Mission Planning and Control

MODULE - 5

Air Vehicle and Payload Control

- **The remote operators**, usually assisted by computers located both on the ground and in the AV, must perform the functions of the aircraft commander, pilot, copilot, radar and/or weapons operator, and any other functions that would be performed by humans onboard for a manned system.
- While not all of these functions are present in every manned aircraft or every UAV, a **pilot** is always required, and for all but the most basic UAV missions a separate **payload operator** commonly is used.
- There always must be an **aircraft commander**, but in many manned aircraft that function is combined with that of the pilot.

Air Vehicle and Payload Control

- However these functions are divided between the **"air crew**," they all are required. There are significant differences in the issues and tradeoffs associated with how each is performed.
- For the purposes of this discussion, we define **the key functions** as follows:
- **Piloting the aircraft:** making the inputs to the control surfaces and propulsion system required to take off, fly some specified flight path, and land.
- **Controlling the payloads**: turning them on and off, pointing them as needed, and performing any real-time interpretation of their outputs that is required to perform the mission of the UAS.
- **Commanding the aircraft**: carrying out the mission plan, including any changes that must be made in response to events that occur during the mission.
- **Mission planning**: determining the plan for the mission based on the tasking that comes from the "customer" for whom the UAS is flying the mission.

Air Vehicle and Payload Control
Modes of Control

There are a number of modes of control that require various levels of **operator interaction with the AV**:

- **Full remote control:** the humans do all the things that they would do if they were onboard the AV, basing their actions on sensor and other flight instrument information that is downlinked to the operator station and implemented by direct control inputs that are uplinked to the AV.
- **Assisted remote control:** the humans still do all the things that they would do if they were on the AV, based on the same information downlinked to them, but their control inputs are assisted by automated inner control loops that are closed onboard the AV.
- **Exception control:** the computers perform all the real-time control functions based on a detailed flight plan and/or mission plan and monitor what is happening in order to identify any event that constitutes an exception to the plan. If an exception is identified, the computers notify the human operators and ask for directions about how to respond to the exception.
- **Full automation:** the only function of the humans is to prepare a mission plan that the UAS performs without human intervention.

Air Vehicle and Payload Control
Piloting the Air Vehicle

- At the most basic level, modern autopilots are capable of taking off, flying any desired flight plan, and landing without human intervention. This is possible because there is a relatively well-defined set of situations and events that call for an equally well-defined set of pilot responses
- Most pilots would say that this oversimplifies the role of the pilot and neglects the “art” and nuance that a good pilot applies to his control of the aircraft. That certainly is true.
- However, for the rather routine flying that is involved in most UAV missions today, the software in the autopilot may be adequate to fly the aircraft in a manner that would be hard to distinguish from what would have happened with a live pilot at the controls.
- In fact, under normal circumstances an autopilot may be able to fly the aircraft better than the best human pilot.
- Many state-of-the-art fighter aircraft operate near the boundary of instability, and always have an autopilot assisting the human pilot to maintain stability by making small control adjustments with a bandwidth and sensitivity that a human cannot match.

Air Vehicle and Payload Control

Piloting the Air Vehicle

Remote Piloting

- It is possible directly to pilot the AV remotely with little or no autopilot assistance, as was implied by the now-abandoned terminology "remotely piloted vehicle."
- This is particularly applicable to small AVs using technology similar to model airplanes, particularly within line of sight.
- Beyond line of sight, the piloting must be based on visual cues from onboard cameras and flight instruments using information from onboard sensors transmitted on the downlink.
- In this case, the human pilot has to have significant piloting skills, to include a capability to fly the AV based on the instruments alone should the imaging sensors fail or be rendered useless by fog or clouds.
- In the early days of military UAVs, this mode often was used for takeoff and/or landing with the remainder of the flight being performed using one of the more automated modes.
- There can be serious issues in directly piloting the aircraft if there are significant delays in the up- and downlinks of the data link, as is certain to be true when the data link uses satellite relays to allow the "pilot" to be on another continent from the AV.
- These issues relate to responding to turbulence and other rapidly changing conditions.
- The most straightforward, and perhaps only, solution to that problem is to use an autopilot-assisted control mode when there are significant delays in the remote control loop.

Air Vehicle and Payload Control

Piloting the Air Vehicle

Autopilot-Assisted Control

- piloting the air vehicle in the form of operator commands that are relative to the present attitude and altitude of the AV.
- In this case, the operator commands a turn right or left and/or climb or descent, including some indication of the rate of turn, ascent, or descent, and the autopilot converts that command into the set of commands to the control surfaces that will accomplish the intent of the operator while maintaining AV stability and avoiding stalls, spins, and excessive maneuvering loads.
- The assisted mode may be the primary mode for small systems using very simple control consoles and intended for operation largely within line of sight of the operator. It is simple to implement, flexible in operation, and suitable for controls.
- The assisted mode requires more pilot training and skill than a fully-automated mode, and some users have required AV operators using such systems to be pilot qualified.
- Landing is in many ways the hardest thing that a pilot does, particularly in bad weather, gusting, and/or crosswinds. If the landing is fully automated, whatever mode may be used during the rest of the flight, then the piloting qualifications of the operator can be relaxed.

Air Vehicle and Payload Control

Piloting the Air Vehicle

Complete Automation

- Many modern UAV systems use an autopilot to automate the inner control loop of the aircraft, responding to inputs from onboard sensors to maintain aircraft attitude, altitude, airspeed, and ground track in accordance with commands provided either by a human AV operator or contained in a detailed flight plan stored in the AV memory.
- The human inputs to the autopilot can be stated relative to the earth as the map coordinates of waypoints, altitudes, and speeds. In a modern system using a GPS navigator, it is not even necessary to require that the operator deal with airspeed and headings, taking into account the direction and speed of the wind through which the AV is flying.
- This mode of control could be called "fly by mouse" or perhaps "fly by keyboard" as it is basically a digital process in which coordinates, altitudes, speeds, and, perhaps, preplanned maneuvers contained in libraries, such as orbits of various shapes, are strung together on a computer on the ground and the autopilot does the rest.

Air Vehicle and Payload Control
Controlling Payloads

most of the possible payloads fall into one of a few generic classes:

- Signal relay or intercept payloads
- Atmospheric, radiological, and environmental monitoring
- Imaging and pseudo-imaging payloads

Air Vehicle and Payload Control

Controlling Payloads

Signal Relay Payloads

- the primary characteristic is that their mission involves detecting electromagnetic signals and either (1) amplifying and retransmitting them or (2) analyzing and/or recording them.
- In the relay case, the mission plan is likely to be very simple, consisting of orbiting at some position over the area to be supported by the relay and relaying some set of signals whose frequency and waveform is well specified.
- In the intercept case, it is likely that the mission plan also involves orbiting at some location and receiving signals in specified frequency bands and of specified waveforms, but there is a significant additional function that may be required in real time, which is to analyze those signals and exploit their content.

Air Vehicle and Payload Control

Controlling Payloads

Atmospheric, Radiological, and Environmental Monitoring

- These missions are similar to the signal intercept mission in the sense that they monitor information sensed by specialized sensors on the AV and downlink and/or record those readings as a function of time and location.
- If there is no requirement for real-time or near–real-time response to unusual readings, the mission plan consists of flying some specified flight plan while operating the sensors and, at most, monitoring the operation of the sensors. This type of mission can be fully automated with no more than exception reporting and intervention

Air Vehicle and Payload Control

Controlling Payloads

Imaging and Pseudo-Imaging Payloads

- Imaging and pseudo-imaging payloads present a special challenge for automation of the operator function because the ability of the human eye–brain system to interpret images is not yet even nearly matched by any computer.
- Of course, if the only function of the sensor is to downlink and/or record images of preplanned areas, with no real-time interpretation, then the function of the operator is simply to point the sensor in the correct direction and turn it on and off.
- Similarly, there are some missions in which an imaging or pseudo-imaging system might be able automatically to detect objects of interest with reasonable reliability. In particular, if the sensor is a radar system or is augmented by a range-sensing subsystem, such as a scanning laser rangefinder, it may have a capability to reliably detect some special classes of object.
- Another important class that can reliably be detected by radar systems consists of objects that are moving across the ground, the surface of a body of water, or in the air.

Air Vehicle and Payload Control
Controlling the Mission

- One possible reason for a change in the flight plan has already been mentioned—loss of power. This is one of the more dramatic events that might be anticipated. Others include the following:
  - Loss of the command uplink of the data link
  - Loss of GPS navigation (if used)
  - Payload malfunctions
  - Weather changes
  - Change in flight characteristics (possibly due to structural damage)
  - Something that has been observed with the sensor payload that triggers a task that has a higher priority than the preplanned mission

Air Vehicle and Payload Control

Autonomy

- "Autonomy" is defined in dictionaries as the state of being self-governing or self-directing. Its basic meaning in the context of a UAV or UAS is that the system is capable of carrying out some function without the intervention of a human operator.
- In terms of the aircrew functions, this might be thought of as replacing the aircraft commander with a computer exhibiting "artificial intelligence" while also delegating complete, unassisted, and unsupervised piloting of the aircraft to an autopilot that takes general directions from the computerized aircraft controller.
- The objective of the research in autonomy goes beyond this to attempt to make computers capable of making decisions that require something that might be called "intelligent judgment."
- The well-known "Turing Test" for an "intelligent" computer requires the computer to be able to carry on a conversation (using text messages) that cannot reliably be distinguished from a conversation with a human.
- Using this "UAV Turing Test" and our specific definition of the core control functions for a UAS, we can make some general observations.
- We conclude from this that the basic issues for system-level autonomy are as follows:
  - Real-time interpretation of sensor information
  - Response to exceptions that require alteration of the mission plan

Payloads

- The term "payload" is reserved for **the equipment that is added to the UAV** for the purpose of performing **some operational mission**
- —in other words, the equipment for which the basic UAV provides a **platform and transportation**.
- This excludes the flight avionics, data link, and fuel.
- It includes sensors, emitters, and stores that perform such missions as:
  - **Reconnaissance**
  - **Electronic warfare**
  - **Weapon delivery**

Reconnaissance/Surveillance Payloads

- Reconnaissance payloads are by far the **most common used** by UAVs and are of **the highest priority for most users.**
- Even if the mission of a UAV is to gather some specialized information, such as **monitoring pollution**, it often is essential that it be able to **locate specific "targets"** on the ground for the purpose of **collecting data in the vicinity of those "targets**."
- These **payloads, or sensors** as they often are called, can be either **passive or active**.
- **Passive sensors do not radiate any energy**. For instance, they do not provide their own illumination of targets. **Photographic and TV cameras** are examples of passive sensors. Passive sensors **must rely on energy radiated from the target**, for example, **heat in the case of an infrared (IR) sensor, or reflected energy, such as sun, star, or moon light for a TV camera**.
- On the other hand, **active sensors transmit energy to the object to be observed and detect the reflection of that energy from the target. Radar is a good example of an active sensor.**

Reconnaissance/Surveillance Payloads

Three **key terms** used to describe the operation of the sensor are as follows:

- ***Detection*****:** Defined as determining that there is an object of interest **at some particular point** in the field of regard of the sensor.
- **Recognition:** Defined as determining that the **object belongs to some general class**, such as a truck, a tank, a small boat, or a person.
- **Identification:** Defined as determining **a specific identity for the object**, such as a dump truck, an M1 tank, a cigarette-class speedboat, or an enemy soldier.

Reconnaissance/Surveillance Payloads
Imaging Sensors

- A sensor is described as "imaging" if it presents its output in a form that can be interpreted by the operator as a picture of what the sensor is viewing.
- In the case of a TV sensor, the meaning of an "image" is straightforward. It is a TV picture of the scene being viewed.
- Imaging sensors are used to detect, recognize, and identify targets.
- The successful accomplishment of these tasks depends on the **interrelationship of the system resolution, target contrast, atmosphere, and display characteristics.** The means of image transmission to the remote operator (a data link) also is an important factor.

Reconnaissance/Surveillance Payloads
The Search Process

- The analysis methodology deals only with the static probability of being able to detect, recognize, or identify a target, given that it is present within the display.
- The mission requirements for using a UAV to search for something are conveniently discussed in terms of **military or pseudo-military applications** (such as police or border patrol) because those are the missions for which UAVs have been most often employed up to this time.
- Civilian search applications generally will fall into the same categories as illustrated by some examples cited in the discussion, so the conceptual framework developed by the military provides a good way to organize the discussion.
- One of the most common missions for a UAV is **reconnaissance and/or wide-area surveillance**.
- These missions require the UAV and its operator **to search large areas on the ground, looking for some type of target or activity.** An example might be to **search a valley looking for signs of an enemy advance.**

Reconnaissance/Surveillance Payloads
The Search Process

There are **three general types of search**:

- **A "point" search** requires the UAV to search a relatively small region around a nominally known target location.
- **An "area" search** requires the UAV to search a specified area looking for some type of targets or activity.
- **A "route" search** can take two forms. In the simplest case, the mission is to determine whether any targets of interest are present along a specified length of a road or trail, or, perhaps, whether there are any obstructions along a section of a road.

Weapon Payloads

We distinguish between **three classes of unmanned "aircraft" that may deliver some lethal warhead to a target:**

- UAVs that are designed from the beginning to operate in an intense surface-to-air and air-to-air combat environment as a substitute for the present manned fighters and bombers,
- General-purpose UAVs that can be used for civilian or military reconnaissance and surveillance but also can carry and drop or launch lethal weapons, and
- Single-use platforms such as guided cruise missiles that carry a warhead and blow themselves up either on or near the target in an attempt to destroy that target.

Other Payloads

- Radar
- Electronic Warfare: Electronic warfare (EW) payloads are used to detect, exploit, and prevent or reduce hostile use of the electromagnetic spectrum.
- Chemical Detection
- Nuclear Radiation Sensors
- Meteorological Sensors
- Pseudo-Satellites

Data Links

- A data link may use either a radio-frequency (RF) transmission or a fiber-optic cable.
- An RF data link has the advantage of allowing the AV to fly free of any physical tether to the control station.
- It also avoids the cost of a fiber-optic cable that usually will not be recoverable at the end of the flight.

Data-Link Functions and Attributes
Data-Link Functions

- **An uplink** (or command link) with a bandwidth of a few kHz that allows the ground station to control the AV and its payload. The uplink must be available whenever the ground control unit wants to transmit a command, but may be silent during periods when the AV is carrying out a previous command (e.g., flying from one point to another under autopilot control).
- **A downlink** that provides **two channels** (which may be integrated into a single-data stream). A **status (or telemetry**) channel transmits to the ground control unit such information as the present AV airspeed, engine RPM, etc., and **payload status** information such as pointing angles. The status channel requires only a small bandwidth, similar to the command link. The second channel transmits sensor data to the ground. This channel requires a bandwidth sufficient to deal with the amount of data produced by the sensors, typically anywhere from 300 kHz to 10 MHz. Normally the downlink operates continuously, but there may be provisions for temporary onboard recording of data for delayed transmission.
- The data link may also be used to measure the range and azimuth to the AV from the ground antenna, which will assist in navigating the AV and to increase the overall accuracy of target locations measured by the sensors on the AV

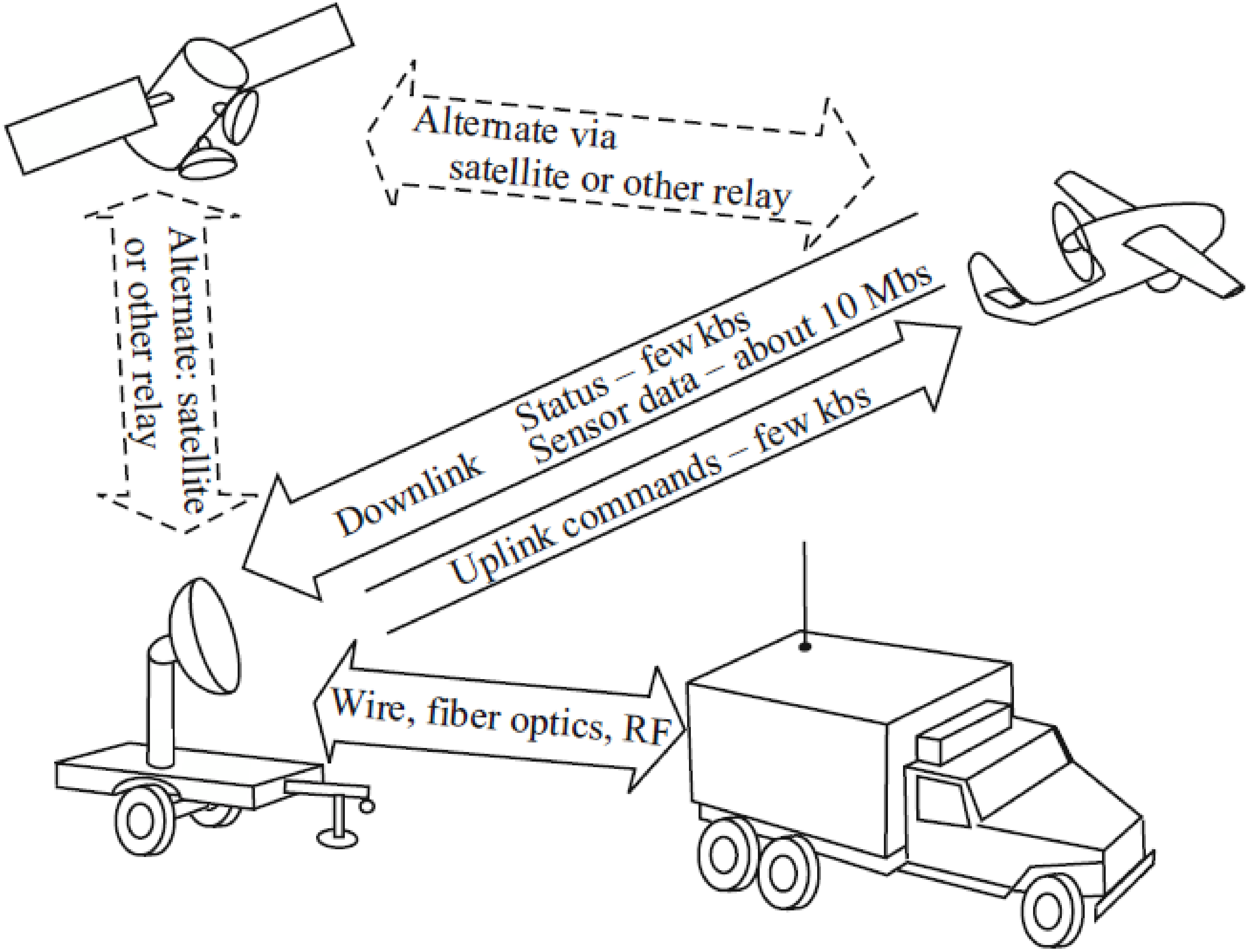

Figure 13.1 Elements of a UAS data link

Data-Link Functions and Attributes

Data-Link Functions

Data-Link Functions and Attributes
Desirable Data-Link Attributes

There are seven desirable attributes for a UAV data link related to mutual interference and EW:

- **Worldwide availability of frequency allocation/assignment:** Operate on frequencies that are available for test and training operations at all locations of interest to the user in peacetime as well as being available during wartime.
- **Resistance to unintentional interference**: Operate successfully despite the intermittent presence of in-band signals from other RF systems.
- **Low probability of intercept:** Difficult to intercept and measure azimuths at the ranges and locations available for enemy direction finding systems.
- **Security:** Unintelligible if intercepted, due to signal encoding.
- **Resistance to deception:** Reject attempts by an enemy to send commands to the AV or deceptive information to the GDT (ground data terminal).
- **Anti-ARM:** Difficult to engage with an ARM (anti-radiation munitions) and/or minimize damage to the ground station if engaged by an ARM.
- **Anti-jam:** Operate successfully despite deliberate attempts to jam the up- and/or downlink

Data-Link Margin