pesticide and programmed to dispense the chemicals in a precise pattern over cropland.

Able to take off and land independently of an airfield, these unmanned helicopter[s] can fly crop dusting missions much lower and slower than a conventional aircraft sprayer, ensuring that the chemical payload lands only where intended and reducing the risk of inadvertent exposure to pesticides for pilots and bystanders.

Spraying-Capable UAVs: Mitigation Considerations

- **Mitigation possibilities with the original equipment manufacturers (OEMs) based on**
 - Unusual sales (source, quantity)
 - Unusual requests for training
- **Mitigation possibilities based on regulation**
 - Possibility of putting these agricultural systems under an “arms control” regime

Our limited research discovered only one domestic and a few foreign manufacturers of these spraying-capable UAVs. Terrorists would likely want to buy more than one system for the following reasons: (1) potential damage during practice; and (2) the capability for multiple missions.

Direct contact with the OEMs to ask them to voluntarily provide information on suspicious sales or inquiries might work for the US producer, but probably would not work elsewhere. We believe that the foreign companies would not cooperate because they would suspect that the data would be used by potential US competitors. It may be possible to work with friendly foreign governments to obtain the information.

The limited number of foreign OEMs could, however, be targeted for intelligence collection activities. Any purchase of more than one system at a time should be considered suspicious and therefore investigated. If someone is buying it for use on his/her own land, one system is probably enough to start. If someone is purchasing it for use as a service provider, owning more than one might make business sense, but it seems more likely that the quantity is built over time, not all at once. Purchases, or even inquiries for information could also be correlated with known terrorist individuals or fronts.

It is likely that the OEMs are the training providers. A terrorist scenario could be more demanding—flying a distance to the target vs. transporting the UAV close to the spraying area; greater ability to control at a distance; etc. These may imply unusual training questions or requests, but not necessarily so. Again, intelligence monitoring is a possibility.

Finally, sales might be regulated in some way, even if voluntary cooperation is not forthcoming. If there were some sort of notification requirement on orders, an investigation between order time and delivery time might be sufficient to check the legitimacy of the buyer.

Exploring Payload Capacity: Fully Assembled System Basis

Large Model Airplanes Can Be Used To Achieve Terrorist Objectives

- An explosive air burst has a much more devastating impact on people than does detonation on the ground
- The larger the UAV, the larger the payload, the larger the effect
- The payload capacity runs, typically, between 15% and 25% of the take-off gross weight for a fixed wing UAV (depending on design mission and maximum speed desired)

For instance, if you have a 50 lb payload, the aircraft will need to weigh, at minimum, 200 lb. This will be a slow speed, “loiter” type UAV. If high speed flight is desired, the vehicle weight will grow to ~300 lb.

Large Model Airplanes: Swordfish

- So-called “model” aircraft are a tech-base that can support sizeable remotely-piloted vehicles
- GTOW can exceed 150kg (airworthiness certificate required)
 - <20 kg are common
- High levels of flight reliability are achieved
 - \$\$ investment
 - 100+ flights/model



Many of the pictures we are about to show you are one-of-a-kind, handcrafted models that can take 2 to 3 years to fabricate and assemble. However, there are numerous companies that sell nearly ready-to-fly models and kits of large aircraft. Cost of these aircraft can start at ~\$2,000 and run up to ~\$20,000 depending on the materials, complexity and state of assembly.

The models that are commercially available typically weigh less than 55 lb; however, some jumbo models are obtainable. The commercially available aircraft are also not designed to carry a payload or cruise from point to point, but rather fly for a short time (~15 min) around an airfield while in visible contact with the pilot, but modifications could be made to give them greater capability.

Large Model Airplanes: Passenger Jet Model – Dehaviland Comet



- Some very large models have been equipped with true turbojet engines



Large Model Airplanes: RAF Vulcan



RAF Vulcan
bomber—yes this
is really a model!



**Large Model Airplanes:
Other Examples—These Are All Flight-Proven**



Many Available Models Are Fully Flight Ready

- German model
- 10-ft wingspan
- 16 HP engine
- ~€5000



Large Model Airplanes: Mitigation Considerations

- **Quantity buying or repeat purchases may offer mitigation potential**
 - The large-scale systems are expensive enough to deter enthusiasts from buying 3 or 4 systems at once, they would buy 1 and treat it with loving care
 - If the enthusiast did buy more than 1, it would be over a range of time to put into aircraft as they were manufactured (maybe 1 system / year)
- **Training requirements may be both a deterrent, and a mitigation consideration**

As was the case for spraying-capable UAVs, quantity buying of large model airplanes should be investigated. While there are many hobby shops where these large models can be purchased, there are a limited number of OEMs. Foreign OEMs could be monitored as was described for spraying capable UAVs – through cooperation of friendly governments or through intelligence activities. Voluntary cooperation from domestic sources may be feasible. We don't know to what extent the FBI could monitor activities if the company refused to cooperate voluntarily.

If someone had no experience with remote-controlled aircraft, the path to flying a large UAV would require significant time and experience.

Requires either many flight hours with small, inexpensive remote-controlled aircraft to learn basics of flight, or flight training from a company or an individual

If the goal is only to take off, get the aircraft flying, and turn on an auto-pilot that would fly aircraft by waypoints (a possible terrorist scenario), the required skill level is reduced significantly. However, a terrorist probably would not neglect developing that skill. He/she would not want to crash models during the learning period and especially not during practice for the mission. "With some jumbo models costing as much as a car, all those crashes add up fast. The radio controllers by themselves can cost \$2,000 or more. It is no coincidence that the hobby draws many retirees with plenty of disposable income." <http://jscms.jrn.columbia.edu/cns/2005-05-03/bario-jumboplanes>.

Flyers of large model airplanes are a relatively small, tight-knit group. A novice wanting training in flying a large aircraft model (aircraft weight > 50lb) would be highly unusual. Voluntary cooperation from these groups to report suspicious activity may be feasible as well as possible FBI involvement. For example, there is an Official Academy of Model Aeronautics that publishes safety codes and other guidelines.

Exploring the Propulsion Subsystem

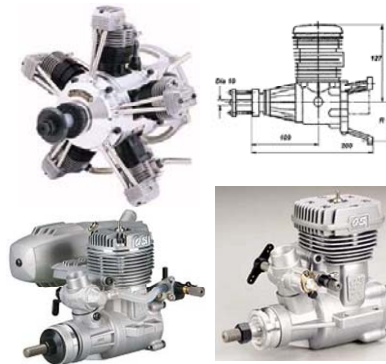
The Engine Can Have Significant Impact on Achieving Terrorist Objectives

- Greater engine power (coupled with smaller size) enhances UAV speed, range, and potentially endurance
- This will enhance utility for terrorists
 - Greater standoff implies a lower probability of apprehension after launch
 - Greater power enables the use of larger UAVs with correspondingly larger payloads

Jet engines with ~50 lb thrust are adequate for a 150 lb aircraft; this allows flight speeds up to ~150 kt with a range of about 40 mi and ~25 lb of payload.

A Wide Variety of Small Engines

- Some are designed for aircraft models
 - Up to several HP!
- Others adapted from commercial equipment



These are hobbyist engines, but others are available as well.

Microturbo Turbojet Engines for Missiles, Target and Reconnaissance Drones



Professional grade aviation and military jet engines are also available commercially on the open market. A URL is shown on the graphic. The material pictured is from a French company that is one of the biggest producers.

Engine-Related Mitigation Considerations

- Many engine sources, both domestically and internationally
- Probably impractical to investigate all purchases

We do not see any workable mitigation considerations in this area.

Exploring the Autopilot Subsystem

The Autopilot Can Have Significant Impact on Achieving Terrorist Objectives

- An autopilot combined with a GPS guidance and auto-takeoff-and-land capability will enable precision guidance and control
- This will enhance utility for terrorists
 - It increases the probability of hitting the target in the most damaging way
 - It decreases the vulnerability at launch since it allows for more surreptitious operations

The available systems are GPS capable; some even are designed to be compatible with differential GPS (DGPS). Standard GPS uses the timed signals from 3 or 4 satellites to locate itself. DGPS is a GPS receiver that can use satellite distance errors broadcast from a GPS receiver with a known location to correct its position. The system works because a known location can calculate its current satellite derived location and then calculate the errors due to things such as atmospheric delays. This error is then broadcast. Because the errors due to atmospheric delays affect all receivers in an area the same, the error for the fixed location is approximately the same as the moving GPS receiver. Using this error signal and its own calculated position, a DGPS can improve the accuracy from 50 –100 m for standard GPS to less than 10 m. The development of DGPS was one of the reasons that the selective availability option of the GPS system was disabled.

Many of the autopilot systems have auto-takeoff-and-land capability and can control aircraft up to 275 kt and 2 g

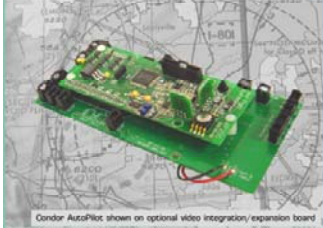
Most systems also come with ground station software.

Some even have 6-DOF simulator that can be used to generate the aircraft's control laws.

Autopilots

Expected Availability early 2008

Condor AutoPilot
Flight Management System



Specifications

- ARM7 32-bit CPU (lowpower)
- 1.5 mW radio
- Integrated GPS, comm link, altimeter, airspeed sensor, 3-axis sensors
- Busc system provides flight, stabilization/navigation
- Calibus SPI, RS-485 interfaces
- Size: 125mm X 50mm X 25mm
- Weight: 40 grams

Condor AutoPilot shown on optional video integration/expansion board

Autopilots are being sold on the open market.

Micropilot system is another company where you can buy everything for <\$20K.
http://www.micropilot.com/prod_mp2028g.htm

Autopilot-Related Mitigation Considerations

- **Complexity may be a deterrent**
 - Set-up can be complex to and may require contact with manufacturer
 - Given adequate time, resources, and background (electronics and aircraft design), someone might be able to understand and incorporate off-the-shelf systems into aircraft w/o outside technical assistance
 - More difficult to set up for auto-takeoff-and-land capability than waypoint flight; auto-land not necessary to make aircraft crash where desired
 - Mastery of one autopilot and its integration into a UAV does not imply the same capability with an autopilot from a different manufacturer
- **May be too difficult to monitor suspicious purchases from suppliers**

Although there are a limited number of autopilot suppliers (we think about 12), it may not be an effective use of resources to try to monitor quantity purchases. Purchases of one or two from each source over a period of time would be hard to detect. Autopilot components could be purchased separately. This is probably common in the hobbyist community for upgrading capability and to replace damages. Hobbyists may purchase one controller and multiple sets of sensors and move the controller from aircraft to aircraft (changing the control system gains for each aircraft). This would be the most cost-conscious way.

Outline

- Background assumptions and motivation
- What we learned early (we aren't the first...)
- What we can add
- Conclusions

Conclusions (1 of 2)

- While a wide range of scenarios using improvised or commercially available precision-guided UAVs at stand-off ranges are possible, many of the more interesting ones can be analyzed through their effectiveness in achieving terrorist objectives
- Attributes associated with effectiveness can be used to identify warning indicators
- These warning indicators imply mitigation considerations

We believe that our approach has utility.

Conclusions (2 of 2)

- **Some very preliminary mitigation considerations are beginning to emerge**
 - Monitoring purchases of individual components does not appear to offer much potential
 - Correlating purchases with known bad guys may help
 - Monitoring suppliers of all-up special purpose UAVs may be viable and worthwhile
 - Monitoring trainers has promise
 - There are a limited number of providers of training and simulation devices for sensory UAVs
 - Some out-of-the-box ideas may be worth considering
 - Watch center for stolen UAVs
 - Locator chips
 - Regulations on UAV operations and/or security
- **Further effort is needed to flesh out both terrorist options and their implications to develop recommendations for specific action**

Within the scope of this very modest research project, we were able to generate some ideas that warrant further pursuit.

Follow-On

- **Thorough research on improvised or commercially available precision-guided UAVs**
 - Characteristics, sources, capabilities
- **Payload research**
- **Warning indicators**
- **Mitigating actions**
- **Maybe even something on how to shoot them down**
- **Risk analysis**

There are many potential follow-on possibilities, some of which are shown above. Pursuing any of them would be dependent on sponsor interest. With a very small amount of money, we have demonstrated a feasible approach and some interesting topics for further analysis. We need some assistance in identifying who and how to market for additional funding.

Some level of risk analysis should also be a part of a larger study. The list of terrorist possibilities is too long to deal with. Questions to be addressed may include: Under which circumstances would a terrorist use a UAV? What would the payload be under those circumstances? The answers may serve to help focus the potential targets and scenarios to a manageable set, and provide a further basis for selecting among mitigation strategies.

REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.					
1. REPORT DATE (DD-MM-YY) October 2005		2. REPORT TYPE Final		3. DATES COVERED (From - To)	
4. TITLE AND SUBTITLE Terrorist Use of Improvised or Commercially Available Precision-Guided UAVs at Stand-Off Ranges: An Approach for Formulating Mitigation Considerations				5a. CONTRACT NO. DASW01-04-C-0003/W74V8H-05-C-0042	
				5b. GRANT NO.	
				5c. PROGRAM ELEMENT NO(S).	
6. AUTHOR(S) Jay Mandelbaum, James Ralston, Ivars Gutmanis, Andrew Hull, Christopher Martin				5d. PROJECT NO.	
				5e. TASK NO. C6172	
				5f. WORK UNIT NO.	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Institute for Defense Analyses 4850 Mark Center Drive Alexandria, VA 22311-1882				8. PERFORMING ORGANIZATION REPORT NO. IDA Document D-3199	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Institute for Defense Analyses 4850 Mark Center Drive Alexandria, VA 22311-1882				10. SPONSOR'S / MONITOR'S ACRONYM(S) IDA	
				11. SPONSOR'S / MONITOR'S REPORT NO(S).	
12. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution unlimited.					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT After providing some supporting evidence for terrorist use of UAVs, the report suggests an approach for analyzing terrorist options. While a wide range of scenarios using improvised or commercially available precision-guided UAVs at stand-off ranges are possible, this research demonstrated that many of the more interesting ones can be analyzed through their effectiveness in achieving terrorist objectives. Attributes associated with effectiveness were determined and then used to identify warning indicators that in turn implied preliminary preparedness and mitigation considerations.					
15. SUBJECT TERMS terrorism, unmanned aerial vehicles, UAVs					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT UU	18. NO. OF PAGES 102	19a. NAME OF RESPONSIBLE PERSON Mr. Jay Mandelbaum
a. REPORT U	b. ABSTRACT U	c. THIS PAGE U			19b. TELEPHONE NUMBER (Include Area Code) (703) 845-2123

