19 Use of airborne vehicles as research platforms

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ABSTRACT

The use of aircraft is often valuable to position airborne sensors or to conduct experiments in ways not possible purely on the ground. An airframe, typically an older one, must be selected then adapted to the role – likely to include inlets, windows, structural changes, power supply, computing and data recording capacity, and likely the provision of external hardpoints. Once the research vehicle is created, the instruments on board will require calibration, either in isolation or by interccomparison against already calibrated instruments on board another aircraft. This calibration process will continue throughout the life of the airplane. Additionally, an operating organisation must be created and obtain any necessary organisational approvals. For some specialist applications, Unmanned Aerial Vehicles may also be used, which carry some special considerations of autonomy and interoperability, but similar concerns of instrument, vehicle and operational integrity.

KEYWORDS
Research aircraft; atmospheric science; surveying; instrumentation

Acronyms and abbreviations used in this section

AR	Aspect Ratio
CapCom	Capsule Communicator
C_D	Drag Coefficient
C_{D0}	Zero lift drag coefficient
CRM	Crew Resource Management
DGPS	Differential GPS
DI	Drag Index
DLR	Deutsches Zentrum für Luft- und Raumfahrt e.V. (German Aerospace Centre)
EAP	Experimental Aircraft Programme
EGPWS	Enhanced Ground Proximity Warning System
FoM	Figure of Merit
GLONASS	Globalnaya Navigatsionnaya Sputnikovaya Sistema (Global Navigation Satellite System)
GPS	Global Positioning System
ISA	International Standard Atmosphere
MNPS	Minimum Navigational Performance Specifications
MOCCA	Met Office Civil Contingency Aircraft
NASA	(US) National Aeronautics and Space Administration
Radalt	Radio Altimeter
RVSM	Reduced Vertical Separation Minima
SOFIA	Stratospheric Observatory for Infrared Astronomy
SSP	Sidewall Service Point
UAV	Unmanned Aerial Vehicle
VOCALS	VAMOS (Variability of the American Monsoon Systems) Ocean Cloud Atmosphere Land Study

Why a research airplane?

There are numerous reasons why an airplane may be used for research, although they may reasonably be divided into two: aeronautical research and scientific research.

Aeronautical research is that which is aimed at producing future developments in aeronautics – for example the testing of new sensors, navigation platforms, control systems, or even external aerodynamics or weapons systems. This may inevitably occur at any scale and control system of airplanes or spacecraft, manned or unmanned.

Scientific research is that where the aeroplane itself (it is almost always an aeroplane – helicopters seldom offer particular research advantages, and UAVs, whilst growing in utility, remain a minority amongst research platforms. Substantially the largest area of scientific research flying is that in support of the geosciences: particularly atmospheric science where an airplane allows in-situ data to be obtained over a large area that could not be obtained by other means, but also various aspects of surface observation, for example hyperspectral imagery of surface features to determine the characteristics of surface life, or carriage of ground penetrating radar, magnetometers or gravimeters to determine sub-surface conditions. On occasion an airplane may also be used to carry upward facing sensors – an extreme example being SOFIA: a NASA/DLR airborne 2.5m infra-red reflecting telescope built into a Boeing 747 (NASA 2012/1).

Selection and availability of airframes

It is very seldom that a new or latest technology airframe will be used as a research platform. There are sound reasons for this: airlines will typically buy latest technology airframe platforms at high purchase cost in order to minimise the per-hour operating cost of high utilisation airframes. In the research flying environment however utilisation will typically be very low: typically 50-500 hours per annum compared to typically 2,000 – 5,000 hrs per annum for aeroplanes in a transport role. So, hourly operating costs are relatively insignificant compared to initial purchase and fixed operating costs. Additionally, whilst airline economics generally dictate a large fleet of very few types, a research fleet will normally be very small : seldom more than 10 aeroplanes and often only a single airframe: with multiple roles. Thus the economies achieved by a large single type fleet generally do not exist. So, with the major expenditures being initial purchase and fixed annual costs (e.g. insurance, hangarage, crew training), there is little real benefit in measures to create small reductions in hourly direct operating costs.

At the same time, there is very substantial flexibility in selecting a research aeroplane –if only a single airframe is being purchased, then almost any type in current service worldwide is potentially available. In the first instance it is wise to carry out a needs analysis, which will typically include the following:

- Number of science crew to be carried?
- Instrument payload requirements?

- Minimum range and endurance requirements.
- Service ceiling (for example, if an airplane is to be used for investigating the stratosphere, then a 30,000ft ceiling renders it effectively useless, or if is unpressurised then operations above 10,000ft become problematic – requiring personal oxygen systems and potentially interfering with some equipment)
- Operating hard deck (the minimum flying height required by the research question may well require special facilities such as a modified Radalt/EGPWS capability).
- Operating speed range (typically this is of less interest for research purposes than range and endurance, although it is important to be aware of best range and best endurance speeds so that it can be confirmed that these are compatible with science objectives)
- Whether the nature of likely operations will require multi-engine redundancy, and if so, whether a twin engine aeroplane will provide that adequately, or more engines are required.
- Airport operating environment (runway surfaces and lengths and support infrastructure available in the areas of scientific interest).
- Ability to fly internationally and overfly conurbations.

This needs analysis in the first instance can be used to eliminate totally unsuitable airframes – for example if 2+ engine redundancy is required all single engine aeroplanes can be eliminated, or if the operations are to be primarily Arctic/Antarctic, then the initial "longlist" can be reduced to those with available modifications for short semi-prepared runways, and if operations are to be primarily in central Africa for surveying purposes then all aeroplanes requiring ground power and runways longer than 1000m may be automatically excluded.

From this position, the most suitable airframe may then be selected by use of "Figure of Merit" calculations using known values available from standard industry data sources, most especially Janes (Janes 2012) but also manufacturers data. Construction of this FoM should be carefully considered and use the best available advice from senior scientific users (who are usually referred to as PIs or Principle Investigators). It is not realistic to simply state a specification that the intended airplane must meet, and instead an informed assessment of the most suitable (or least unsuitable) airplane should be sought. Similarly, it is inevitable that potential vendors or service providers will have existing airframes for which they are seeking work and these will be offered with potentially optimistic estimates of modified capability or strong political pressure to accept these airframes.

Airframe modification programs

Once an airplane type has been selected, and presumably acquired for a program, it will always be necessary to modify the airframe to accept the research equipment or instrumentation. Such modification programs are usually extensive, and typically take 2-5 years, although under 1 year can sometimes be achieved for relatively simple programs such as MOCCA – the Met Office Civil

Contingency Aeroplane (Figure 1), a converted Cessna 421C which was commissioned in about 9 months.

Figure 1, MOCCA - Met Office Cessna 421C Civil Contingency Aeroplane, during modification program

All modification programs will include requirements for additional power, mounting for instrumentation, and data recording. In most cases a high quality navigation capability (usually GPS based, although dual GPS/GLONASS systems and DGPS can offer advantages) that is logging in parallel with experimental data will also be required, as will high accuracy air (pitot and static) data. The minimum standards of navigational data for flight safety purposes – RVSM (FAA 2011) and MNPS (ICAO 2011) minima for example, are seldom fully adequate for research purposes. It is likely also, particularly for a pressurised airplane, that consideration needs to be given to enhancing cooling capacity since instrumentation may well have high power consumption leading to heating within the airplane substantially in excess of that for which the aeroplane was originally designed; this particularly applies if equipment carried involves pumping equipment (which may also present noise difficulties). An additional consideration in this regard, particularly for an aeroplane with a long fuselage, is if the optimal "science speed" (typically close to best endurance speed) is substantially slower than the normal airplane design case, because the relatively high nose-up attitude will tend to cause thermal pooling in the nose. A severe case of this is the UK's BAe-146-301 Atmospheric Research Aircraft (Figure 2) which in a chemistry fit typically uses 21kVA of electrical power within the cabin, generating a similar amount of heat, compared to a design case of around 10kW of heat that would be generated by a full passenger load – together with a science speed of 200 knots that is rather less than the 280-320 knots typical cruise speeds in airline service. The result is a temperature differential of up to 10˚C between nose and tail within the cabin, and peak cockpit temperatures in excess of 35˚C in tropical conditions.

Figure 2, BAe-146-301 Atmospheric Research Aircraft

All research airplanes will require significant computing power and data storage on board. For pressurised airplanes this is reasonably straightforward and conventional office/laboratory computer hardware can be used. For unpressurised airplanes, or where equipment is operated outside of the pressure hull (such as inside a PMS canister) more care may be required – in particular hard discs with moving parts may be designed to use air density and so may regularly fail to operate above around 10,000ft: solid state hardware is usually preferable. Modern computers also often are designed to make regular software updates or internet connections – the limited, if any, (and if present, expensive) internet connectivity on board a research airplane make it imperative that any such automatic connectivity systems are disabled, reserving internet (usually satellite based, if fitted) connectivity for the specific requirements of the research platform. Duplicate data recording can be wise, but increasing reliability of data recording methods has made this less vital than it was in the 1990s or earlier.

External modifications will be required in the case of most research aeroplanes; this might include inlets for atmospheric analysis, camera doors, external mounting of sensor equipment, and potentially aerodynamic changes to the aeroplane. These may modify handling, which will require assessment, but will almost inevitably increase drag – which will require a combination of analysis and flight testing. Typically C_{D0} will be increased for the airframe overall, although the k term in the standard drag equation (Glauert 1926) $C_D=C_{D0}+(k/\pi.AR)C_L^2$ is unlikely to be significantly modified. The result of this is likely to be increased take-off distances, reduced climb performance, increased fuel consumption in the cruise, although probably substantially unchanged descent and landing performance.

Military fast jet aeroplanes will normally use a Drag Index (DI) (*US DoD 1990)* system to relate actual drag in any given external stores configuration to performance. This option is likely to be available and of benefit to, any military fixed wing types being used for research. In a civil aeroplane however, regulations are unlikely to permit this without significant negotiations with the applicable authorities and in most cases performance figures will be published either for a single "worst case" configuration, or for several discrete cases, each of which represent a worst case within a range of permitted configurations. In any case, instruments are likely to have unorthodox shapes which do not lend themselves readily to analysis, and wind tunnel testing of all new instruments in order to determine their drag profile will generally be required.

Very few research aeroplanes are single purpose, particularly in the budget constrained 21st century where airframes are likely to be expected to serve multiple research programs. Given this, some form of modularity is usually essential. Within the airplane this is likely to form racks within which instrumentation can hopefully be fitted with reasonably minimal certification – structural and power requirements at the least being met by adherence to design manuals: one of the most sophisticated such racking systems is that on the BAe-146-301 ARA (Figure 3) which uses both standard racks that attach to conventional seat rails, and standard power, data and intercom connections at uniform Sidewall Service Points (SSPs) along the cabin walls.

Figure 3, Interior of BAe-146-301 Atmospheric Research Aircraft, SSP visible bottom right and further units beyond that

Externally the most common standardised system for mounting external stores is the use of PMS (Particle Measurement Systems) Canisters which can be fuselage, hard point or window blank mounted – as illustrated in Figure 4 and Figure 5, and also visible on pylons outboard of the No.s 1 and 4 engines in Figure 2.

Figure 4, Dornier 228 ARSF (Airborne Research and Surveying Facility) airplane showing two pairs of pylon mounted PMS canister below the outboard wings

Figure 5, Showing pylon mounted PMS canisters on the nose of NCAR's Gulfstream 1 research airplane

Within the airplane, there is a tendency to commit two significant errors with instrumentation design, both usually rooted in the laboratory-equipment origins of much of the equipment. The first is to disregard ergonomics: in practice the poor ergonomic design (often including poor switch and display location, complex manual operation sequences, failure to guard critical components, and failure to create and use efficient operating checklists) of onboard experimental equipment can very frequently lead to incorrect handling and consequent data loss or corruption. The second is the failure to enhance safety procedures to allow for extremely safe operations onboard, and in particular to have emergency containment or shutdown procedures, immediately to hand and useable by any available member of the airplane crew. Best practice is an ergonomically designed workstation, supported by clear checklists for both normal use and emergency actions –supported by a properly trained operator. Managing organisations can find enforcing this difficult, when the instrument provider is also usually the customer, but it is important to do so.

All research airplanes should be fitted with suitable intercommunication systems; in all but the smallest airplanes this should be a minimum of two systems because the science crew are likely to need to discuss scientific requirements in parallel with pilots discussing high workload flying tasks. At the same time, it is important that flight crew are able to make whole-crew safety announcements at any time. Equipment, or the airplane itself, may often be extremely noisy: in larger airplane a cabin noise survey should be considered and in all cases high quality headsets should be made available for all crew. Formal assessment of headset types, in these complex one-off intercom systems, will almost certainly be required in larger research aeroplanes (*Gratton 2011)*.

Calibration and intercomparison

For all airplanes, some instruments – most especially the pitot-static system, compass and the OAT gauge, require careful calibration, since accurate readings from these can be fundamental to flight safety. That does not change for research airplanes, but in all cases there will be research instrumentation that requires its own separate calibration. This task can be extremely problematic since although a laboratory based calibration at something close to ISA conditions with minimal vibration is relatively straightforward to manage, the calibration results may differ substantially from those at altitude, in non-ISA conditions, where any sensor results are modified by atmospheric conditions that are not fully quantified, where the sensor must contend with engine and airframe vibration, and where temperatures and pressures may be substantially lower than were available during ground testing.

There is no universal rule for best practice in instrument calibration, because the instruments vary so widely. However, there are basic principles:-

(1) Where possible, use multiple instruments for the most critical values. For example, a meteorological airplane is likely to use a variety of temperature and humidity instruments, a surveying airplane may use multiple cameras, and a flight mechanics research airplane at-least two data recording systems with potentially duplicated control position and flight parameter sensors. These may then be continuously intercompared.

(2) The instrument "owner" should endeavour to understand as well as possible the environment within which any given instrument is operating. This understanding may well include, but is not limited to, airframe boundary layer characteristics, vibration, motion at the position of the instrument (which will be a function of the airplane's motion in six axes, and the position of the instrument within the airplane), effects of engine proximity, effects that flow around the airplane and instrument has upon the quantity being measured (for example an angle of attack gauge, or a cloud particle imager will, albeit in very different ways, suffer from significant measurement distortion due to flow around the aeroplane and

the instrument head). The understanding of flow around the airplane should include boundary layer characterisation, and local flow prediction.

(3) Recognise that instrument characterisation is specific to an airframe, and a particular station on that airframe. Moving instruments between airplane and stations is likely to require recalibration; this means that there are significant advantages to maintaining a suite of "core instruments", alongside a core data logger and time signal, which can be used both to maintain data quality of the most commonly required measurements and also as a comparator for more specialist measurements.

(4) Most scientific research aeroplanes have found it helpful to determine a single "science speed", typically close to best endurance speed, used for calibrations. This is seldom a reasonable option where the airplane is to be used for aeronautical research, and therefore the full flight envelope is likely to be required – but works well where an airplane is to be used for geosciences sensing, particularly if aerosol sampling is included in the work.

(5) Also record every parameter that the aeroplane will have available in a form that can be recorded, and either access reports from the airplane manufacturer showing the calibration states, or generate new calibrations specific to the research airframe. Recording the intercom, ideally with a time stamp, is also very helpful – all data that may potentially exist can be of use to researchers during their subsequent analytical work.

In the operation of many research aeroplanes, there are opportunities to make intercomparison flights with other research airplanes – typically these occur during multi-facility research programs (Andrés-Hernández et.al. 2010), (Moore et.al. 2004), (Quant et.al 1996). So long as formation flight (normally wingtip to wingtip so as to avoid contamination of each others instruments) and a common time base can be established, then comparison of data from similar-purpose instruments can provide valuable indicators of data quality: although sometimes a cruder "same area same direction" loose formation can provide satisfactory data. Instruments can also be flown on the same airplane, but caution should be applied to this because instrument characteristics become very installation dependent – although on, for example, a balloon this becomes extremely viable (Schmidt et.al. 1987), as it does for most imaging or navigational equipment. Of course for multi-airplane intercomparison flights, pilots must be trained and current in formation flying, which can sometimes be difficult to achieve.

Operating a research aeroplane

Organisationally, a research aeroplane and its customer research program require a three part management structure; those three parts may potentially be combined in 1, 2 or 3 organisations – or each may involve several groups rather than single organisations. These parts will usually be:

(1) The operating organisation – comprising pilots, maintenance and inspection, and ground operations staff.

(2) The research organisation (or more typically a grouping of research organisations or research customers)

(3) The managing organisation, which will typically manage scheduling, core instrumentation, instrument integration.

Very few research airplanes serve a single customer, and multiple research stakeholders are likely. For this reason, there are likely to be one or more likely multiple steering committees, particularly informing the managing organisation and development of the platform capability. External /overseas expert membership of such committees is often also encouraged as part of the scientific communities demands for peer review.

Research programs will generally be prepared in a collaboration of the managing organisation, research organisation(s) and steering committees and depending upon the nature and complexity of the facility, are likely to be prepared at-least 6 months but sometimes up to 4 years in advance. Parallel facility development programs – continuous improvements to the vehicle, instrumentation and data capability are likely to exist in parallel with these flying programs but probably to a longer timescale. Whilst less likely in aeronautical research or surveying, research organisations supporting geosciences airplanes are likely to pursue collaboration with other airplane teams – particularly those with different instrument, range or altitude capabilities, which may well be planned some years in advance. A typical example of this was the main experimental component of the Chile based VOCALS program (Vocals 2012) which comprised three American and two British research airplanes, along with one American research ship in conjunction with various ground and satellite assets.

A coherent safety management system must be in place, encompassing the expertise of all expert players (not just, for example, the flight crew). This must include ground risks, particularly where the aeroplane is operated away from its home base.

Inevitably research airplanes will have an operating base, although in particular geosciences research and surveying airplanes tend to operate primarily away from that base – alternately aeronautical research airplanes such as EAP (Figure 6, formerly based at BAe's company site at Warton) tend to operate primarily from a main base which is usually co-incident with a lot of the design and analysis support structure.

Figure 6, British Aerospace EAP technology demonstrator aircraft (*Wikimedia commons*)

The operating team for any given flight will tend to be dependent upon the nature of the task, and will be determined by program requirements. However, in Table 1 are illustrated typical crew constructions:

Table 1, Typical research airplane crews

Type of program	**Typical Team**
Single seat high performance aeroplane	Test pilot
Light aeroplane research project	Test pilot, development / flight test engineer,
Small geosciences research aeroplane	Trials pilot, scientist
Medium geosciences research aeroplane	Two pilots, mission scientist, 1-5 instrument scientists.
Large geosciences research aeroplane	Two pilots, mission scientist, 1-3 additional supporting mission scientists, flight manager, 4 – 40 instrument scientists, 1 cabin crew

Flights however are likely to be require very substantial additional support; apart from the obvious requirements for maintenance and ground handling, and ground operations staff / flight monitoring and following, there will be a continuous requirement for development and maintenance of instrumentation, and it is likely a very substantial pre-flight period in order to prepare instrumentation and trials equipment. Post flight there will be data download, and in particular data processing needs – data from each instrument or recording system requires post processing to reduce raw data to calibrated useable data, supported by metadata (data describing data). It is likely that the calibration task, particularly for science instruments, will be continuous and require substantial staff support – it must be recalled that the primary task of any research airplane is to provide users with the highest possible quality of data; this must maintained and enhanced, and regularly reviewed – which may even include significant historical reviews. Some continuous or controlled data telemetry is likely – and particularly for high value small aeroplanes such as a X-29

(Figure 7) or for any spacecraft, substantial real-time telemetry is appropriate, with a single CapCom (Capsule Communicator) speaking to the pilot or airplane/spacecraft crew, who is in turn part of a larger team accountable to a flight director, but containing other specialist teams, each with its own team leader. For unmanned vehicles, clearly the CapCom role ceases to be required, and for simpler tasks and airplanes the role of CapCom may for instance be combined with that of a safety observer test pilot, supported perhaps by a very small number of Flight Test Engineers.

Figure 7, X-29a variable stability research aeroplane, courtesy of NASA (Photo ID: EC90-039-4.)

<u>Special Considerations for Unmanned Research Airplanes</u>

There is an increasing role for unmanned vehicles in research – primarily for environments where manned airplanes are not viable – for example high risk hypersonic flight (X-43 (NASA 2012/2)), flight over inaccessible territories such as the Antarctic (BAS 2012) , or high altitude long endurance missions such as those flown by the NASA Dryden Global Hawk (NASA 2012/3), or the Qinetiq Zephyr (Qinetiq 2012). In many ways they are inferior to manned airplanes – requiring far greater degrees of automation, usually miniaturisation, and very high levels of instrument reliability: without the ability to have expert users in the aircraft using their knowledge to continuously achieve the best from complex and usually constantly in-development instrumentation systems. Extremely high values of data bandwidth may also potentially be needed, depending upon the likelihood of aircraft return or immediacy of the data requirements. Also, clearly, an unmanned airplane normally lacks one very powerful piece of equipment – a trained Test Pilot. An additional consideration with some vehicles is that the very long endurance (over 24 hours in the case of the Global Hawk or Zephyr) preclude a single crew, so multiple crews, and crew handover procedures – not normally a requirement – become necessary.

One exception to this omission of the pilot is use of pilot in the loop (PiL) simulation, which may typically be used for very innovative or very high risk aeronautical research flying. For example, the NASA / Boeing / Cranfield Aerospace X-48b UAV (Figure 8) whilst unmanned and too small to take a human being, was configured as if manned, with information from the “cockpit” relayed to a ground based cockpit occupied by a Test Pilot. This allowed a Test Pilot to evaluate the flying qualities of a novel configuration airplane, without the requirements to man-rate the vehicle (Sizoo & Well 2010), and also meaningful flight test results to be obtained in free flight with a scale (approximately 1:12 from a nominal blended wing airliner) model aeroplane. However, despite these benefits it remains prudent to manage safety of such a vehicle as if it were manned, because loss of a single test airframe can potentially terminate, or at-least severely delay, a limited resource program.

Figure 8, X-48b research UAV (courtesy of NASA)

In theory, it should be possible to avoid expensive certification procedures appropriate to manned airplanes; at smaller scale UAVs this is true, but on larger airplanes there is little saving. Additionally, there is a known and substantial problem with the requirements for “sense and avoid” in most airspace – which UAVs do not yet do adequately compared to a manned airplanes with pilots maintaining a normal lookout although ongoing research is addressing that and it may be hoped that UAVs capable of being operated in non-desegregated airspace become available for research flying in the next few years.

Experience has shown that failure to apply normal test flight planning principles – configuration control, CRM, test plan review, and formal safety assessment, to UAV operations in the research and development flying environments, creates a high risk of airframe loss, usually at great cost to the programs. These principles should be regarded as applying equally to manned and unmanned research vehicles (and many other activities (Gawande 2011)).

Training and Personal Equipment

The requirements for training of all crew involved in the operation of a research airplane are critical. For pilots, the minimum requirements are relatively straightforward, but are likely to require enhanced training in trials planning and conduct, as well as some familiarisation with the science or research requirements of any given campaign. It is rare that pilots who do not have some form of research or test background work well in the research environment.

CRM training(UK CAA 2006), (FAA 2012) has been found of very substantial benefit – typically a team based initial 2-3 course followed by an annual half day refresher. It is important that such training is tailored to the team and program, and that a cross section of the team train together. Whilst targeted at safety, good CRM practices are also powerful tools to ensure effective delivery of research outputs and so CRM training should be completed by all members of a team, not just primary test conductors.

All instrument or specialist equipment operators should be given significant training in the operation of their equipment, to approved procedures, and the effectiveness of this training must be evaluated before they are permitted to operate this equipment unsupervised. This should extend also to operators of ground / telemetry facilities and include regular practice sessions.

Whilst certain legislation may divide those on board a research airplane into “crew” and “passengers”, it is more convenient to regard them as “flight crew” and either “flight test observers” or “science crew”. This emphasises that it is important that all but irregular flyers should also be trained in appropriate safety procedures – likely to include emergency equipment, evacuation / abandonment, and communications, and that the conduct of all team members are vital to successful mission outcomes.

It is often difficult to ensure that researchers to wear appropriate safety clothing on board a research aeroplane – particularly on board larger vehicles which are designed as a shirtsleeve environment. The reality of large amounts of power, immature equipment, and often potentially hazardous fluids on board, should make clear that this is highly advisable. Good practice in most aircraft is normally a natural fibre inner layer with a one-piece Nomex outer suit and flame retardant gloves.

Conclusions

Flight vehicles can be used for either scientific or aeronautical research; in either case it is most likely that an existing and probably elderly airframe will be adapted, but this itself gives the opportunity to select the most appropriate airframe from a wide variety of available choices. An extensive modification programme will then be required, which must include detailed characterisation of the airplane’s aerodynamics and calibration of the onboard instruments. The managing organisation must be complex, encompassing operations, instrument management, and science requirements – and training and equipment for the personnel working on board the aircraft must be given careful consideration. Unmanned aircraft have particular considerations, in particular data transmission, instrumentation automation and reliability, but also the human side of managing remote and long endurance missions.

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