Appendix B

Capabilities and Technologies (condensed versions)

Capabilities

The following sections discuss the specific capabilities required to accomplish the missions listed in Appendix A. For each capability, a description will be provided followed by a status of the current capability to be contrasted with the required levels. A first-cut estimate of the mission need for that capability is given for each of the identified capabilities based on the outcomes of the workshops. If the capability supported at least half of the missions, it received a “High” indicator; if it supported at least 25% of the missions, it was given a “Medium” designation; and the remainder (those supporting less than 25%) were rated “Low”.

Access to the National Air Space

Need: High

Virtually all of the missions discussed will require access to either the United States national air space and/or foreign air space at some point in the flight pattern. Even missions intended for remote areas require access to get the aircraft to the area. Often, this will require access not only to United States air space, but foreign air space as well. Access to the National Air Space can only be obtained through certification of the aircraft or through a waiver termed a Certificate of Authorization (COA). There currently exists no method to certify a UAV through the FAA. Therefore, all UAV flight within the NAS has been obtained through certificates of authorization thus far. A certificate of authorization takes up to sixty days to obtain and only permits execution of a predefined mission flight path on specific dates at specific times and is typically valid for a very limited time period. Many of the missions require fast access to the air space; it is not sufficient to obtain a certificate of authorization because many of the missions intend to study phenomena which are not predictable sixty days in advance. The goal is to achieve seamless integration into the NAS (the so-called “file-and-fly” status) through certification which means that the flight may begin shortly after the flight plan is filed. This is the same system used for piloted aircraft. An FAA certification process must be established to achieve this. Several attributes of the UAV will likely be required to be assessed before it is granted a certification. One of these attributes is a method for the UAV to safely integrate into the air traffic system. This will require the UAV operator to respond in a timely fashion to commands from air traffic control. Typically changes to course, altitude, speed, etc. are required to avoid other air traffic. Another likely system is called contingency management which allows the vehicle to plan for an alternate course of action if something goes wrong requiring it to deviate from its original flight plan. Inherent in contingency management is a vehicle health management system which is capable of detecting anomalous conditions or situations. A third attribute is a collision avoidance system which allows the UAV to detect other aircraft and maneuver around them. In summary, the UAV must achieve the equivalent level of safety as a manned aircraft. A significant effort in systems sophistication, aircraft reliability, and policy/regulation development, including policy on operator training standards, will be required to accomplish this. The technologies discussed in Sections 0 through 4.3.2.5 are large contributors to this effort.

Currently, UAVs cannot fly in the air space in the manner described here. Developing the ability to provide “file-and-fly” is the goal of NASA’s HALE ROA Access to the NAS project (often called Access 5). This project is to be accomplished in four steps.

1) Develop and recommend policy to the FAA for routine UAV flight above 40000 feet assuming launch and recovery in controlled air space.
2) Develop and recommend policy to the FAA for routine UAV flight above 18000 feet assuming launch and recovery in controlled air space.
3) Develop and recommend policy to the FAA for launch and recovery in designated ROA-capable airfields.
4) Develop the technology (if necessary) for sophisticated contingency management handling.

Steps 3 and 4 are currently unfunded. The Access 5 approach towards achieving these goals is a seamless integration of UAVs into the air space with little to no additional requirements being placed on existing piloted aircraft. Before UAVs have file-and-fly capabilities, two other steps are necessary. Once the policy has been developed and recommended, it will still require FAA implementation. Finally, UAVs will likely need the on-board technology to satisfy the policies adopted by the FAA.

Command and control from an outside entity

Need: High

Typical UAV operations utilize a mission manager programmed during pre-flight to steer the vehicle around a prescribed course and altitude. Some mission managers will allow the operator to define new waypoints in flight. Future mission concepts require an ability for the aircraft’s mission manager to be directed during its mission from a number of sources, including a ground-based operator or scientist observer, other aircraft (e.g. formation flying), a payload sensor, or satellites. This ability to re-direct a flight is instrumental for tracking dynamic phenomena such as hurricanes or volcanic plume, for adjusting to unplanned phenomena of interest, and for steering around unplanned obstacles, such as adverse weather, to meet a mission objective. An enabling technology to meet this capability is OTH communication, where a ‘sensor web’ approach to the mission can easily be achieved. One consideration is that allowing other entities to take control of the vehicle provides a mechanism that hostile entities (e.g. terrorists, hackers) can take advantage of. The system which develops must preclude takeover by any hostile operations.

Currently some limited command and control authority can be exerted from a ground-based operator on some UAVs. However, the technology required for future missions has much broader implications on command and control in terms of the level of autonomy it interfaces with and the infrastructure that is implied. One example is in the scenario where the payload sensor ‘drives’ the platform.

Long Range and Endurance

Need: High

Many of the missions conceive of a platform, or series of platforms, which clearly extend range and endurance beyond the capability of existing vehicles. These missions require ranges of 10,000 to 13,000 nautical miles (18500 to 24000 km) and endurances between 24 to 72 hours. A few of the missions indicated that endurances up to two to three weeks would be beneficial, if feasible. In particular the long-endurance requirements of these missions, as conceived, highlight the necessity for a UAV platform.

Some existing production UAVs are capable of endurance in the 24 to 36 hour time frame. A few, notably Northrop-Grumman's Global Hawk, have significant range capability. NASA, in conjunction with several private companies, is working on the technologies to enhance this capability. Under the HALE ROA demonstrator project, NASA is developing several new aircraft with long endurance (one to two weeks) capability. The largest advances in technologies for these aircraft are expected to come in the propulsion and power generation areas.

Increased Platform Availability

Need: High

A key development for enabling future missions will be to increase the availability of the science platform for collecting data. In other words, future missions will require that the ratio between the amount of time the platform is either on a mission or ready to start a mission to the total time the platform is on deployment be increased. One key component in increasing availability is the ability to significantly reduce the amount of time to pre-flight and launch a mission. This not only increases the availability of the platform for data collection, but also increases the likelihood of being able turn a mission around to collect data on dynamic events as they are discovered. Electrical and power interfaces will have to be standardized. The ability to integrate varied payloads in a 'plug and play' capability is necessary for quick deployments and for quick turn-around between missions where a sensor package may change. Intuitive flight planning tools and pre-flight processes and an efficient process for downloading and archiving on-board recorded data will also be key factors in reducing the time on the ground. And platforms must allow maintenance and pre-flight procedures to be performed easily and efficiently. Another key component to increasing availability is increased platform endurance, which allows the capability to extend mission duration. Analysis of current piloted Earth Science missions show that significant costs are incurred based on payload integration and de-integration time, and pre-flight and post-flight preparation time. An added benefit to increasing availability is a lower cost per flight hour, as the personnel required to be on station are reduced.

Current technology assessments indicate limitations on availability are based on human endurance, turn–around processes, payload, aircraft and payload maintenance processes, and data downloading and archiving procedures. Taking the on-board pilot 'out-of-the-loop' and smart integration of these processes with intelligent vehicle health management technology, autonomous mission management technology, and the OTH web-based approach to communication will allow much greater aircraft availability. For example the ability of the flight planner to interface with the mission manager at the mission objective level will reduce the level of human involvement in pre-flight processes. Another example is the ability of the platform management system to identify when excess bandwidth exists in the OTH and then to download and archive on-board recorded data during the mission. This will reduce the level of human interaction in performing this function post-flight. NASA's Earth Sciences Capability Demonstration project is working on payload interface standards to facilitate the "plug-and-play" concept for payload integration. Much of this type of interface has not been done before and depends heavily on other technologies such as autonomous mission management.

Quick deployment times

Need: High

Several of the missions envisioned a UAV which could deploy within a few days to an area of interest and launch a mission to collect data on a dynamic phenomenon as it developed. The capability to quickly deploy ties together many of the other capabilities previously defined. Key enabling technologies are those that support access to the NAS, quick and efficient payload integration, an OTH network available when needed, and an intelligent mission management system which reduces pre-flight planning activity.

This capability is strongly linked with platform availability. Currently, quick and easy access to the NAS is not available but is being developed by NASA and the FAA. Payload interface standards have been developed to some degree and will be improved by NASA's Earth Science Capability Demonstration project. OTH capability will also be improved by the same project. The intelligent mission management capability, formerly covered in AuRA, will be developed by NASA's HALE ROA demonstrator project.

Terrain Avoidance

Need: Medium

To increase the spatial resolution for some missions, a requirement is placed on the platform to fly 500 feet (152 m) above ground level or even lower. The missions envision the use of both MAVs and UAVs in this capacity and may include flight in mountainous terrain. As such, complex flight path maneuvering and terrain avoidance is required of the platform's flight management system.

The technology for terrain avoidance and terrain following has existed for several years on military vehicles. Commercial airliners have employed an Enhanced Ground Proximity Warning System for many years. While the technology is available to implement this capability, the integration to the platform requirements still exists.

Formation flight

Need: Medium

A technology related to precision trajectories is the ability to fly a formation of aircraft maintaining precise distances between them. Formation flight provides the ability to carry a synchronized set of scientific sensors on a team of coordinated vehicles. In a flight formation, one entity would be the "lead"; all other aircraft would fly relative to the lead. The lead could be another UAV, a piloted aircraft, or even a satellite. While it is not expected that an aircraft would keep pace with a satellite, the ability to position the aircraft relative to the satellite is desirable. Formation flight can be thought as two separate capabilities. The first is a series of aircraft which might be hundreds of meters to several miles apart. In this case, precision is desirable, but sensors would need to work over large distances. The second capability is close maneuvering wherein a pair of aircraft would fly relative to each other in close proximity. This capability would be used to accomplish air refueling as well as a small aircraft "docking" to a larger one. Proximity sensors for this requirement would probably be different from large-distance formation navigation and would require accuracies down to the several-centimeter level.

Most UAV operations involve one aircraft on a single mission. It is expected that there will be a significant reduction of human operators necessary to control a group of UAVs leading to a reduction in cost per flight hour. The closest system to the "distant" formation is DOD's station keeping equipment, but accuracies for this capability are far less than what is desired for precision formation flight. Some components of the close formation technology have been successfully flight tested in NASA's Autonomous Formation Flight program and in the J-UCAS program. These technologies can be leveraged to meet the future science mission capability for formation flight.

Monitor/control of multi-ship operations

Need: Medium

Many of the future mission concepts require ground (operator) control of multi-ship operation and coordination. A key enabling technology which supports multi-ship missions is the over-the-horizon communication (see Section 0). Since a key motivation for using UAVs as an earth science platform is reduced cost per flight hour, the ability of one operator to monitor multiple vehicles significantly reduces the support personnel required on-station. Also, some of the missions describe coordination with mini- or micro- air vehicles.

Currently UAV operations involve one aircraft on a single mission. The concept for future missions, where one operator controls a team of coordinated vehicles, is just beginning to be developed with MAVs and J-UCAS. Part of the J-UCAS program is to develop the capability of four or more UAVs to operate as a coordinated team.

Precision aircraft state data

Need: Medium

Several missions required the ability to measure attitude data to relatively high precision (as high as 0.001 degrees). There is an additional requirement, however, for the aircraft to provide state data to the sensors or experiment packages. For example, the need for precise trajectories, accurate sensor pointing, and the onboard real-time geographically referencing of cameras all require accurate vehicle state data. The state data might be in the form of aircraft attitudes, position, ground speed, air speed, etc. While it is possible that each individual experiment packages might measure their own data, this approach would be cumbersome, expensive, and inconsistent with the plug-and-play philosophy. Provisions should be made for the UAV to accurately measure its state data and make it available to the experiment package(s).

For the most part, current technology can provide instruments capable of generating state data to the desired level of precision. Therefore, this capability exists but must be specified in the requirements for a given platform, and there will be a cost associated with the requirement.

High Altitude

Need: Medium

Many of the missions require a platform, or series of platforms capable of sustained flight at altitudes above 40,000 feet (12 km), with up to 100,000 feet (30 km) being desirable for some missions. A complicating factor in required aircraft design is performance for an aircraft which climbs to an altitude and cruises there versus an aircraft that must traverse wide altitude bands. The latter capability is called vertical profiling and is discussed in Section 0. An aircraft that will accomplish both high altitude and vertical profiling is decidedly more complex.

Although an important capability, the ER-2 and Global Hawk have routinely flown at most of the altitudes outlined in the future science missions. Therefore, the ability to fly at relatively high altitudes is an existing capability that only needs to be defined as a requirement in the aircraft development. One caveat is that some missions desired flight in the region of 100,000 ft (30 km) altitude. The Helios aircraft has flown in that altitude region, but it is considered to be a prototype and has limited payload capability. The inclusion of the 100,000 ft (30 km) requirement with a significant payload presents an added level of difficulty.

All-Weather

Need: Medium

Some of the missions, such as the Hurricane Tracking Mission, indicate that platforms are required to penetrate severe storms and fly in all types of weather, including icing conditions, strong wind shears, lightning, and severe convective environments.

Building a platform rugged enough to withstand flight in severe storms is within current technology. However this requirement places additional burdens on flight controls, and potentially platform performance goals, depending on the design solution of system. For example, it would be difficult to develop a high altitude, long endurance aircraft (which may require a “gossamer” design) which would also survive high winds and turbulence. One design solution for performing these is to launch a series of rugged MAVs into the storm from a mother ship. The mother ship can meet performance requirements without the burden of meeting this requirement. The technology currently exists to build all-weather aircraft, but the requirement must be stated at the time aircraft is developed. It is difficult to “retrofit” all-weather capability to an existing aircraft. All-weather capability will add to the cost of the aircraft design and construction.

Vertical Profiling

Need: Medium

Some of the missions depict the collection of spatial data in the vertical axis above a particular ground station of interest. Although drop-sondes can be used for a limited set of vertical spatial measurements, some of the missions envision the entire platform performing vertical profile maneuvers to collect the data. As such, the platform must deploy to a region of interest and collect data across a vertical profile from its altitude ceiling down to 1000 feet above ground level. This implies that the aircraft has sufficient performance and power to maintain a reasonable climb rate over the majority of its envelope which will impact the trade study for efficient climb versus efficient cruise.

Designing a flight management system to perform vertical profiling requires no new technology. Many current UAVs are capable of vertical profiling. However, the combination of vertical profiling and high altitude, long endurance may tax the aircraft designers.

Deploy / potentially retrieve

Need: Medium

One of the capabilities required for several of the missions is to have a UAV act as a mother ship for the deployment of drop-sondes, buoys, or small UAVs called daughter ships. In the case of the drop-sondes or buoys, the mother ship would release these at designated locations (pre-defined or initiated from the ground). The dispensing of drop-sondes or buoys is relatively simple but suffers from several drawbacks. First, the drop-sondes or buoys are not controllable; they are maneuvered only by the wind and gravity. Second, a long mission may require a large stock of drop-sondes or buoys to adequately cover the area of interest. This may have some significant consequences on mother ship payload weight and volume. Third, there are some environmental concerns about "littering" areas with many drop-sondes or buoys which may not be recoverable. An alternative to this approach is the use of daughter ships which would be launched, fly to an area to collect data, and then would fly back to the mother ship and re-dock. Daughter ship data would be downloaded to the mother ship and the daughter ship would be refueled for later use. This has the advantage that the daughter ships would be re-usable, so the mother ship would not need to carry nearly as many of them. The daughter ships would also be under the control of the mother ship so that precise areas for information gathering could be targeted. Daughter ships would be more complex and, consequently, more expensive, but their ability to be recovered and used again may offset the increased cost of purchase.

Deploying aircraft or drop-sondes from a mother ship has been done previously and does not require new technology developments. However, retrieving a daughter ship does require some technology development, principally in the area of precision state data and formation flying. Also, very little experience has been accumulated with the concept of re-docking. Lockheed-Martin has made some proposals involving launching and re-capture of UAVs. The common feeling is that if the technology exists to autonomously refuel a UAV, that same technology can be used to re-dock it. The concept of re-docking to a high altitude, long endurance aircraft is also without precedent.

Precision trajectories

Need: Medium

Several missions require the location of the UAV to be controlled very precisely. Flight trajectories within ±5 meters from the prescribed flight path are desirable. This capability requires both the real-time knowledge of where the UAV is and the ability to control or maneuver the UAV to the desired position in the sky. Additionally, some missions have constraints on the dynamics of the flight path so that high-gain system may not be suitable.

The development of UAV control systems to maneuver the aircraft correctly will be largely dependent on the characteristics of the UAV in question. For years autopilots have been designed that follow a given trajectory. The issue is whether a particular UAV system can be adjusted to provide the desired precision. Unfortunately the ability to achieve the desired precision is dependent on the type of aircraft. Aircraft with light wing loadings and low speeds are more susceptible to crosswinds and gusts which may hamper the ability to maintain an accurate position. Regardless of the controllability characteristics of the UAV in question, this capability has been demonstrated. The

Danish Center for Remote Sensing has demonstrated flights to approximately five-meter accuracy using a business jet. NASA's Earth Science Capability Demonstration project is pursuing the capability to maintain aircraft position with a 10-meter (or better) tube. However, the integration to UAVs on a wide scale has yet to be demonstrated.

Base of operations in remote area

Need: Low

The capability to deploy a small, inexpensive UAV from a remote location near an area of interest was conceived to obtain specific scientific data in remote areas. The requirement for this capability is a UAV platform which requires very little support equipment and minimal personnel for pre-flight, launch, and recovery. With this capability, range and endurance requirements on the UAV platform can be reduced. This concept may also impact the mode of operation for an autonomous ground station which could pave the way for a planetary-exploring UAV.

Certainly MAVs can be launched with minimal support personnel and equipment without any advances in technology; however the concept of a fully automated ground station has not been demonstrated. Using them for the Earth Science application may depend on payload sensor technology advances, since payload weight and volume capability is limited. Also, it is likely that high levels of automated mission management, intelligent flight control, and health monitoring may not be available because of the limited computation resources on a MAV. Therefore payload sensors on a MAV may have to be expendable. The construction of a more sophisticated, even autonomous, base of operations in a remote area (even the Moon or another planet) remains in the conceptual state only.

Covert Operations

Need: Low

A subset of the missions, primarily from the Homeland Security and wild-life monitoring communities, required platforms with low detection probability. Implicit in this requirement is low noise emission propulsion systems and low signal emissions.

Conventional propulsions have undergone low noise emission developments to support stealth for the military application and airport considerations for the commercial sector. Although certain propulsion systems, such as electric motors, provide very low emissions, it is unclear they can sustain some of the endurance and payload requirements envisioned in the missions. Development programs to enable more efficient electric motors are being conducted in both the commercial and government sectors that may enhance the capability for low noise operations.

Technologies

Technology Analysis

The following sections describe each technology in detail, summarizing development programs and forecasting maturation over the next 10 years. A determination of when the technology has matured enough to support the capabilities identified from the missions is provided where appropriate. More detailed information on the technology development can be found in Appendix G. Within the title of each technology section, a first-cut estimate of the need of that technology or capability is given. If the technology supported at least half of the missions, it received a "High" rating. If it supported at least 25% of the missions, it earned a "Medium" rating. The remainder (those supporting less than 25%) were rated "Low".

Autonomous mission management

Need: High

A high level of autonomy in the mission management function is required to take advantage of using a UAV platform to support the missions. Less direct human interaction in flying the UAV allows less on-station personnel, less on–station support infrastructure, and one operator to monitor several vehicles at a given time. These goals must be balanced with the requirement for the operator and vehicle to respond to air traffic control in a timely manner. The mission management system should also allow re-direction of the mission (including activating the contingency management system) from the ground. This would especially be useful for moving phenomena which cannot be adequately located prior to mission initiation. It is envisioned that the human interaction with the on-board mission manager system will occur at the mission objectives level. In the ideal scenario, the on-board mission manager, starting with the mission objectives, would be responsible for pre-flight planning, real-time flight path adjustments during the mission, and even real-time mission objective adjustments during the mission based on air traffic control and contingency management. It is also desired for the scientist or possibly the payload sensor to interact with the mission manager, as well as the operator responsible for the mission. Providing these functions will require a shift in the paradigm of how flight management software is currently written. The desired system is an open behavior system. This approach enables much of the capability conceived in the future missions, such as efficient mission re-tasking, increased platform availability, efficient contingency management, and coordinated team formation flying. As such it is highly dependent on the current condition at the time a behavior is executed and is difficult to precisely predict. Increasing the complexity is the fact that any intent to deviate from the original mission plan must be first conveyed to and approved by air traffic control prior to being executed. The level of autonomy in the system presents significant human factors challenges to the operator, who must maintain sufficient situational awareness of the intention and execution of the platform to fulfill his responsibility.

The level of autonomy in the future mission management function is significantly more sophisticated then exists with current UAVs. Additionally, verification and validation of these systems will be a challenge. Currently the Joint Unmanned Combat Air System program (J-UCAS) is employing a similar software approach to mission management. NASA, under the HALE ROA demonstrator program, is also working on a similar Intelligent Mission Management system. The TRL is estimated at 4, since some components of these methods are modeled in the simulation environment.

Collision Avoidance

Need: High

To fly with few restrictions in the NAS, UAVs will require some sort of collision avoidance system. The intent is to have an “equivalent level of safety” when compared to piloted aircraft. This system will allow UAVs to “see” or detect other aircraft (piloted or uninhabited) and avoid them. The technology for this system is decomposed into two elements “see” and “avoid”. The “see” portion involves the detection of intruding aircraft through some type of sensor. The “avoid” portion involves predicting if the intruding aircraft poses a danger and what course of action should be taken through a software algorithm. For sensors, the priority should be to detect aircraft at sufficient distance so that emergency maneuvering can be avoided. The first step in this development will be to implement a ***cooperative*** sensor for collision avoidance. Under the cooperative category, aircraft will have transponders or data links notifying other aircraft of their position. The second and more difficult portion is ***non-cooperative*** detection. In this case, the “other” aircraft does not share its position (as would be the case for many general aviation aircraft) and must be detected with radar or optics. For avoidance, sensor information must be used to predict future positions of host (ownship) and intruder aircraft to determine collision potential. If a collision potential exists, a safe escape trajectory must be derived and automatically executed if the operator has insufficient time to react.

Some significant work has already been done in this area. The NASA ERAST project tested both a cooperative and non-cooperative sensor. Also, the Air Force has completed a project evaluating an avoidance algorithm coupled to an automatic evasion maneuver. Both cooperative and non-cooperative sensors were demonstrated in the Air Force project with promising results. Collision avoidance systems are also being worked under NASA HALE ROA Access to the NAS project. The overall TRL for this technology is estimated to be at 6. However, no viable non-cooperative sensor or sensor suite has been developed to date placing this component at a TRL of 2.

Intelligent system health monitoring

Need: High

The ability of a UAV system to reliably identify failures and classify them according to their impact on vehicle safety and mission success is a key technology for flying UAVs with an acceptable level of safety. This technology, generic to any UAV application, allows intelligent contingency management based on the failed vehicle state and is a foundation for free access to the air space by UAVs. Additional cost benefits are accrued by using this system to monitor sub-systems for maintenance purposes. Identification of sub-systems as they deteriorate will focus maintenance efforts, decreasing the turn-around times between missions and reducing costs per flight hour.

Health monitoring concepts and limited systems have been around for some time, but comprehensive and generic systems have languished due to lack of funding. Specific systems have been developed and proven, particularly for new fighter aircraft. Additional work is in progress under NASA’s HALE ROA demonstrator project (previously under the AuRA program). An overall TRL of 5 is assigned.

Reliable Flight Systems

Need: High

The ability of a UAV flight system to adapt to system or hardware failures is a key technology for flying UAVs with an acceptable level of safety and perhaps the most critical system for the aircraft is the flight control system (FCS). This technology, generic to any UAV application, provides for high reliability and is one of the foundations for unrestricted access to the air space by UAVs. Initial reports from the FAA regarding UAVs indicate they are looking for "reliability comparable to a piloted aircraft". The issue of reliability can be addressed from two viewpoints. The first is basic reliability of the onboard systems. The second is the reliability of an on-board pilot in being able to recognize a failure and adapt to the situation (see Section 0 on Sophisticated Contingency Management). Both of these viewpoints must be considered in assessing the reliability of UAV flight systems. This technology is especially important for long endurance flights in remote areas, where options for recovery are limited.

One approach to system reliability is simply to increase the redundancy of flight systems. This comes with both an initial cost and an on-going weight penalty. Another approach would add on-board intelligence to recognize and remedy a failure. Simulations of adaptive flight control systems have shown promise for many years, and several methods of adaptive control have found their way to flight test projects. The latest of these is a neural-net based system scheduled to fly on an F-15 aircraft at NASA. It is likely that the final solution will be a compromise or combination of the two approaches. Based on ongoing intelligent flight control efforts, a TRL of 6 is assigned.

Sophisticated contingency management

Need: High

UAVs will require some level of contingency management system to all flight in the NAS. The on-board contingency management system should react to unforeseen events and failures according to the something like the following priorities:

1) Minimize expectation of casualty (E_c)
2) Minimize external property damage
3) Maximize the chance of aircraft survival
4) Maximize the chance of payload survival

For the long term, it will be unreasonable to consider many UAVs as expendable. In addition to the cost of UAV, the cost of its sensor suite (which may be one-of-a-kind) must be considered. Loss of the UAV and payload should only be considered when there is a significant risk to the general public or property. One of the primary contingencies to be planned for is the loss of link between the UAV and the operator. In this case, if the vehicle can not continue on its original mission plan the vehicle should have the capability to achieve an approved landing area while considering the priorities above and attempting to re-establish the communications. During these events, the UAV must have alternate means to communicate its intended flight plan. However, other contingencies must also be considered. These might include sensor or payload failures, aircraft failures, and other communication failures. The contingency management system should be able to decide, depending on the nature of the problem whether it should attempt landing at the airport it was based out of, or a landing at an alternate airport, or some other impact (ditch) in a remote area. Intelligent contingency management will also reduce the human oversight required for UAV flight and contribute to the goal or reducing mission costs.

Contingency management for UAVs at the level described will require a sophistication that currently doesn't exist. Relatively little development of this capability has occurred to date although several promising concepts have been proposed. Global Hawk and Predator have contingency management systems to some degree, although they lack the sophistication and intelligence that would be desirable for ease of use. NASA, under the HALE ROA in the NAS project, is currently working to define a UAV "code of ethics" and policy regarding contingency management systems. An overall TRL of 4 is assigned.

Intelligent Data Handling and Processing

Need: High

As UAV's become more ubiquitous in their use to gather science data or perform other civilian tasks, the gathering of very large amounts of data will become an operational hindrance, and provide an opportunity to the system developer. The ability to intelligently handle and process large amounts of data, either onboard the air vehicle, or on the ground immediately after being transmitted from the vehicle, is required. Technology that would provide this capability would significantly provide greater efficiency to the operator or payload scientist, and would help expedite vehicle turn-around, quick deployment, and multi-ship operations; particularly for long-endurance missions.

If this data analysis capability were to be available on the ground, and if high-bandwidth communication (probably satellite based, to enhance the timeliness of the action) is available, the air vehicle could transmit the data to the mission control center for quick analysis and possible mid-mission re-tasking.

The ability to process the data onboard goes a step further and becomes even more useful, because it doesn't require a high-bandwidth satcom capability. Intelligent onboard data handling and processing would lead to the use of onboard decision aids and intelligent payload-based mission management technology, which could result in efficient onboard mission re-tasking. Alternatively, onboard processing could allow only low-bandwidth high-order processed data being relayed to the mission planners for decision-making and mission re-tasking if necessary.

In addition, onboard processing and transmission could allow scientists quick and easy data retrieval, which could relate to faster post-mission processing and the beginning turn-around processing, all while the vehicle is still returning to base.

Intelligent data handling and processing would require technology innovations in automation and autonomous data analysis systems, efficient and effective techniques for assembling and processing large amounts of data, and intelligent searches of large distributed data sets.

For this technology a TRL of 2 is estimated.

Over-the-Horizon Communication

Need: High

A key technology that supports almost all of the future missions is the ability to transmit data over the horizon (OTH). This satellite-based communication capability is being used by the military today to provide UAV over-the-horizon C2, FAA air traffic control communication, and sensor data transmission. Although low-bandwidth OTH communication is used by civilian UAV's, access to OTH resources for high-bandwidth civilian use is limited and needs to be expanded. Also, the issue of OTH communication being non-interruptible, jam resistant, damage tolerant, and all-weather capability must be addressed. The OTH technology must also include the ability to pass high bandwidth data from remote areas or at extreme latitudes such as the poles.

In addition, it will be very valuable to develop a "web-based" network capability to OTH communication (see Network-Centric Communication technology section). The vehicle, operator, and payload scientist would be seen as nodes of the network. For example, this approach means that an operator in California could control an aircraft flying over the North Pole while a scientist in Washington, DC was monitoring the vehicle's science data. Additionally, this network concept for OTH communication should be configurable based on the data flow requirements for a given mission. In other words the network should be able to provide the level of bandwidth required for a given mission so that missions which don't require high bandwidth communication do not have to pay for the resources necessary to affect it. This technology will reduce the cost per flight hour by creating more efficient data handling and reducing the need for personnel at the base of operations.

However, the concept described here significantly expands the concept of OTH communications. Adjustable bandwidth's and a 'web-based' use are concepts that still require significant technology developments. There is strong interest in this concept from both civilian (NASA) and DOD agencies. NASA is pursuing this technology under their Earth Sciences Capability Demonstration project in conjunction with the Integrated Network Enhanced Telemetry (iNet) efforts. For this technology a TRL of 3 is estimated.

Network-Centric Communication

Need: High

Network-centric communication is a command and control and sensor data communication architecture concept that is comprised of multiple directional, asymmetric links that provide a network communication approach – similar to the Internet. This communication architecture is under development by the military for use between manned and unmanned air vehicles and personnel within a particular battle space – but it is also needed to enhance civilian UAV operations, communications, and science data flow. For a given mission, key elements within the UAV's mission are to be considered as a node; data can then flow to and from any node to any other node. Examples of nodes are the UAV operator, a scientist observer, the vehicle platform's mission manager, satellites orbiting overhead, the vehicle's payload, other aircraft, remote command and control locations, etc.

Although the obvious key benefit is increased command and control and data routing flexibility, this same flexibility also adds communication signal protection, allowing entirely different received and transmitted radio waveforms that can be used to advantage to provide more secure communication.

In concept, the network should be available with very little interface required by the mission planning team. Additionally, the network should be bandwidth configurable based on the data flow requirements for a given mission. This technology will reduce overall operational cost by creating more efficient data handling and reducing the need for personnel at the located at the UAV's primary base of operations.

NASA is pursuing this technology under their Earth Sciences Capability Demonstration project in conjunction with the Integrated Network Enhanced Telemetry (iNet) efforts. For this technology a TRL of 3 is estimated.

Open Architecture

Need: High

Many civilian UAV mission requirements require quick deployments and/or quick turn-around times between flights. These requirements have implications on the UAV's system architecture – and thus the need for open architecture.

Open architecture is envisioned as a system design technology that literally provides a "plug and play" capability within the UAV system. If a UAV system or its modular payload component has an operational problem – ground maintenance personnel can easily and quickly replace the faulty element. Sensors, sensor systems, and even mission payloads could be designed as modular components for easy change-out between storage and air vehicle, or from air vehicle to air vehicle – in some cases, even if the air vehicles are different.

Open architecture could encompass the advanced communications systems network at well. As the air vehicle's communication system moves towards a more generic network centric design, some vehicle-system communication elements could be designed with the same quick change-out methodology as well.

For this technology a TRL of 4 is estimated.

Power and Propulsion

Need: High

Many missions call for flight to high altitudes, to have long endurance, or to fly within "dirty" air (such as through the smoke plume of a forest wild fire). Such missions will require specially designed power and propulsion technologies.

A high-altitude flight requirement typically dictates the use of turbine engine propulsion – or for slower flight, the use of electric propulsion; each of which are well developed and demonstrated at this point. If internal-combustion engine technology is desired for this flight requirement, due to its inherent low cost and relatively low rate of fuel consumption, a two-stage turbocharger can be used – and this has been demonstrated.

For long endurance flight, the propulsion options are varied, and continue to be developed. Typically, conventionally powered long-endurance vehicles require a fuel load equal to 40% to 60% of their gross takeoff weight. This, in turn, provides design and payload tradeoffs that can limit function. Another method that has been used with long-endurance UAV's is to use solar power and electric propulsion. Solar power cells, more technically known as "photovoltaic (PV)" cells, are not very efficient (with modern technology conversion factors on the order of 18%-21%), and the amount of energy provided by the Sun over a unit area is relatively modest. This means that a solar powered aircraft must be lightly built to allow low-powered electric motors to get it off the ground. Considerable technology development in this area is required.

Clearly, for long endurance and high altitude flight, electric propulsion is a key technology and one that hold great promise. New technology is being developed in many areas: high-efficiency and high-torque brushless “outrunner” motors, advances in non-silicon flexible PV technology that could be used as embedded aircraft skin, advanced standard and regenerative fuel cells, and advances in lithium polymer battery technology hold great promise. Other relevant technologies could also enhance long endurance flight with conventional engines: efficient combustion technology, intermittent combustion, hydrogen engines, and new efficient power management and distribution technology are being pursued.

For the advanced technologies discussed, their TRL’s are estimated to vary within the range of 3 and 5.

Navigation Accurate System Technology

Need: Medium

The need for navigational accuracy within the UAV’s onboard system is required for a number of mission tasks. For example, the need for precise trajectories, accurate sensor pointing, and the onboard real-time geographically referencing of EO or IR pictures all require accurate vehicle position and attitude data.

Such navigation accurate technology can be obtained with current technology. A vehicle’s position can be easily obtained onboard with a GPS receiver. And the vehicle’s 3-axis attitude can be determined with an onboard inertial measurement unit (IMU).

However, standard GPS data may not be sufficiently accurate. In this case, the use of differential GPS (dGPS) data, to correct the embedded random GPS errors, may be necessary. This is available real-time onboard a UAV by use of a small omni-directional antenna and a subscription to commercial satellite-based data. Normal computation drift of a miniature IMU can also be self-corrected by use of the accurate GPS data. NASA’s Jet Propulsion Laboratory (JPL) has flight tested a Global Differential Global Positioning System (Global DGPS) which advertises accuracies in the 10 centimeter range over populated land areas and 50 centimeter range over areas like the North and South Poles.

This navigation and attitude data is then used to either point on onboard camera to a desired GPS location on the ground; or the reverse, to calculate the ground location of an object that was visually captured by the science payload.

All of this is currently being used on large UAV’s, but the technology development required is to miniaturize this technology for use on small UAV’s and thus expand the mission utility to these vehicles.

For application to a small UAV the technology is estimated at a TRL of 4.

Enhanced Structures

Need: Medium

The flight performance and utility of a UAV designed to fly either, or both, at high altitude or with long endurance can sometimes be significantly constrained due to the weight and design limitations placed on these unique aircraft by the aircraft's structure. Conventional structural materials provide adverse penalties on vehicle weight and design flexibility.

The use of advanced low-weight structures, and advanced low-cost composite manufacturing methods, and active flight elements, will allow significantly reduced structural weight and the use of bold, unconventional aerodynamic designs. This, in turn, can significantly enhance the useable science payload size and weight.

New lightweight material development, flexible structural controls, "morphing" aircraft airfoil and planform shapes, and active flights controls for gust alleviation and to maximize performance efficiencies may have significant impact in this area.

For the advanced technologies discussed, their TRL's are estimated to vary within the range of 1 and 3.