ADVANCED TECHNOLOGIES AND APPROACHES FOR NEXT GENERATION UAVS

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Abstract

This paper presents the advanced technologies and approaches which potentially form the basis for determining the "Next Step" in the capabilities of unmanned air vehicles (UAVs), from the aspect of improvements in flight performance, operational safety, readiness and operating costs. These technologies are currently under development but additional effort will be required to achieve a maturity level of technological availability.

These technologies can be divided into groups as follows :-
Airframe – Developments in airframe technologies include aerodynamics, structures and propulsion.
Avionics – Developments in avionics technologies include flight control, computers and communications.
Safety – Developments in safety technologies which include integration within ATC/ATM, Sense & Avoid concepts and certification.
Technologies relating to development and production will be aimed at reducing Life Cycle Costs (LCC).

It is our opinion that the new technologies and accumulated experience in the field of development and manufacture of UAVs, will allow the next generation of UAVs (within a timeframe of 10 years) to realize a doubling of flight endurance, a reduction in operating costs to about one fifth and an improvement in safety of flight by a factor of 10 – 100 times. The directions in which efforts need to be expended in order to achieve these objectives, are presented in the paper.

The paper presents the state-of-the-art (2002) from the point of view of current UAV capability in the sphere of flight performance, safety and costs. It indicates the various parameters which influence this capability, such as:- aerodynamic efficiency (L/D), empty weight, propulsion system efficiency with respect to weight and fuel consumption, subsystems' reliability, effect of avionics architecture and redundancy.

The airworthiness principles are presented, and the target is to improve the Mean Time Between Uncontrolled Landings (MTBUCL) to be between 10^4 *and* 10^6 *hours, dependent on the operational scenario and type of UAV.*

The paper presents examples of potential directions for future systems, based on advanced technologies of aircraft configuration and avionics concepts, for a series of defined missions.

1 Introduction

The concept of remotely piloted vehicles (RPVs) or UAVs, first took wing in the late seventies, but it was not until the mid eighties that the first functional UAVs appeared on the scene. These early days were very much a learning phase. Major improvements in safety and reliability were introduced in the ensuing years until the level of maturity of today's UAVs was achieved.
Fig. 1 illustrates this development trend.

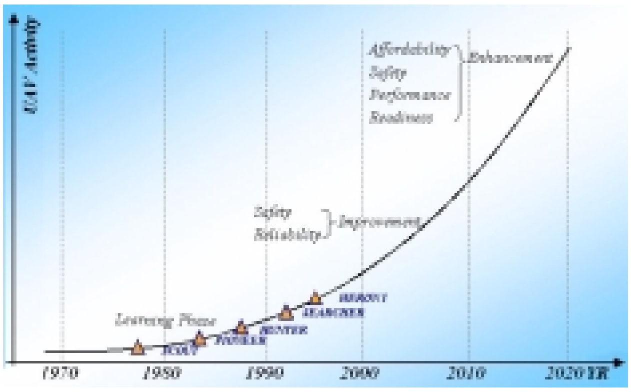


Fig. 1 Tactical UAV development phases

During the next decade we can expect to see considerable advances not only in performance and safety but also in mission readiness and affordability. The main aspects for enhancement of future UAVs can be summarized as follows :-


Affordability
Acquisition Cost
- *Airframe*
- *Payloads*
- *Ground Control*
- *Communications*

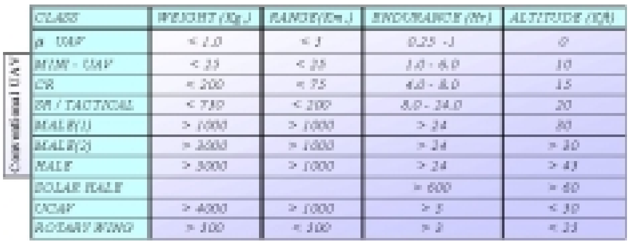
Operations Cost
- *Crew*
- *Training*
- *Infrastructure*
- *Maintenance*
- *Spares*
- *Logistic Support*
- *Operations Concept*

Safety
- *Reliability*
- *Redundancy*
- *Emergency Operation*
- *ATC Integration*
- *Airworthiness*

Performance
- *Payload Capability*
- *Endurance*
- *Speed*
- *Altitude*

Readiness
- *Inherent Availability*
- *Maintainability*
- *Reliability*
- *Logistic Support*
- *Weather Operation*

In considering technological advances, we must take into account the very broad spectrum of UAV classifications and their widely differing missions (both military and civilian). With reference to Fig. 2, this paper addresses the conventional group of UAVs.



	CLASS	WEIGHT (Kg.)	RANGE (Km.)	ENDURANCE (Hr)	ALTITUDE (Kft)
	μ UAV	< 1.0	< 5	0.25 - 1	0
Conventional UAV	MINI - UAV	< 25	< 25	1.0 - 6.0	10
	CR	< 200	< 75	4.0 - 8.0	15
	SR / TACTICAL	< 750	< 200	8.0 - 24.0	20
	MALE(1)	> 1000	> 1000	> 24	30
	MALE(2)	> 3000	> 1000	> 24	> 30
	HALE	> 5000	> 1000	> 24	> 45
	SOLAR HALE			> 600	> 60
	UCAV	> 4000	> 1000	> 5	< 50
	ROTARY WING	> 100	< 100	> 3	< 25

Fig. 2 UAV sizing and flight performance

Typical military UAV missions comprise :-

- Reconnaissance - EO, IR, SAR
- Target designation
- Battle management
- Chem-bio reconnaissance
- Mine countermeasures
- Digital mapping
- Etc. etc.

Typically, civil UAV missions could comprise:-

Surveillance
- Aerial photography & mapping
- Border control
- Fishing zones
- Road traffic

Monitoring
- Forest fires
- Nuclear reactors
- Weather
- Natural disasters
- Oil pipelines
- Power cables
- Road accidents
- Environmental conditions

Communications
- Cellular telephone relay
- “Poor man’s” satellite relay

Scientific Research
- Atmospheric research
- Marine
- Agriculture
- Geophysics

Having identified the market requirements and its applications, the process of creating a UAV system is both interactive and iterative in applying new technologies to achieve increased performance of the subsystem elements.

Fig. 3 below illustrates the UAV creation cycle. It is our experience that all the products created are as a result of tradeoffs made between the elements of this cycle. The final product is a compromise between the market, the available technologies and the performance desired. Tradeoffs are also made in the economic and business aspects of the product.

Fig. 3 UAV system creation cycle

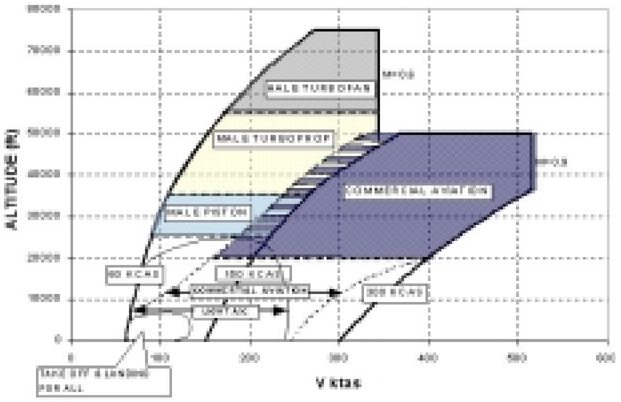
2 Airframe Technologies

The following airframe technologies are considered the most significant ones and are summarized below :-

2.1 Aerodynamics

- Clean design
- Advanced wing design, laminar airfoil
- Multi element wing
- Variable camber wing
- Retractable landing gear
- Reduced cooling drag

The flight envelope of the UAV is different from that of other aircraft. The requirements for long endurance and low operational speed, produce a new region of operation as shown in Fig. 4, and is characterized by lower air density and lower speed.



New Flight Regime Lower Speed, Lower R_{e}, Lower ρ

Fig. 4 General flight envelope – Tactical UAV

The field of this envelope demands new aeronautical requirements both in aerodynamics and propulsion. An important parameter which expresses the aerodynamic efficiency is $(L/D)_{MAX}$.

We believe that by adopting a good aerodynamic approach, it is possible to improve the aerodynamic efficiency by about 30%.

2.2 Propulsion

In the area of propulsion, the main challenges facing UAV designers are related to the type of engine to employ. The main area of concern for small piston engines (under 50hp) is reliability and maturity. The trend today is moving towards engines which have obtained certification and are of a high level of maturity.

Improvements in UAV propulsion systems are very much dependent on improvements in engines developed for manned aircraft in general aviation, and turbofan / turboprop engines for larger aircraft. The improvements in piston, diesel, turboprop and turbofan engines are summarized below :-

- Improved power/thrust to weight ratio
- Lower SFC
- Noise reduction

An example of an interesting development in the 100hp class engines is the diesel engine with improved SFC, reliability and maintainability. Fig. 5 illustrates new engines in this class.

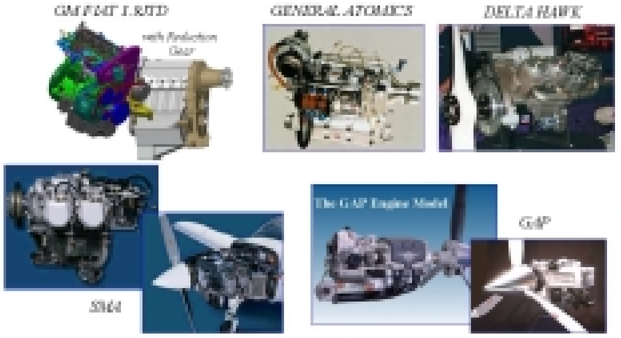


Fig. 5 New generation diesel engines

2.3 Structures

Another basic technology is that of structures. The emphasis here is on the reduction of weight and cost. The important aspects of this technology are described below.

- Composite materials
- Unitized structures
- Low cost / low weight processes
- Load & gust alleviation
- Aeroelastic tailoring

For example, employing active load control to adaptive wings, reduces the structural weight and improves aerodynamic performance. Maneuver Load Control (MLC) reduces static loads by redistributing air loads towards the wing roots during maneuvers. Gust Load Alleviation (GLA) reduces the gust loads by using the trailing edge surfaces. Elastic Mode Suppression (EMS) is used to dampen structural oscillations in the wing for the dominant structural mode.

Maneuver Load Control will be flight tested on the Heron 1 UAV.

Fig. 6 Heron 1 UAV

2.4 Improved UAV flight endurance

We are of the opinion that the general improvements in aerodynamics, structures and engine technologies, together with a correct approach to the design, will enable us to improve the performance of future UAVs by 100%. Details of our estimates are presented here.

Flight Endurance ~ $(L/D)x(1/SFC)x(W_F/W)$

Where :-

(L/D) - Lift to drag ratio
(SFC) - Specific fuel consumption
(W_E) - Empty weight
(W) - Takeoff weight
(W_F) - Fuel weight

(L/D) Improvement 25-40 %
(SFC) Improvement 25-30 %
  - Turbofan, turboprop
  - Diesel
(W_E) Reduction 15-25 %
  - Structures
  - Avionics
  - Propulsion
  - Systems

These figures should result in :-

Endurance Improvement = 80% - 130%

3 Avionics Technologies

3.1 Many of the avionics systems which are in use today will continue to evolve :-

- Computer processing
- A/V sensors
- Navigation
- Automatic flight control
- Automatic takeoff & landing
- Autonomous control
- Internal communications data buses
- Communications
- Failure detection, voting, monitoring
- DGPS (ATC, ATOL, navigation)
- SATCOM

Other more revolutionary technologies, which are being developed in unrelated industries will be applied to avionics systems. Some of these technologies are not yet sufficiently mature, while others which are familiar to us have simply not yet been adopted for avionics applications :-

- Autonomous operation
- Automatic takeoff & landing
- MEMS (Miniaturized Electro-mechanical System)
- SATS - NASA - general aviation initiative
- Automobile electronics technology
- COTS (Ethernet, Internet, communications)

3.2 Several key issues are considered in the following paragraphs which we believe will influence future UAV development.

A considerable increase in UAV autonomy can be foreseen in all phases of flight – takeoff and landing, mission execution and pre and post flight maintenance. Autonomous operation will not only improve flight safety (no operator error), but will also lower operating costs (less operators and less maintenance).

Autonomous operation involves numerous technologies, all integrated into a comprehensive architecture comprising hardware and software. These technologies include :-

- Autonomous planning
- Relative navigation
- Sensing
- Learning and adaptation
- Decision-making

Automatic takeoff and landing could be based on triple redundancy (2 DGPS sensors and laser tracker). The equipment is relatively low cost and widely supported and its evolution to a satellite based correction concept is relatively simple. The method increases the capability of re-routing and forced landings.

Fig. 7 shows automatic landing of an IAI Hunter B UAV.

Fig. 7 ATOL - IAI Hunter B UAV

MEMS (Miniaturized Electro-mechanical System) offers weight and cost reduction with improved reliability through increased redundancy. An example of a micro-UAV employing MEMS technology is illustrated in Fig. 8 below :-

Fig. 8 MEMS technology

SATS (Small Aircraft Transport System), being developed by NASA for general aviation, is aimed at all-weather operation with low cost avionics utilizing Fly-by-wire and capable of automatic takeoff and landing. The NASA 5 year program is shown in Fig.9.

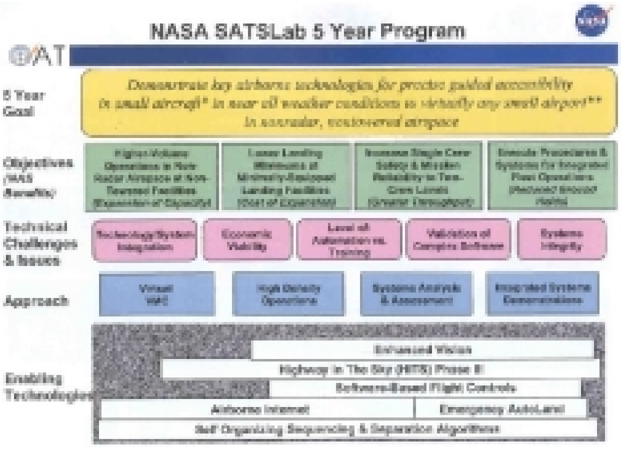


Fig. 9 SATS technology

Technologies developed for the automobile industry, particularly in the field of electronics, look very promising, e.g. engine control and external vision control. Bi-directional data buses for vehicles and "Drive-by-wire" systems for control of brakes, steering and throttle. All of these can contribute to a reduction in weight and cost of the UAV avionics and wiring.

4 UAV Safety & ATC Integration

4.1 UAV Safety Approach

When considering safety the UAV system must be viewed in its entirety – Air vehicle, ground control station / MMI and communications data link. Failure statistics and remedies are shown in Fig. 10 and are based on IAI's experience from 100,000 flight hours of its UAV fleet.

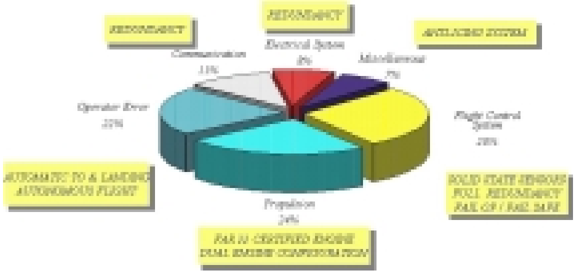


Fig. 10 IAI UAV failure statistics (10^5 flight hrs)

The safety approach should be based on currently existing airworthiness and safety design criteria for manned aircraft, modified and tailored to UAV specific features and types of operation. The prime objective is to minimize the risk of uncontrolled UAV flight and uncontrolled landings.

Subsequently, operational procedures and limitations will be defined. A possible approach is to employ FAR 23 AC23.1309-1C as a guideline.

The most significant criteria for UAV airworthiness are as follows :-

- Airframe structure & design:
  - Tailored manned aircraft criteria
- Propulsion system:
  - FAR 33 / JAR E certified engine
  - Endurance tests (FAR 33 / JAR E)
- Hardware & software qualification
- Ground control station
  - Flight safety parameters indications and warnings
  - Redundancies and backup
- Fail safe design principles for critical systems:
  - Flight control
  - Communications
  - Navigation
  - Electrical power
  - Redundancies and backup
- Failure detection capability (preflight & in flight)
- Flight termination recovery
  - Autonomous control and preprogrammed course of action to safely land in predefined landing area(s)

The MTBL / MTBUCL requirements should be with respect to the type of operation planned.

MTBL - Mean Time Between Losses
MTBUCL - Mean Time Between Uncontrolled Landings

Operations could be military (wartime or peacetime) or civil. Applications must take cognizance of :-

- Population density below
- Loiter time in the defined region
- Flight corridors
- Size & weight of UAV (hazard magnitude)

Fig. 11 below shows the correlation between MTBL and the size of the aircraft, based on existing data for current state-of the-art UAVs. It is our opinion that it will be possible to improve on these figures in the future.

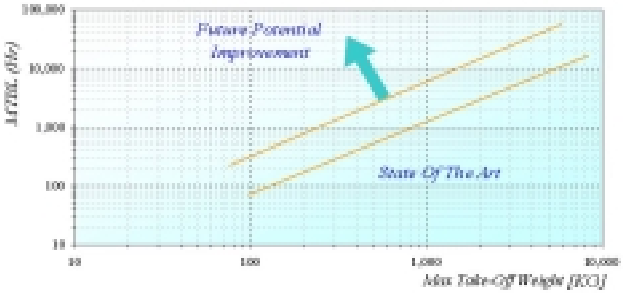


Fig. 11 Reliability with respect to size

Possible Goals For Future UAV Systems:
MTBL - 10^4 - 10^5 Hr
MTBUCL - 10^4 - 10^6 Hr
This estimate is dependent on the operational scenario and the size and type of UAV.

4.2 ATC & Airspace Integration

The objective of a safe and reliable UAV system in line with the above airworthiness criteria, demands the following :-

- Qualified UAV operators / crew qualification requirements.
- Flight plan and ATC co-ordination as per airspace category and constraints.
- Pre-flight risk analysis / well defined emergency procedures including flight termination.
- Close co-operation with ATC (military or civil) :
  - Safe communication capability (air vehicle to ATC, ATC to GCS via air vehicle).
  - Compliance with ATC instructions (altitude & navigation accuracy).

UAV Operational Design Features :-

The current means available for mitigating the risk of collision are as follows :-

- IFF/ATC Transponder
- Two Way Communications Voice Relay
- Anti-collision Lights
- Forward Vision Camera
- TCAS Feature

Other means of “Sense & Avoid” at an advanced stage of development and trial, offer improved means of collision avoidance or evasion. A particularly promising system is ADS-B (Automatic Dependent Surveillance Broadcast).

ADS-B consists of a digital message comprising of position and flight data broadcast in a short time slot. A particular time slot is assigned to each particular aircraft. Since near future maneouvering intentions are included in the message, any listener in the air space is able to construct the trajectory of that particular flight. Risk of collision may be computed by the listener (relative to his own flight path) and evasive maneouvers may be planned before the risk materialises.

5 UAV Readiness Approach

The readiness or availability of a UAV system is influenced by the following factors :-

- Mission reliability
- Built-in reliability and redundancy
  - Air vehicle
  - Avionics
  - Payloads
  - Communications
  - Ground control systems
- MTBCF (Mean Time Between Critical Failures) design targets tailored to flight endurance
- Maintainability
- Logistic support
- Bad weather operational capability

Long endurance requires a high MTBCF. For example, for a mission reliability of 0.9 and corresponding MTBCF of 250 hrs, we obtain an endurance of 26 hrs. For MTBCF of 50 hrs and the same mission reliability we obtain an endurance of only 5 hrs.

Fig. 12 provides MTBCF reference data with respect to UAV size, for state-of-the-art military UAVs.

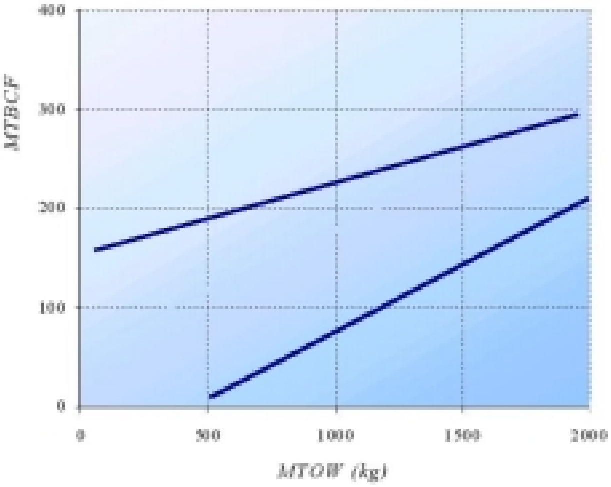


Fig. 12 MTBCF (measured & estimated)

5.1 UAV Bad Weather Operation

To increase mission readiness, operation of UAVs must be broadened to almost all weather conditions, including rain, thunderstorms, icing conditions, turbulence and side winds. In order to cope with these conditions, design of future UAVs must take into account :-

- Structural design and systems
- Integrated de-icing systems
- Flight operation appropriate to weather conditions (operational altitude, operating conditions)
- Automatic take-off and landing

For example, TKS provides a potential solution for de-icing which can be incorporated in the leading edge of a laminar wing. This consists of a metal leading edge with laser-drilled holes, through which de-icing fluid can be wept from a cavity using small pumps. An example of TKS based on glycol fluid, which is an acceptable solution for UAVs, is illustrated in Fig. 13. It is a simple and partially removable system with a minimal impact on performances. The system can be activated either automatically (by the ice detector) or manually from the ground control station.

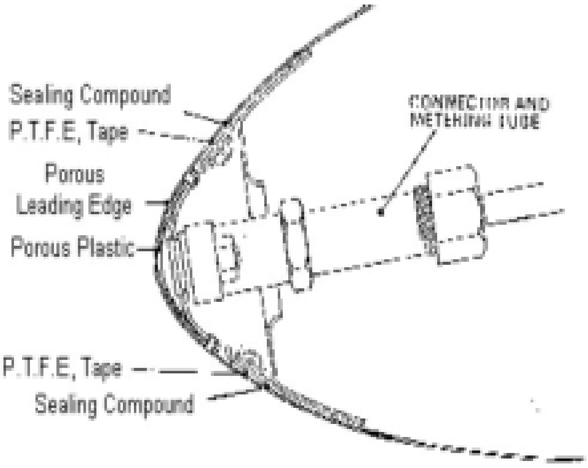


Fig. 13 De-icing / anti-icing system

5.2 UAV Readiness summary

Design for high mission reliability and inherent availability have an impact on the fleet size of the UAV systems and an impact on cost effectiveness of the mission.

Design for almost all-weather operation provides better UAV systems utilization which also improves the total availability of the systems.

6. UAV Affordability - Cost Reduction Potential

One of the main issues which will influence the UAV industry in the future, is the capability to provide affordable solutions to the diverse missions, compared to other competing solutions.

The main issues relating to costs are :-

- Acquisition cost
  - – Air vehicles
  - – Payloads
  - – Ground control stations
  - – Communications
- Total operating cost per flight
- Initial ILS cost

Fig. 14 shows a cost model for a typical UAV system. It takes into account the cost of aircraft, ground station, communications and payload.

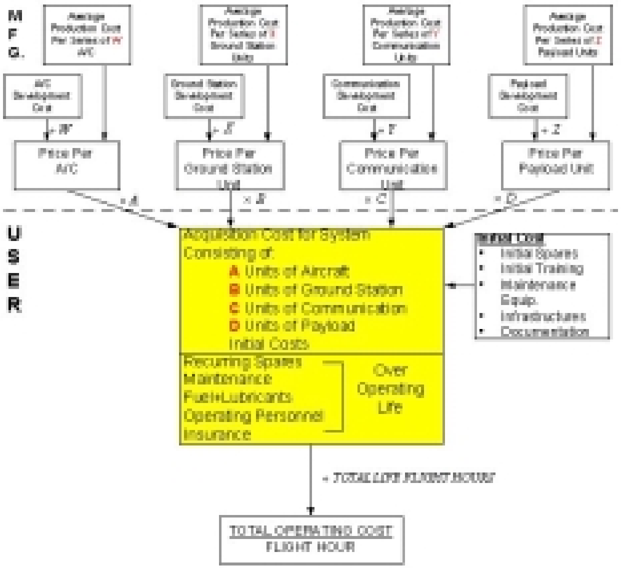


Fig. 14 Typical UAV cost model

6.1 Acquisition Cost Reduction Potential

Acquisition costs of the air vehicle have considerable potential for reduction by means of:-

- – Efficient and innovative use of composite materials manufacturing.
- – “Lean” concepts for manufacturing as employed in the aircraft industry.
- – Lower subsystems cost due to production quantity increase.
- – Lower avionics costs due to the use of COTS, MEMS, automotive electronics.
- – Reuse of software.
- – Use of new general aviation concepts to be developed in the future (SATS).

Fig. 15 shows the acquisition cost with respect to the empty weight of the aircraft. From the chart we can compare state-of-the-art UAV trends with those of general aviation and business aircraft.

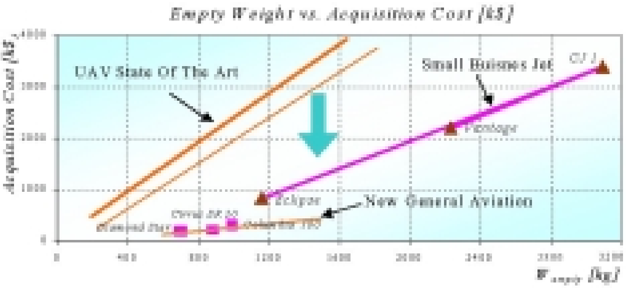


Fig. 15 UAV Cost Reduction Trend

We believe that by employing the methods mentioned above, acquisition costs can be reduced by between 30% and 60% within the coming years.

6.2 Total Operating Cost (TOC)

The total operating cost is a function of the UAV operational scenario.

- Number of operative UAVs
- Flight hours per year for each UAV (readiness)
- Operating from fixed or mobile base
- Continuous or intermittent operation

The total operating cost is the sum of the direct (DOC) and indirect (IOC) operating costs.

Direct Operating Costs can be reduced by :-

- Reducing operational personnel
  - Automation, autonomy
  - Operational new concepts
  - Automatic take-off and landing
- Maintenance reduction
  - Automatic health monitoring and BIT (advanced sensors)
- More electronic control
- More electrical systems

Indirect Operating Costs can be reduced by :-

- New concepts of operation training
- Manpower organization
- Infrastructure organization

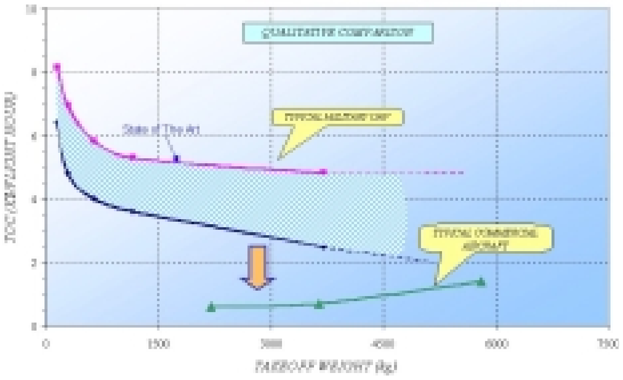


Fig. 16 Future TOC Targets for UAVs

Fig. 16 above illustrates the total operating cost per flight hour with respect to the takeoff weight of the UAV. The chart shows TOC of typical state-of-the-art, military UAVs compared to typical commercial aircraft, and indicates the trend for further reduction of TOC. The reduction in total operating cost per flight hour for the next generation of UAVs is foreseen to be in the order of magnitude of 5. This also takes into account the fact that the endurance time of the UAV is likely to be doubled.

7. Some Examples of New UAV Directions

The potential for improving the configuration can be seen in the following examples. Fig. 17 shows versions of the Heron UAV. Heron 1, which is a production UAV and Heron TP which is a larger UAV and is still in the development phase.

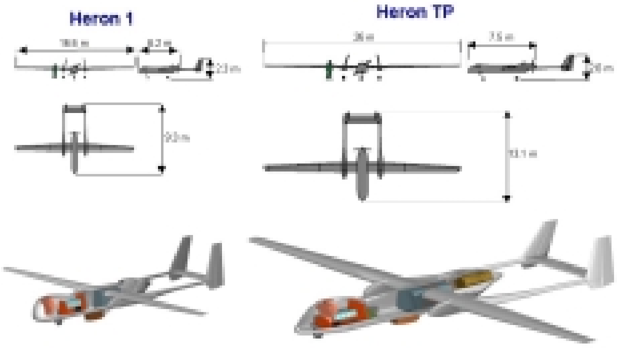


Fig. 17 Heron UAV versions

An additional example is shown in Fig. 18 of the improvement in flight performance by replacing the engine, increasing the body size and reducing the drag of the UAV.

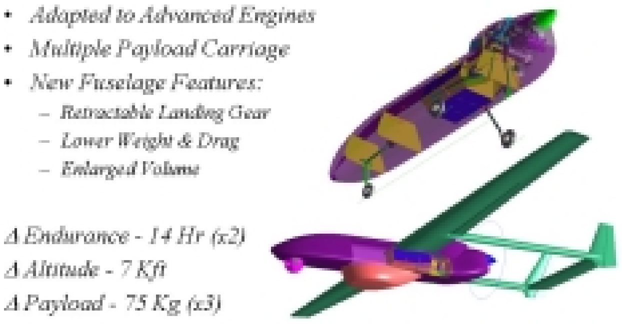


Fig. 18 Examples of UAV improvements

Some additional examples of trends in future UAV development are illustrated below. These are based on various customer requirements with technology available today.

Heron TJ (shown in Fig. 19) is a turbofan derivative of Heron TP intended for high altitude and long endurance flight.

Modular HALE UAV (shown in Fig. 20) is a concept for integrating different fuselage shapes, shaped according to the mission requirements, into a single configuration. This UAV is in the 10,000 kg TOW class.

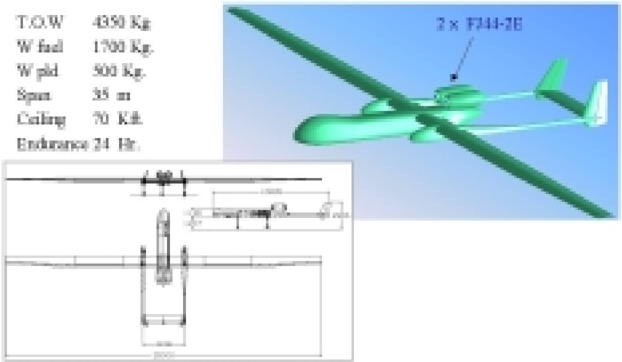


Fig. 19 Heron TJ UAV

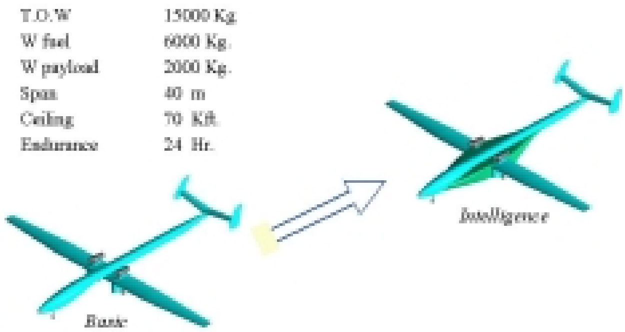


Fig. 20 Modular HALE UAV

The new miniaturization technologies of today enable the development of very small UAVs with great capabilities. For example a mini UAV, in the 10 kg class, is shown in Fig. 21.

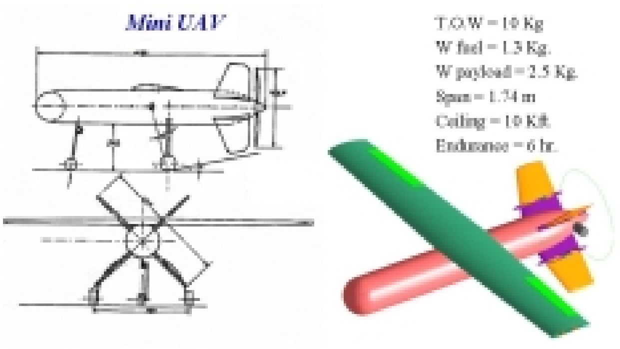


Fig. 21 Mini UAV

8. Summary

The above review indicates possible scenarios in the development of the next generation of conventional UAVs. Major expansion is expected in activities in the field of UAVs in the coming years in which currently new technologies will mature. In our opinion this broadening activity and use of new technologies will considerably advance UAV improvements. Emphasis during the coming years will be in the sphere of affordability, performance, safety and readiness. These efforts will be supported and fed by other activities occurring in the world about us:-

- Technologies of computers
- Technologies of manned aircraft
- Technologies of automobiles
- Technologies of miniaturization
- Technologies of communications, entertainment and internet

In our opinion, possible attainable objectives are:

- Doubling the endurance of UAVs (with the ability to carry heavier payloads)
- Halving acquisition costs of UAV systems
- Reducing "total operating cost per flight hour" to about one fifth
- Safety improvement by 10 to 100 times
- Readiness improvement by maturity and correct airworthiness approach

The new advanced technologies provide opportunities for the creation of new UAV systems directions and applications.

9. Acknowledgements

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