CP594

System Integrity Considerations for Unmanned Tactical Aircraft

D. Scheithauer, G. Wunderlich
Industrieanlagen-Betriebsgesellschaft mbH
Einsteinstraße 20
85521 Ottobrunn
Germany

SUMMARY

In general, unmanned aerial vehicles (UAVs) and Cruise Missiles (CM) have demonstrated their operational value in the limited conflicts of the last years. This experience and technological advances promise similar successful results for more sophisticated Unmanned Tactical Aircraft (UTA) covering a wider range of airborne mission roles [1]. Throughout this publication the term UTA will be used in favour of the term uninhabited combat aerial vehicle (UCAV).

In this paper UTA concepts are evaluated with respect to system integrity. In a first step mission scenarios are analyzed with respect to the hostile threats an UTA will encounter. These external threats together with internal threats affecting reliability and system safety are the reference for the evaluation of the required integrity levels.

On the basis of a generic system architecture essential and non-essential functions are considered. The assessment led to the result that UTA will be quite complex. This will have a major impact on the life cycle costs according to the experience with manned aircraft programmes. However, compared with manned aircraft weapon systems UTA life cycle costs will be lower due to less operating costs.

1. INTRODUCTION

The vision of unmanned airborne systems has a long history. Cruise missiles for attacking fixed targets and Unmanned Aerial Vehicles (UAVs) for surveillance and reconnaissance have demonstrated their operational value in this decade. A common understanding has emerged that unmanned airborne systems may be useful for other operational tasks as well, especially for air-to-ground roles which means heavily defended areas and targets will be encountered. In addition, there is a need to replace ageing aircraft within the next twenty years. The JAST programme in the US and the various studies on future airborne weapon sytems (FAWS) in Europe consider unmanned airborne elements to complement manned aircraft.

Although some airframe concepts are underway, it is still obscure which kind of UTA will offer the best value for money. Will it be an improved cruise missile with additional return to base capability? Or, will it be interchangeable with manned aircraft on a one-to-one basis? What degree of autonomous operation makes sense? Will we have complex automated systems? Or, are simple systems following a 'no avionics' approach better suited?

The answers to these and other similar questions have to be looked at from various perspectives like weapon system performance, handling during the mission and on ground, etc. The viewpoint of this paper are system integrity criteria.

In very general terms system integrity is defined as the capability of a system to fulfil its intended function without unwanted side effects while operating in an environment with specified external and internal threats. From this definition the wide spread influence of system integrity matters is obvious. Therefore, system integrity considerations may assist from early concept studies onwards to assess the required functionality, the necessary complexity and the affordability with respect to available technology and budget constraints.

Starting point is a brief analysis of the mission scenarios for which UTA are promising certain advantages over alternative means. In particular, UTA should survive when they are exposed to the mission environment. Partly for that reason system integrity requirements have to be derived from the mission scenarios. They may have a high impact on the affordability of UTA weapon systems also.

On the basis of UTA functional requirements, key elements of a suitable system architecture will be defined in the next step. The complexity of the individual system functions depends mainly on the degree of operating autonomy and the necessary level of automation. Especially in case of complex functions, system integrity aspects have a far ranging influence on mission accomplishment rates and affordability. A generic block diagram will be presented that is adequate to discuss system integrity further. System integrity will be affected by two kinds of internal threats too:

Paper presented at the AGARD MSP Symposium on "System Design Considerations for Unmanned Tactical Aircraft (UTA)", held in Athens, Greece, 7-9 October 1997, and published in CP-594.

- the susceptibility to random hardware failures and
- the limited capability to design a complex system not only as required (by its specification) but as desired.

From the analysis results from above it will be concluded to what extent operational and system integrity aspects have an impact on the affordability of UTA weapon systems. In addition, the technology areas are defined which need special attention in research and development prior to a successful release of UTA weapon systems to service.

2. MISSION SCENARIOS

2.1 Military Conflicts Characteristics

With the decline of the cold war and the emerging demand for peace keeping and peace making, the mission scenarios have changed. While the planning concentrated on high density conflicts in the past, today adversaries with more or less sophisticated armament have to be considered as well.

As far as relevant for the scope of this paper, in dense conflicts the adversary's potential is characterized by

- high value targets
- high level of reconnaissance and intelligence
- massive air defence en route and at target site
- high level of electronic and information warfare

For peace keeping and peace making missions the potential may vary from case to case. Compared with dense conflicts the following items may roughly indicate the differences:

- high and low value targets
- limited reconnaissance and intelligence
- air defence more concentrated on object level
- varying jamming levels

For out-of-area missions political issues have to be considered as well. The acceptance pilots' losses is extremely limited or may be unacceptable in democratic societies. Collateral damage of own weapons at adversary's sites will also face criticism and may cancel the entire peace-keeping or peace-making involvement. These issues influence the freedom of military commanders to plan and decide according to military needs only and will have a significant impact on the next decades weapon system procurements.

2.2 UTA versus Manned Aircraft

Only two good reasons exist to introduce a new kind of weapon system. Either a specific existing mission can be accomplished more efficiently or a new type of mission is possible providing an advantage over an adversary. So, what are the promises of UTA in this instance? As the name indicates the main difference between current tactical aircraft and UTA is the fact that UTA are unmanned respectively uninhabited. This leads in particular to the following characteristics:

- UTA are not impacted by pilot's fatigue.
- By UTA missions no pilot's life is endangered.
- The operator's training effort can be reduced because only few real life flight hours are required.

The absence of pilot's fatigue allows long endurance and high stress missions. While long endurance missions like surveillance, reconnaissance and intelligence gathering have been successfully accomplished already by UAVs, no weapon delivery role has been performed yet.

Physical and psychical stress to a pilot is mainly induced by the required flight profiles over all mission phases and by the exposure to hostile threats. An UTA is not affected by such limitations.

Due to more aggressive manoeuvring capabilities, advantages would result for a number of mission phases including terrain following, weapon delivery, air combat and defence against incoming hostile missiles. Combined with a long range capability UTA may be used for deep strike missions. Less predictable flight pathes may also enhance the survivabillity in tactical reconnaissance missions.

That UTA losses are not coincident with losses of pilots' lives makes them suitable for dangerous missions with a high loss probability and situations in which human losses are not acceptable for political reasons. In the first case, a high loss probability is likely in dense conflicts with massive air defence of the adversary. The second case is more related to peace keeping and out-of-area missions.

A further reason for the attractiveness of UTA is the envisaged significant reduction of life cycle costs compared with manned systems. In the past several calculations have been performed under various constraints. However, comparisons of manned aircraft and UTA on an equal mission basis (same fire-power, same mission) or with a less capable UTA have led to strong indications of significant life cycle cost reductions. The reason is the small number of training flights required to establish and maintain operators' proficiency. Because the operator will never have the cues of a pilot sitting in an aircraft, there is no difference in training on a simulator or by real flights. Nevertheless, UTA flights will be necessary to validate the availability of the weapon system, to practise missions performed by a mix of manned aircraft and UTA and last but not least to give military planners and commanders the confidence in their assets.

2.3 UTA versus Cruise Missiles

As far as weapon delivery roles are concerned, Cruise Missiles (CM) are clearly an alternative to UTA. To some extent it is a matter of semantics if UTA should more be down scaled aircraft or up scaled CMs with a return to base capability. For the purpose of this discussion CMs are considered on the basis of today's features. These features are the fire-and-forget philosophy and the existence of one warhead only.

Initially designed for nuclear strike missions, CMs rely on pre-planned missions that are accomplished autonomously. In particular, it is impossible to adjust target data in flight. This limits the flexibility and might be an important risk factor in peace-keeping or peace-making missions, if the adversary tries to provoke hits of non-military assets. The application of CMs is restricted to fixed point targets. Furthermore, the lack of flexibility allows no integrated missions (same target, same time slot) with other flexible means, especially manned aircraft. CMs are best suited to attack high value single point targets that can be destroyed with their limited fire-power. Attacking locally extended targets with CMs is not a cost-effective choice.

Requirements for an advanced CM comprise more flexibility, interoperability with manned aircraft and an increased fire-power. Starting with the first item, increased fire-power depends on the future development of munition technology. Improved explosives and higher impact velocities may offer the opportunity to build smaller weapons. However, these improvements would be beneficial for all weapon platforms.

Flexibility improvements are especially related to the final target acquisition phase. Targeting information may be updated. The CM may be redirected to alternative targets. Or, the attack may be abandoned in the last minute. E. g., in scenarios in which collateral damage should be avoided (peace-making, peace-keeping) a decision relying on on-board sensors may be helpful due to the available resolution of optical and opto-electronic sensors. Real-time updates would also allow missions against moving targets. These could for example be provided by UTA in a tactical reconnaissance role.

A fulfilment of the interoperability requirement is highly related to the flexibility requirement. When command and control of advanced CMs and manned aircraft is similar, combining both types in one mission gives no additional problems.

However, an advanced CM as described above would need sophisticated on-board installations for data transmission and sensing. This will increase CM value and costs. In the end, it may be more efficient to drop the weapon and let the platform return to base. Internal studies performed by IABG at the end of the last decade have shown that the additional development effort for a return to base system is about 10 % to 20 % higher than for a one-way system with the same mission capabilities. According to that study, procurement and operation costs for a whole fleet are comparable with a small advantage for the one-way system. Because these figures were derived a decade ago they should be taken as an rough indicator only. Incorporation of new trends in technology may alter these results.

2.4 UTA Mission Roles

2.4.1 Surveillance and Reconnaissance Mission Types

The first UAV applications were dedicated to surveillance, reconnaissance, electronic support missions (ESM) and jamming. Starting with relatively simple optical sensors, payloads as well as complexity, weight and value of the mission equipment have increased over time. Synthetic aperture radar (SAR) are the most sophisticated sensor equipment used today on UAVs. The potential of current UAVs extends to intelligence gathering as well as to electronic warfare equipment.

A substitution of UAVs in these roles is not expected unless space based systems demonstrate a better value for money. With design concepts for UAVs flying long endurance missions at altitudes of approximately 80 kft, UAVs can operate off-side the combat zone over friendly territory and can still provide useful surveillance data.

In general the mission effectiveness of current UAVs has been demonstrated in low density conflicts like over Bosnia. Despit low reliability records [2], the survivability of the early designs in scenarios with strong air defence capabilities on the adversary's side is questionable. The velocity is low and the flight path simple.

When operating in the combat zone, the measures to enhance survivability include increased subsonic velocity levels, less predictable flight pathes and signature reductions over a wide frequency range. Additional functionality and more sophisticated on-board systems will complement these improvements regarding sensor data processing as well as command and control.

With these enhancements in place, UAVs have all features to evolve to UTA. Due to speed ranges similar to manned aircraft, UTA can be operated together with manned aircraft. More flexible command and control features will support interoperability further. In the end UTA may substitute manned aircraft in the tactical reconnaissance role for a wide mission range. UTA equipped with jammers may assist manned aircraft and other UTA in attack missions.

2.4.2 Air-To-Ground Missions

Once concepts for non-reusable attack drones (e. g. TAIFUN) may be anticipated as the first step to air-to-ground missions performed by UTA. Unlike CMs these vehicles participate in the target acquisition process by identifying and selecting targets autonomously.

UTA promoters concentrate on the air-to-ground role due to the following reasons: Improvements of air defence weapons with respect to performance and costs have transformed attack missions to high risk adventures. By the world-wide proliferation of modern air defence systems, attacking aircraft have to expect this threat even in lowest density conflicts. Suppression of Enemy Air Defences (SEAD) is therefore the preferred mission type for UTA. Saturation of the foe's air defence systems by quite simple UTA could be an option. High agility of these UTA with normal accelerations up to 20 g and beyond may outperform most available ground-to-air missiles. Other UTA launching anti-radar missiles may substitute todays similar equipped manned aircraft (e. g. ECR TORNADO, „Wild Weasel" aircraft).

The UTA capabilities for long endurance missions as described above may allow deep strike missions that are less affordable for manned aircraft due to pilot's fatigue. For other typical missions like air interdiction, manned and unmanned aircraft may be interchangeable. It can be assumed that a mix of manned and unmanned aircraft will be the most efficient solution.

However, the availability of a reliable, jam-resistant real-time data link providing the necessary throughput capacity is paramount to accomplish such missions successfully.

2.4.3 Air-To-Air Missions

The advantages of UTA over manned aircraft in the air-to-air role are long loiter times and the high g-loads by which most current missiles may be outperformed.

For beyond-visual-range combat, pilots have to rely on identification and flight path data provided by the aircraft systems to perform the manoeuvres best suited to be successful. Remote control and/or automation of this process seems not necessarily more challenging than the air-to-ground roles.

In visual-range combat, transport delays from digital processing limit tracking performance. Unless sampling rates will be significantly increased, manned aircraft will be superior to UTA in this role due to better situational awareness of the pilot.

Advanced concepts assign UTA to Tactical Ballistic Missile (TBM) and CM defence. Such missions evolving in the future are not considered in this paper because the characteristics of TBM and CM defence are only briefly defined today.

2.5 Offensive Mission Scenario

Figure 1 shows a schematic overview of an offensive mission scenario for which UTA application is favoured. Assumed is an air interdiction or deep strike mission in a high density conflict situation. The functional elements involved and the appropriate weapon systems are defined in the following subparagraphs.

Airborne Network

Having the right information in the right place and at the right time is one of the key prerequisites to accomplish complex missions successfully. While today's airborne information distribution is centralized around systems like AWACS and J-Stars, modern information technology provides the means to go one step further by providing networks with alternative distribution pathes. Main nodes of the network will be AWACS and J-Star as today complemented by high altitude flying, long endurance UAVs and satellites. Even in dense conflict situations with losses of some nodes survivability of the network will be remarkably enhanced.

The invention of decentralized airborne and space based networks may have other design drivers as well. UTA will profit from the introduction of high capacity and survivable data links. UTA will receive command and control data and will transmit own sensor data and status information. However, the real-time requirements for UTA operation will probably be more stringent than for other tasks.

Command and Control

With the availability of capable networks new options for improved command and control arise. Control of UTA may be performed from ground stations, AWACS aircraft or other manned aircraft preferably those participating in the same sortie as the UTA.

Surveillance and Reconnaissance

In the foreseeable future, surveillance and reconnaissance will be performed by nearly the same means as today. These are manned aircraft, UAVs and satellites. Technological enhancements will shift the importance of satellites. The tactical value of UAVs will be increased by higher operating altitudes around 80 kft.

Electronic and Information Warfare

With the importance of information technology, threats arising from electronic and information warfare will become even more severe than today. Improved defensive as well as offensive measures will be required to sustain the electronic warfare threats. The defensive items will be discussed below together with the system architecture. For offensive measures UTA are well suited to fly ahead of the main attack force with special jamming equipment on-board due to the high risk nature of this role.

Tactical Reconnaissance

With higher quality and higher resolution of remote surveillance and reconnaissance platforms, the demand for tactical reconnaissance may decline. However, its value for final mission preparation and damage assessment will not be surpassed in the near and midterm future. Especially prior to an attack sortie tactical reconnaissance is a high risk mission, making UTA the favorite weapon system to accomplish the mission.

SEAD

For SEAD as the mission with the highest risk UTA may suited best. Two tactical principles may be applied. The first is based on air defence saturation. Easily observable UTA may be used as decoys. Their high agility may outperform the defence missiles while own anti-radar missiles are launched to destroy the air defence sites. The second relies on UTA with low observability launching their anti-radar missiles prior to their own detection by the foe.

Escort

Like today, fighters will escort the main bomber force to provide protection against hostile fighter attacks. As far as beyond-visual-range combat is concerned UTA may participate in this role.

Main Attack

The main attack force has to attack the target with the required fire-power. Depending on UTA size and target characteristics the main attack may be performed by UTA only, a mixed force of UTA and manned aircraft or manned aircraft only.

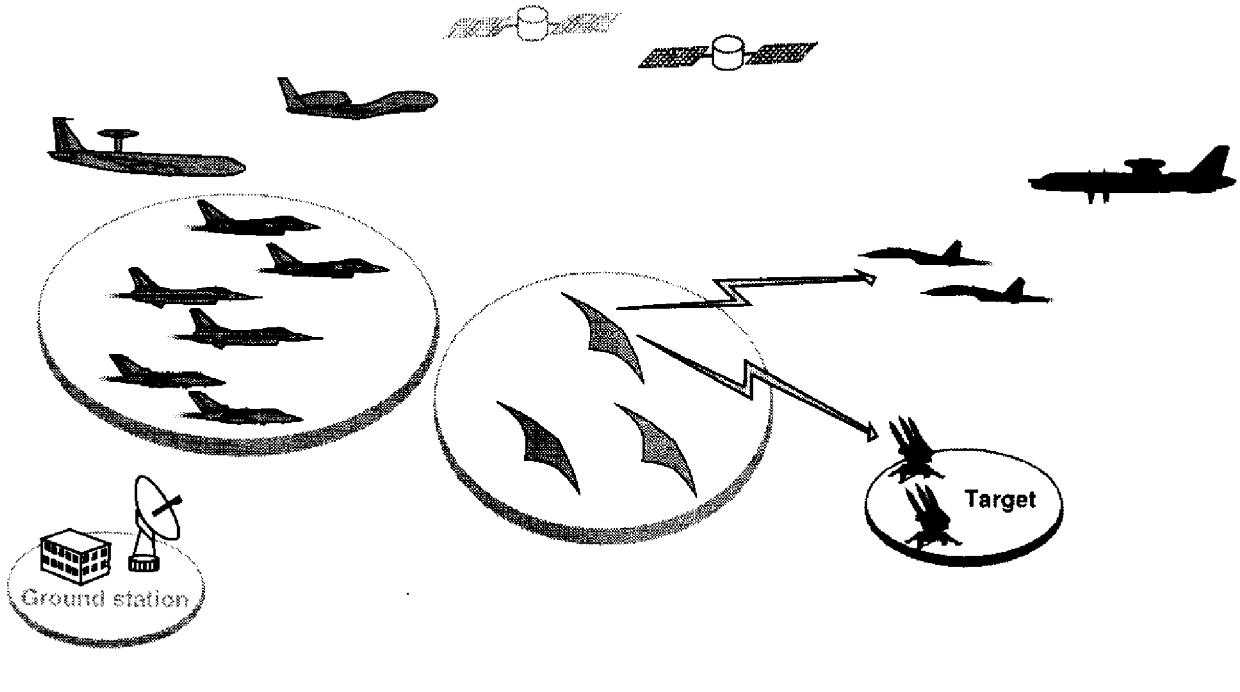

Figure 1: Offensive Mission Scenario.

3. SYSTEM INTEGRITY CONSIDERATIONS

3.1 Threats and System Integrity Requirements

3.1.1 External Threats

For a sufficient integrity level UTA weapon systems have to be designed to accomplish their missions successfully under the constraints imposed by external threats from the mission environment and by internal threats as a result of the UTA system design.

The external threats can be classified by the nature of their origins and severity:

Surveillance, Reconnaissance and Electronic Support Measures of the adversary's air defences

In a high density conflict environment the adversary will have similar means for surveillance and reconnaissance covering AWACS like aircraft, satellites and, depending on the proliferation of those weapon systems, new high altitude reconnaissance platforms. With respect to the networking capabilities, effective usage of the gathered information and the survivability of the complete surveillance system may vary.

Electronic and Information Warfare

In addition to today's techniques for electronic warfare the emerging information warfare technologies have to be considered. Noise input generators to saturate sensors and disturb radio communication links have to be expected in all scenarios. More sophisticated means to manipulate data unperceived by the user may achieve a threat level unknown up to now, on-board information systems have to cope with in future. However, application of these techniques will be limited to countries with the relevant high-tech knowledge.

Anti-Aircraft Missiles

This point comprises missiles launched by aircraft as well as ground-to-air missiles. The availability of very capable modern missile systems to an adversary have to be expected in high density conflicts. The threat may be quite similar in peacemaking out-of area scenarios due to the current degree of proliferation.

Energy Weapons

Although energy weapons play no significant role in military scenarios today, for the future laser weapons and high power microwave (HPM) weapons are likely. If and when they will be available for general use is not foreseeable.

With respect to external threats survivability and vulnerability are the main concerns with respect to system integrity. Survivability describes the capability of a system to withstand the external threats and accomplish the mission. Vulnerability considers the capability of a system to be able to operate after partly damaged.

3.1.2 Internal Threats

Internal threats may be classified in two categories. Expected failures due to random hardware malfunctions may be minimized to an acceptable level by well established technical means (e. g. redundancy, component derating etc.). Unexpected events are the second category. They are usually caused by handling problems or design shortfalls. Even for complex systems that are mostly software-based the capability is limited to design a system not only as specified but as desired.

The main system integrity criteria related to internal threats are reliability and safety. Reliability has to be designed in the system so that mission abortion rates are acceptable. It has an impact on the effort of ground handling and maintenance too. Safety as the capability to protect people from death and injuries is clearly an issue for ground handling as it is for manned aircraft, at least due to the carried weapons.

On the first sight, safety during flight seems not to be important because no on-board crew is involved. But it has to be considered that UTA will not operate independently from manned aircraft, neither inflight in civil airspace nor in a combat sortie. Indeed, no own pilot has to be protected, but the inhabitants of adjacent aircraft are endangered by unsafe manoeuvring and unsafe armament system conditions as are people on ground during taxiing, take-off and landing.

3.2 UTA Functional Characteristics

A reasonable starting point for achieving a balanced UTA design is an existing manned aircraft performing the same or a similar task. But a UTA design may not necessarily look like an aircraft. The absence of a pilot removes many design constraints that are imposed for pilot's accomodation. A complete list of these items is quite long. The list includes:

- life support equipment
- controls and displays
- weight and space of pilot and the equipment as listed above
- safe pilot's ejection in case of emergencies
- pilot's physical constraints (g-load, aircraft attitude, other stress factors)

The new design freedom gained by the drop of pilot related requirements shall be utilized to enhance performance as well as integrity of UTA weapon systems. Moreover, it is the most affordable way to acceptable integrity levels when the inherent UTA capabilities are exploited with respect to integrity criteria. In the remaining of this paragraph it will be discussed how UTA design features that are ventilated to the public from various sources affect system integrity.

For the purpose of this consideration the basic functional characteristics are summarized under the headlines airframe, stealth characteristics, flight profiles/agility and UTA on-board systems. While the first three items are considered in this paragraph, UTA on-board systems will be discussed in the next paragraph when the system architecture is introduced.

Table 1 shows a matrix of these functional areas and the external threats. A cross in the matrix indicates that a certain functional characteristic is susceptible to the particular threat. In other words, survivability with respect to this threat may be minimized by appropriate design measures.

Observability by the adversary's surveillance, reconnaissance and electronic support measures is the threat that influences the whole UTA design.

With respect to the airframe, size and shape have a dominant impact on detectability. A small size combined with an appropriate painting scheme contributes to minimum visual observability. In general, UTA may be smaller than manned aircraft. But more than the pilot, the required range and fire-power determine the actual size. To utilize UTA capabilities for long endurance missions the necessary fuel has to be carried. Regarding weapon technology, smart bombs of the 1000 lb range are under development and concepts for new weapons of the 100 lb to 250 lb range with new developed explosives or alternative warheads, e. g. high power microwave (HPM), emerge. Weapon weight and size will therefore decrease being beneficial for both manned and unmanned aircraft. For the near future a substantial reduction in UTA size cannot be expected if compared with manned aircraft on the basis of equivalent fire-power.

To minimize observability by radar, UTA shapes should be chosen that radar echoes are mainly deflected to uncritical aspect angles. A consequent implementation of this design requirement will demand internal weapon carriage. Considering the availability of smaller weapons in future and the internal space offered by flying-wing designs, a successful realization is likely. Depending from the expected threat levels by airborne and ground based radar, UTA concepts showing always the smoothest surface to radar while maintaining the intended flight path may enhance low observability. However, airborne and ground-based radar working on different frequency bands will limit the effect. Other sensor concepts like LIDAR are not affected by such measures at all.

Stealth techniques have the potential to lower the detection probability essentially. But recent experience shows that substantial development is still required to make stealth techniques reliable [3]. If stealth enhancements become available, they are similarly effective against anti-aircraft missiles.

UTA detection by ground based radar can be minimized by chosing terrain following flight profiles. High g-loads allow more aggressive manoeuvring so that the average height above ground will be lower than of today's manned aircraft with terrain following capabilities. Furthermore, terrain following may be maintained over longer time periods.

High agility will be of even more value when an UTA is attacked by anti-aircraft missiles launched from ground or from aircraft. At first, most current anti-aircraft missiles may be outperformed with respect to maximum g-loads. At second, tracking

	External Threats			
	Surveillance RECCE, ESM	Electr. & Info. Warfare	Anti-Aircraft Missiles	Energy Weapons
Functional Area				
Airframe	x			
Stealth Characteristics	x		x	
Flight Profiles / Agility	x		x	
UTA On-Board Systems	x	x	x	x

Table 1: UTA Susceptibility to External Threats.

algorithms of less sophisticated anti-aircraft missiles may be confused due to less predictable flight profiles UTA could perform for their own defence.

The UTA capability for high g-loads that is advantageous regarding anti-aircraft missiles, will be of less benefit against energy weapon attacks.

3.3 System Architecture

Figure 2 shows a generic UTA on-board system architecture that is appropriate to discuss integrity matters. It is common practice to categorize individual functions as essential or non-essential.

Essential functions will perform tasks necessary to survive. Survival covers a minimum capability to return to base. All other safety related functions are essential as well. Loss of non-essential functions will lead normally to a mission abort depending on the mission phase the loss occurred. The ability to withstand external and internal threats may be constrained.

A sound design will keep essential functions to a minimum and will isolate them from non-essential functions.

The minimum set of essential functions covers weapon safety on-ground and inflight as well as basic flight control functions that are required to manoeuvre the UTA safely during take-off, cruise and landing.

For weapon safety, fire control functions and the weapons themselves have to be designed to fulfil the applicable safety requirements. As derived above, these safety requirements are identical with those for manned aircraft. Relaxations would only be granted for the unlikely case that operators will accept higher risk levels in future than today.

Essential flight control functions comprise flight and engine control including sensors, computing ressources and actuation as well as the engine and the control surfaces. The sensors used shall be passive with respect to the environment. Navigation will probably be based on GPS and inertial platforms.

Electrical power generation and cooling equipment is essential in so far that the supplies of essential functions are maintained. With advances in research to substitute hydraulic actuation by electrical means the need for a hydraulic system may diminish.

Even if not completely, to some extent the data link

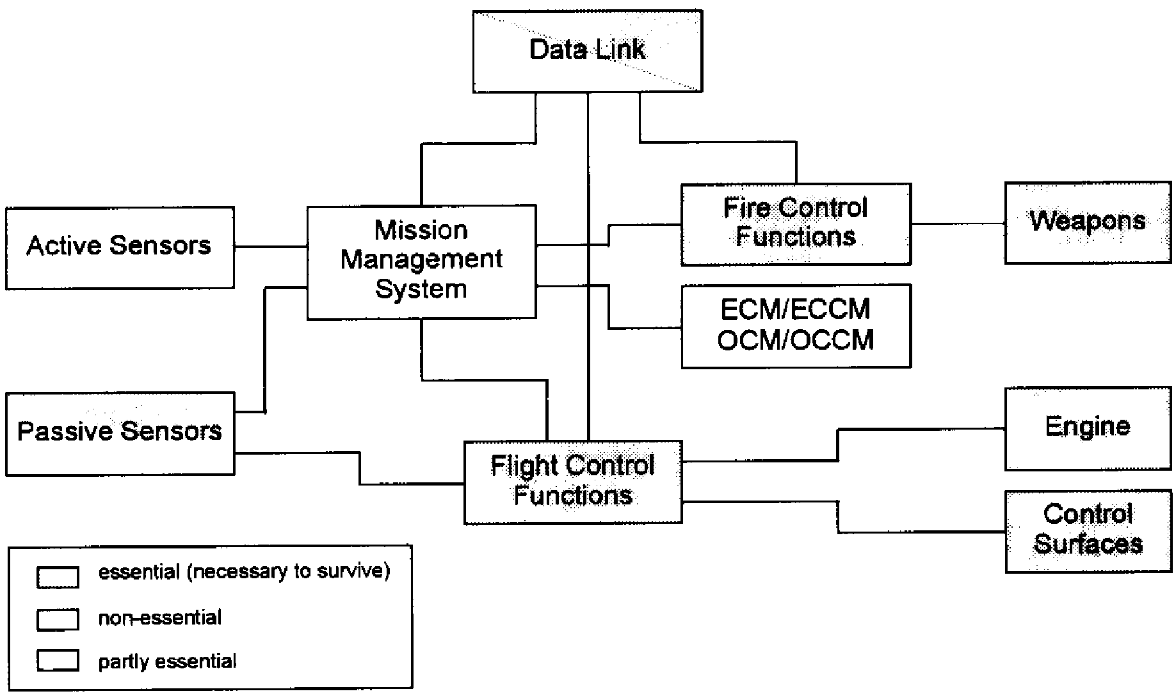

Figure 2: UTA System Architecture.

will be essential. Depending on the degree of autonomy of essential functions, uninterrupted performance of the data link may not be demanded. However, the information integrity of the commands transmitted to release weapons or initialize aircraft manoeuvres has to be ensured. The requirements on data link availability will be considered further below when the susceptibility to external threats will be discussed.

Due to the importance of the communication between UTA and a remote controller, the data link will directly exchange data with the essential functions for two reasons: safety relevant information must not be routed via non-essential functions and real-time requirements may demand minimization of transport delays. The mission management system comprises all mission relating computing. For a specific application the mission management system will likely be refined to subsystems that themselves may be related in a hierarchical fashion. The function included cover at least:

- signal processing of sensor data input from passive and active sensors
- threat evaluation and countermeasures
- mission dependent guidance command processing for fire and flight control
- concentrating information to be sent to the remote controller for maintaining situational awareness
- health monitoring and status accounting to be transmitted to the remote controller and to be used on-board for reconfiguration

In the following the on-board systems will be further evaluated with respect to their susceptibility to external threats. Table 2 provides an overview. It shall be interpreted in the same way as table 1.

In principle all antennas are susceptible to detection by the adversary's surveillance and reconnaissance systems or by electronic supporting measures, especially when transmitting. Therefore active sensors should not be operated in continuous modes but only when operationally required. Onboard radar for example may only be used for final target acquisition.

Electronic and information warfare attacks are a major threat for all electronic devices. Noise and manipulated data can be induced to the on-board systems via all systems that interact with the outside world. These systems are active and passive sensors, the data link and the own electronic warfare suite. Although countermeasures from the own electronic and information warfare suite may augment severity and duration of such attacks, system architecture and design features of each individual system have to complement the defence. The principles for defence include hierarchical protection concepts, dissimilarity and redundancy. Comparable information on the environment should be gathered by several sensors based on different sensor technology and working on different frequency bands to counteract noise generation and decoys.

The data link should consist of redundant broadband communication channels to lower the probability of a total data link breakdown in case of induced noise. However, it is unlikely that the datalink will operate without timely limited disturbances not only caused by electronic warfare but also as a result of geographical conditions or meteorological anomalies. Consequently, continuous data transmissions with high real-time requirements should be avoided. Instead, all time critical functions should be processed on-board autonomously. Data encryption methods and redundant distribution will protect the information from being understood by the adversary and from being manipulated without detection.

Input processing of all systems interacting with the environment shall be used to detect corrupted data and to serve as a firewall for all other systems. Essential functions should not rely on data that has a high potential to be corrupted. The absence of pilot's interfaces on-board allow shielding concepts that enhance isolation of essential functions from the outside world by concentrating the equipment in completely shielded compartments.

With respect to anti-aircraft missiles active sensors and transmitters of the electronic warfare suite are susceptible. Guided by a home-on-jam mode, missiles will utilize the radiated energy to find their target. A capability to switch of the transmitters without a significant impact on mission execution and electronic countermeasures will reduce the severity of the threat.

Energy weapons may become a severe threat in the future. Although the effect is different from electronic warfare, the principles for protection against energy weapons are similar.

Conclusively, the countermeasures against external threats for UTA have a lot in common with what is applicable to manned aircraft because of similar requirements on many on-board systems. Therefore, it makes sense to identify and summarize the differences:

- The reliance on the data link is higher in case of a UTA although effectiveness of manned aircraft is also more and more dependent from the networking capabilities. Especially, strong real-time requirements on the data link makes UTA susceptible to jamming.
- Shielding of UTA on-board systems will achieve a better protection level against electro-magnetic interference caused by electronic warfare and energy weapons.

3.4 UTA Affordability

The requirement for a new kind of weapon system is justified if the following criteria are met satisfactorily:

- New mission types can be executed that are required with respect to operational needs and that cannot be performed by current weapon systems, or an existing mission type can be executed more reliable.
- Operational handling requirements imposed by the weapon system are adequate with respect to the environment and people's skills.
- The technology is available or can be invented with reasonable effort.
- The new weapon system is cost-effective.

The first item was discussed in depth above. With respect to operational handling, recent experience from UAVs was troublesome [2]. The required ground support exceeded the expectations. Low reliability records have led to a maintenance effort that exceeded acceptable levels. Furthermore, other systems may be endangered by operating UAVs. For example, shipboard operation of UAVs may be unfeasible in practice. Therefore, reliability improvements are required prior to fielding UTA weapon systems.

Regarding technology manned aircraft design practices offer a sound basis to start a UTA development. UTA will probably benefit from further technological achievements in manned aircraft design, information technology and weapon technology. However, most of this technology is expensive and ongoing research and development effort is useful to provide the same functionality for less costs.

In some areas technical requirements are more stringent for UTA than for manned aircraft. In these cases UTA concepts have to drive research and development:

- UTA specific airframe performance characteristics have to be analyzed.

	External Threats			
	Surveillance RECCE, ESM	Electr. & Info. Warfare	Anti-Aircraft Missiles	Energy Weapons
UTA On-Board Systems				
Data Link	x	x		x
Active Sensors	x	x	x	x
Passive Sensors		x		x
Mission Management System		x		x
ECM/ECCM/OCM/OCCM	x	x	x	x
Flight Control Functions		x		x
Engine			x	
Control Surface Actuation				
Fire Control Functions		x		x
Weapons				x

Table 2: UTA On-Board Systems Susceptibility to External Threats.

- Reliable data links on the basis of networking technology that provide excellent survivability (even for functions with strong real-time requirements) have to be invented.
- Allocation of data processing within the network has to be defined and optimized.
- Control strategies to manage complex on-board systems autonomously have to be defined utilizing neural networks and other artificial intelligence techniques.
- Advanced concepts for remote control have to be invented considering control tasks, real-time requirements etc.
- Techniques to enhance system integrity have to be developed. In parallel, the costs to implement high integrity systems should be significantly reduced.

Finally, life cycle costs of UTA have to be discussed. From the results of this survey it is concluded that UTA will have to provide a high integrity level. This will severely influence the complexity of on-board systems. Particular systems will have to provide adequate redundancy levels to meet overall system integrity requirements with respect to reliability and safety. Without technology improvements in the relevant areas, integrity requirements will drive development costs to a similar level as for manned aircraft.

Procurement costs of UTA weapon systems will be similar to manned aircraft weapon systems. However, if the capabilities of one UTA, with respect to achievable fire-power and the loss and sortie rates will be at an optimum, procurement cost may be lower compared with an equivalent manned aircraft fleet. Because UTA airframes will be designed for less flying hours this will also contribute to lower procurement costs.

The real cost benefits of UTA are related to operating costs. Basic flight training of UTA controllers can be performed in a simulation environment. Hence the need for actual flying hours will be reduced. Most UTA could be in protected storage while a small number is used for check and demonstration flights as well as for tactical training in case of missions to be flown in a mix of UTA and manned aircraft. This concept requires improvements of long time storage techniques and solutions to gain the necessary maintenance experience. However, military commanders have to get confidence in the capabilities of their weapon systems by training in real world situations. The actual demand of flight hours for this purpose is uncertain.

4. CONCLUSIONS

This paper dealt with system integrity of future UTA weapon systems and the impact on design and affordability. In dense conflicts UTA weapon systems will be used primarily for high risk and long endurance missions, e. g. tactical recconnaissance and SEAD. In lower density conflicts like peace-keeping missions UTA may perform for which the public may not accept pilots' losses.

High integrity is required to withstand external and internal threats in an offensive mission scenario. Especially, the data link is critical to provide real-time control. Safety has to be considered with respect to weapons and flight path control. UTA have to be reliable to minimize the maintenance effort. Consequently, UTA on-board systems will be quite complex.

At all, a UTA will be more similar to a manned aircraft than to an improved cruise missile with a return-to-base capability. UTA development costs will be similar as for manned aircraft. Procurement may be slightly lower. Cost-effectiveness of UTA will be based on essentially lower operating costs than for manned aircraft.

Furthermore, technology areas have been defined which for further research and development is recommended before a dedicated UTA development program should be launched. Among others, system architectures as well as design and verification methods have to be developed to provide cost-effective implementation of high integrity levels.

REFERENCES

1. AGARD: Aerospace 2020, Volume 1 - Summary. AGARD Advisory Report 360. AGARD, Neuilly-sur-Seine, 1997.
2. GAO: Unmanned Aerial Vehicles - DODs Acquisition Efforts. Washington D.C., 1997.
3. GAO: B-2 Bomber - Cost and Operational Issues. Washington D.C., 1997.