HIGH ALTITUDE LONG ENDURANCE (HALE) UAV FOR INTELLIGENCE MISSIONS

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Abstract.

The development of UAVs in Israel Aircraft Industries (I.A.I.) is described herein, with an emphasis on those activities relating to UAVs for High Altitude and Long Endurance (HALE).

The advantages of employing UAVs are described both for military use and for civilian use.

The technologies required for HALE UAVs are described with an emphasis on propulsion systems. The differences between turboprop, turbofan and piston engines with turbochargers are emphasized. Despite the considerable benefits of the latter with respect to performance, there is a tendency to select turbofan or turboprop engines because of their high reliability and availability.

The aerodynamic technologies are described with details of Israel Aircraft Industries' achievements in developing special wing sections for high altitude. The aerodynamic technologies involved are illustrated by presenting a typical wing section developed for high-altitude transonic flight at low Reynolds numbers.

Technologies are described for structures, cooling, reliability, safety and survivability.

Two configurations for high altitude are examined from aspects of performance, reliability and price. The configurations have spans of 90 - 120 ft. and takeoff weights of 9,000 - 11,000 lb.

1. Background of I.A.I in High-Altitude UAVs.

1.1 Background of I.A.I in UAVs.

Israel Aircraft Industries Ltd. (I.A.I.) began developing unmanned air vehicles (UAVs) after the Yom Kippur war, in order to provide an answer to the need for real time intelligence without endangering human life. Since 1973 I.A.I. has developed and produced a family of UAVs, while continuously improving payload weight, altitude and endurance. (See fig. 1.1)

Among the systems which were developed, the following are particularly worthy of attention :-
The Scout which was developed in 1974 and is currently in service with the I.D.F. and other armies.
The Pioneer system which is produced jointly with A.A.I. and has been sold to the U.S. Navy.

The Searcher which was developed in 1988 and is currently in service with the I.D.F.

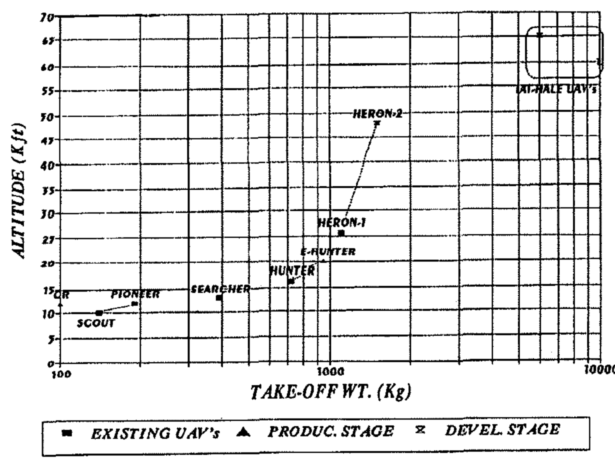


Figure 1.1: IAI - UAV Family Classification

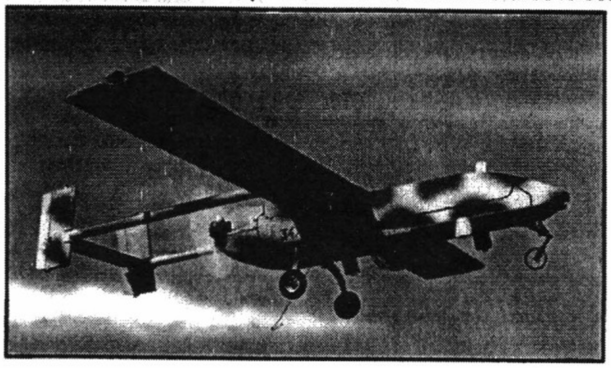
Following a RFP issued by the Joint Program Office (JPO), encompassing all arms of the U.S. military, for a Short Range UAV; IAI, together with TRW won the competition, and were awarded a contract for low rate production.
The Hunter UAV whose requirements were specified by JPO, began development in 1988, and to date seven systems comprising 56 UAVs have been supplied to the US Army.

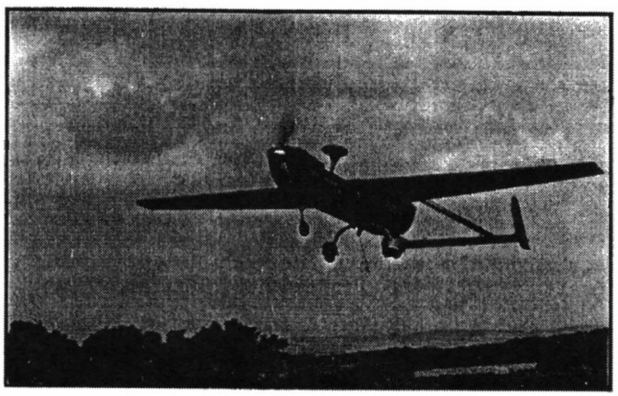
At the top end of the scale is the Heron UAV whose requirements were specified for IDF auxiliary missions. This UAV provides a leap in performance and is capable of carrying a payload of up to 250 kg. to an altitude of 30,000 ft. with endurance of more than 50 hours (2 days). The first flight of this UAV was in 1994. Part of the IAI UAV family is shown in fig. 1.2. Heron 2 is a high altitude version of Heron which, by means of a 550 hp. turboprop engine and larger wings, is capable of an altitude of 47,000 ft. (fig. 1.3)

To date, the UAVs developed by IAI have accumulated over 50,000 flight hr. in service with the IDF, US, and other forces.

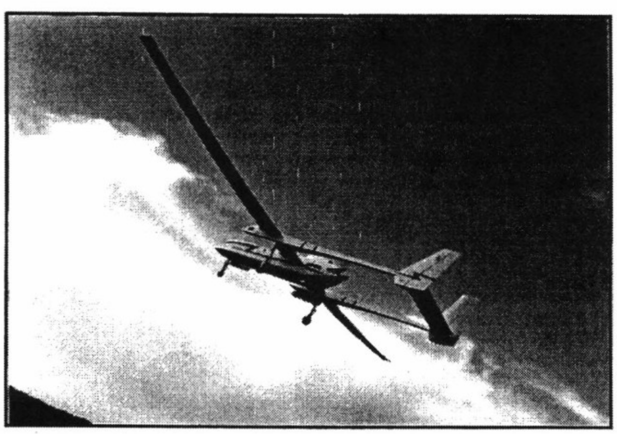
These UAV systems have also matured in terms of reliability, survivability and ease of operation, in addition to the parallel development of payloads, communication systems, avionics and command & control systems..

SCOUT
First generation UAV in operation with the Israel Defense forces





HUNTER
The U.S. short Range UAV



HERON
Long endurance UAV

Figure 1.2: IAI UAV's

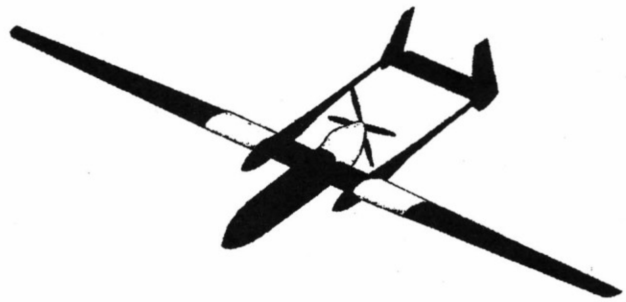


Figure 1.3: Heron 2

1.2 High Altitude and Long Endurance (HALE) UAV Programs

In the past few years I.A.I. has worked on High Altitude and Long Endurance (HALE) UAV Programs. For these purposes high altitude is defined as over 60,000 ft.
Within the framework of tactical ballistic missiles defense programs, I.A.I. has been involved in a number of UAV programs for intelligence missions, and a boost phase interception (BPI).

Involvement in high altitude programs caused I.A.I. to develop technologies and expertise in the fields of aerodynamics, propulsion, structures, fuel systems, electrical systems and cooling systems. The company has created an infrastructure which would enable it to develop HALE UAVs at low cost and a short development cycle.

2. Missions for High-Altitude UAVs.

2.1 Advantages of High-Altitude Flight for HALE UAVs.

The main need for high altitude flight is derived from the ability to lengthen the distance to the horizon for missions which require an undisturbed line of sight.

In atmospheric investigation missions, one needs to get to the air layers which are required to be sampled.

Secondary benefits of high altitude flight are : -

The ability to fly above the region of high wind velocities (35 - 40,000 ft.). (See fig 2.1) [1]
or to fly above commercial aircraft traffic (51,000 ft.).

A high flying UAV has an advantage over a manned aircraft in that there is no need for pilot support equipment. In a manned aircraft it is necessary to pressurize the cockpit and supply oxygen to the pilot. At high altitude a pressure suit must be worn for emergency situations, such as loss of pressure or pilot ejection. This suit makes it difficult for the pilot to endure long periods. A UAV is obviously unrestricted by pilot limitations.

High flying UAVs can be used for special tasks which today are performed by military and civil satellites, with certain advantages from a point of view of availability for covering specific areas. For example, a photographing satellite of the type LANDSAT 5-6 visits the area of interest once in 16 days [2]. If this area is within the range of a UAV, then within a few hours it can be covered by the UAV which provides long coverage periods.

The price of a UAV is less than a satellite by an order of magnitude or more, and can thus serve as the "poor man's" satellite [7].

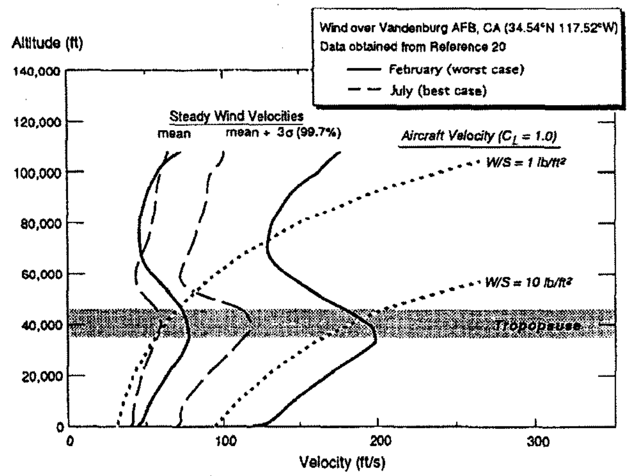


Figure 2.1: Wind and Flight Velocity Profiles

2.2 Civilian Missions for High-Altitude Flight.

The prime reason for preferring UAVs over manned aircraft for civilian missions is the long endurance demanded by these missions which imposes unreasonable workload on a pilot. It is usual to split the missions into the following two categories:-

- Stratospheric science at altitudes of 80,000 - 130,000 ft. for periods of 6 - 36 hr. [1].
- Tropospheric science which includes analysis of climate, radiation etc. at altitudes of about 65,000 ft. for periods of 40 - 200 hr. with payloads weighing 200 - 900 lb. [1].

Civilian missions of a commercial nature are principally those performed today by satellites. Of these we mention the following:

Relay of radio, television and telephone :- In countries having large areas which are thinly populated, it is not economically viable to establish a ground based infrastructure for repeaters, and it is worth considering relaying by means of high altitude UAVs having long endurance. A UAV flying at an altitude of 65,000 ft. has a radio range of about 600 km. this means that it is possible to relay from a ground transmitter to a ground receiver at a distance of 1,200 km. if the UAV is at the mid point.

Aerial photography :- A high altitude UAV equipped with cameras for surface photography is able to cover broad areas in a relatively short time. The advantages of a UAV over a satellite in this case is the purchase price, the availability and the photographic resolution. The photographic resolution of the satellites LANSAT 5-6 and SPOT is 10 - 30 meters [2]. With a high altitude UAV one can obtain better resolution with quite simple electro-optic equipment.
Aerial imaging is the basis for a wide variety of uses :-

- Detecting forest fires and support in directing fire-fighters.
- Border supervision and prevention of smuggling.
- Maritime supervision to detect illegal and accidental oil spillage, illegal fishing, and assistance to trawlers in detecting shoals of fish.
- Detecting minerals.
- Supervision of building regulations.
- Supervision of agricultural development.
- Support in event of natural disasters e.g.: earthquakes, avalanches, floods etc.

2.3 Military Missions.

The prime reason for preferring UAVs over manned aircraft for military missions is not to endanger human life in flights above enemy territory. A secondary reason is to permit longer endurance without the limitations of pilots and their support equipment.

The military missions suited to UAVs are the same missions performed today by manned aircraft and satellites. High altitude enables an increase in range of communication, radar and sensors in the visible and IR spectrum. Of the missions we mention the following :-

- Communication relay to ground, air and sea forces at remote locations.
- Data link relay to UAVs collecting intelligence material.
- Intelligence image collection by radar, film cameras and electro-optic equipment. High speed flight, which is characteristic of turbofan powered UAVs allows broad coverage of areas in a short time.
- Electronic intelligence collection.
  The advantage of height is the ability to achieve long range, or alternatively to remain distant from enemy territory.
- Boost phase interception (BPI) of ballistic missiles. This mission is particularly suited to high altitude UAVs since, the higher the altitude the longer is the time available for interception, thus increasing the chance of a kill. The employment of a UAV appears to be logical since it is necessary to over fly enemy

territory for long periods. An example of a potential system based on a TIER II+ UAV is shown in fig. 2.2 [(8)].

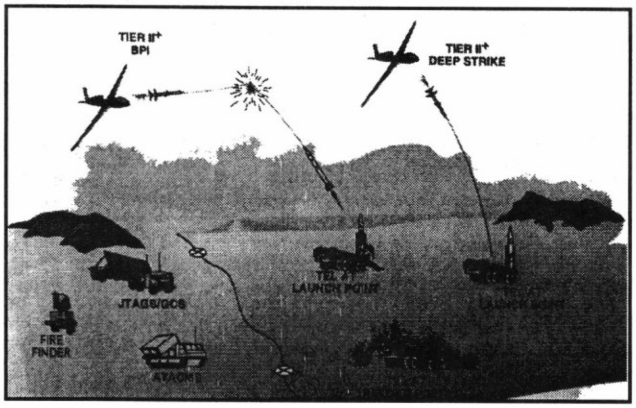


Figure 2.2: BPI and Deep Strike Performed by TIER II+

3. Technologies for HALE UAVs.

High altitude, long endurance flight by an unmanned air vehicle introduces unique demands which requires the development of special technologies. Despite many attempts since the early seventies until the present date, to develop HALE UAVs for military and civil missions, there is still no system operational. Some of the causes for this is that in certain fields, existing technologies are not sufficiently mature to provide solutions for high altitude. (See figs. 3.1.[(6)] & 3.2.[(1)]).

All of the operational high altitude aircraft existing today are manned. e.g. U2, TR1, SR71 and MIG 25. Development of TIER II+ and TIER III- will apparently produce an operational HALE UAV system towards the beginning of the next decade.

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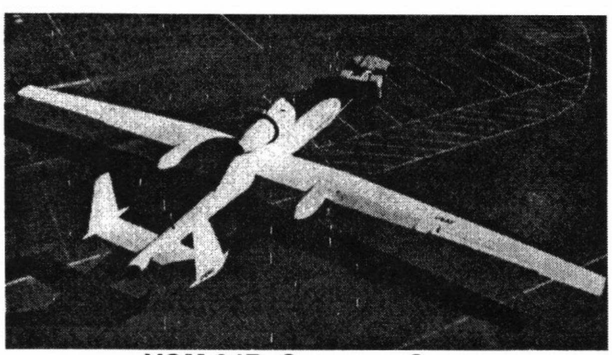
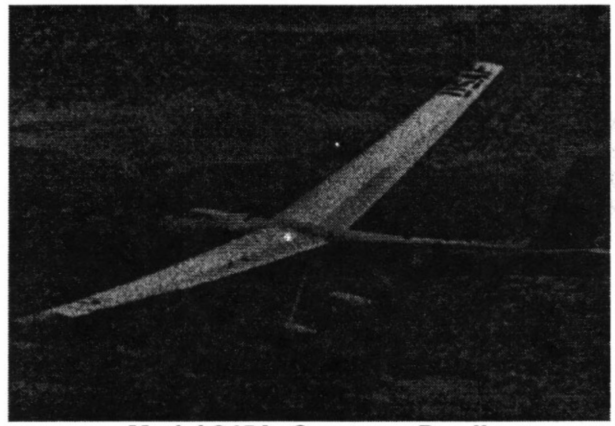


YQM-94B Compass Cope



Model 845A Compass Dwell

Figure 3.1: Early HALE UAV's

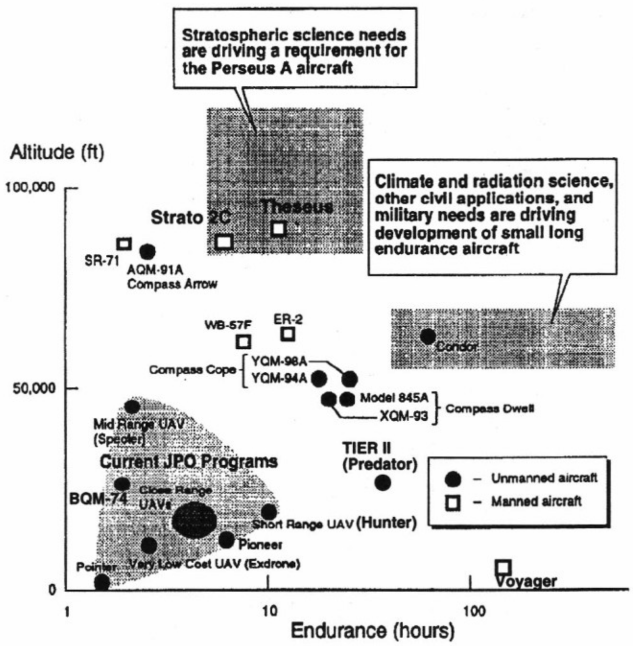


Figure 3.2: Altitude and Endurance Capabilities of High Altitude UAV and A/C

Among those technologies critical to high altitude, long endurance flight we make mention of the following :-

- Propulsion.
- Aerodynamics.
- Structures.
- Electrical system.
- Survivability (for military UAVs).
- Reliability.
- Autonomous control
- Integration with civil traffic (ATC)
- Cooling of systems and payloads.

3.1 Propulsion

The low air density at high altitudes reduces the efficiency of the traditional means of propulsion, which all require oxygen from the atmosphere. Generally it is considered that above 100,000 ft. an independent supply of oxygen is required, or a means of propulsion is selected which does not require oxygen e.g. solar energy.

When considering development of an operational UAV system in the short term, the choice of a propulsion system must be made from the currently available, flight proven propulsion methods. Methods which are still in a basic research stage, should be given time and effort to mature and improve, before being considered appropriate for integration into a near term UAV system.

If we focus on mature, available means of propulsion i.e. piston engines, turboprop and turbofan, we will need to compensate the reduction in thrust with altitude by choosing engines with excessive thrust (usual for turboprop and turbofan), or by adding a means of compression that will supply the engine with air at pressure close to that at sea-level (usual for piston engines). In fig. 3.3 we can see the envelopes of piston engines with one or more stages of turbocharger, and also turboprop and turbofan engines on the altitude and speed graph.

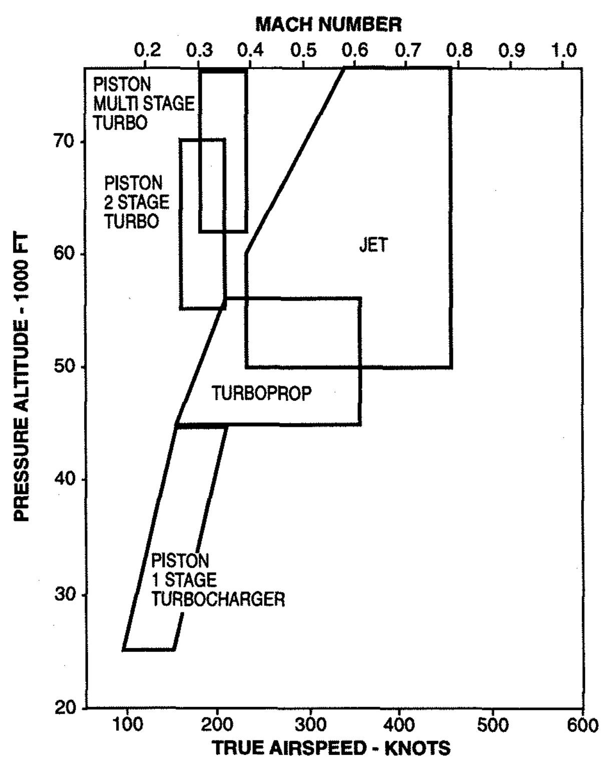


Figure 3.3: Flight Envelopes for Alternative Propulsion Systems

Piston engines with two stages of turbocharger can reach altitudes of 70,000, and with three stages, theoretically could reach 90,000 to 100,000 ft. [4]. at a speed of up to 0.4 Mach. Turboprop engines (after modification) can reach an altitude of 55,000 ft. and a speed of 0.6 Mach.

Turbofan engines can reach an altitude of above 70,000 ft. and a minimum speed of 0.5 Mach at 70 kft. Turbofan engines have a relatively high fuel consumption, whereas turbocharged piston engines have low fuel consumption. Turboprop engines are somewhere between these two.

Comparison between these types of propulsion from a point of view of Thrust Specific Fuel Consumption (TSFC), appears in fig. 3.4.

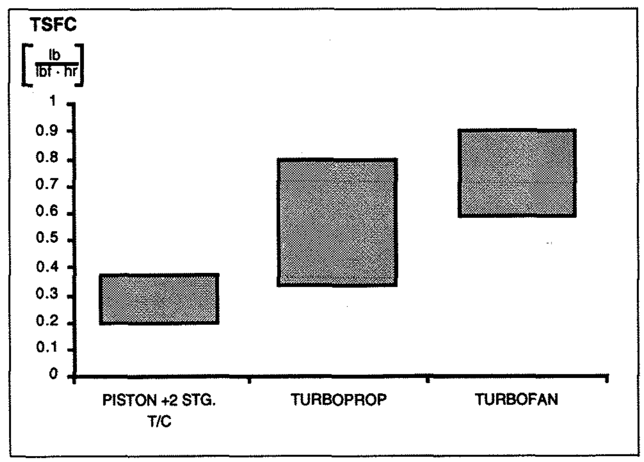


Figure 3.4: Thrust Specific Fuel Consumption for Various Propulsion Systems

At first glance it appears that the piston engine with two or more stages of turbocharger is the most suitable for high altitude, long endurance (HALE) flight, but a closer examination reveals that these engines suffer from the following weaknesses :-

- Complicated system of three machines which need to be mutually matched.
- Complex control system on the exhaust, engines, transmission box, propeller, and cooling.
- Cooling system for the engine, engine oil and the two stages of turbocharger (intercooler and aftercooler) at high altitude conditions demand large area air-intakes and heat exchangers on the propulsion system which increases its size and weight. (see fig. 3.5.[10]).
- Because of the complexity, the reliability of these propulsion systems could be low.

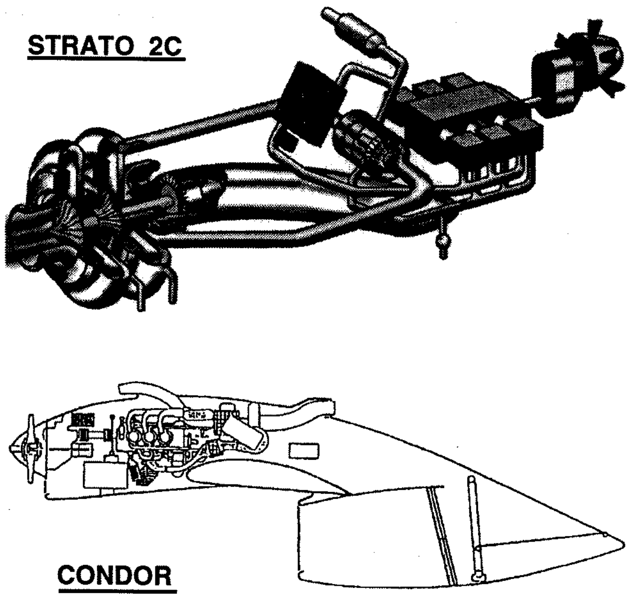


Figure 3.5: Examples of Two Staged Turbocharged Piston Engines

Table 3.1 shows typical data of a piston propulsion system with one and two stages of turbocharger, and a turbofan engine. Whereas the piston engine has a Mean Time Between In-flight Shut-Down (MTBIFSD) of about 3,000 hr., the turbofan engine has an MTBIFSD of 50,000 to 70,000 hr. The reliability of the turboprop engine is somewhat less than that of the turbofan because of the additional influence of the propeller and the transmission.

Table 3.1: Reliability of Turbofan Engine Compared to Turbocharged Piston Engines

		TURBOFAN	2 STAGE TURBOCHARGED RECIPROCATING	1 STAGE TURBOCHARGED RECIPROCATING
MEAN TIME BETWEEN IFSD	[hr]	50,000-70,000	~ 3,000	~ 15,000
MTBMA	[hr]	1,500-2,000	~ 250	~ 250

IFSD - INFLIGHT SHUT DOWN
MTBMA - MEAN TIME BETWEEN MISSION ABORTS

When choosing a propulsion system one must consider all the aspects of the system. From the qualitative comparison in table 3.2. It appears that there is a certain preference for turbofan engines.

In aerial imagery missions the speed is important, therefore there is a preference for turbofan engines for these missions. The US DARO has chosen turbofan engines for two HALE UAVs which are under development :- TIER II+ and TIER III- .

Table 3.2: Comparison of Propulsion Systems

	2/3 TURBOCHARGED RECIPROCATING	TURBOPROP	TURBOFAN
AVAILABILITY	-	++	+
MATURITY	-	+	+
RELIABILITY	-	+	+
FUEL CONSUMPTION	+	+-	-
ALTITUDE CAPABILITY	+	-	+
AIRFRAME INTEGRATION COMPLEXITY	-	-	+
DRAG CONTRIBUTION	-	+-	+
COOLING REQUIRMENTS	-	+	+

3.2 Aerodynamics.

3.2.1 Flight Ceiling.

In order to sustain altitude, the thrust required (T) must overcome the aircraft drag (D): $T \geq D$

Further development produces the equation :-

$$\frac{T}{W} > K \frac{1}{L/D}\left[\left(\frac{W}{S}\right)\left(\frac{1}{M^2 C_L}\right)\left(\frac{1}{\rho}\right)\right]^{\frac{1}{2}}$$

K = Constant
W = Weight
ρ = Density at altitude
S = Wing surface area
M = Flight mach. no.
C_L = Cruise coefficient of lift
L/D = Lift to drag ratio

With air-breathing engines, as altitude is increased, ρ reduces and so does T. In order to sustain altitude, there is a need to compensate for this by reducing the right hand side of the equation. In order to do this we require :-

- To increase L/D. Typical values for HALE UAVs are around 30 - 40. This can be achieved by ensuring extended runs of laminar flow over the wing surfaces. One should design the wing skin to be smooth without protrusions. Composite materials have a clear advantage in this respect.
  In order to reduce the drag caused by lift we need to increase the wing span with respect to its wetted area. See fig. 3.6. Increasing the span is generally restricted by considerations of strength, elasticity and ground handling.

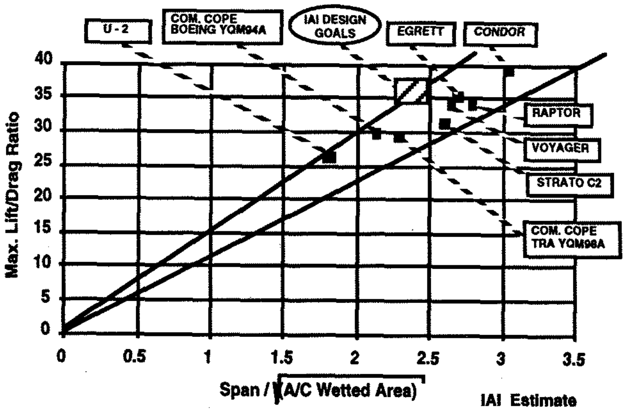


Figure 3.6: Lift/Drag of HALE A/C and UAV

- Reduction of wing loading :- Reducing the wing loading limits the operational usefulness of UAVs in high speed wind conditions (See Fig. 2.1). Increasing the wing area contradicts the requirement for a maximum L/D, and for minimum structural weight.
- Enhanced values of the ceiling parameter (M^2CL_{max}), which should be achieved at relatively low Reynolds numbers typical of high altitude flight. This is made difficult due to transonic effects at the relatively high lift coefficients required for long-endurance flight.

IAI is currently developing a number of airfoils for high-altitude, long-endurance flight. A typical airfoil (LRT-17.5) and its design pressure distribution are shown in Fig. 3.7 [9]. Experimentally evaluated maximum lift coeff. and ceiling parameter are shown in Fig. 3.8 and 3.9.

Fig. 3.10. shows the design goal area for the LRT family of airfoils developed at IAI.

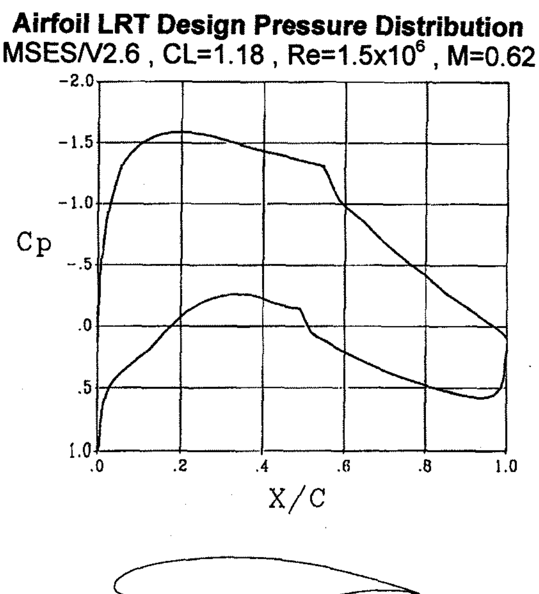


Figure 3.7: Typical IAI Airfoil for HALE

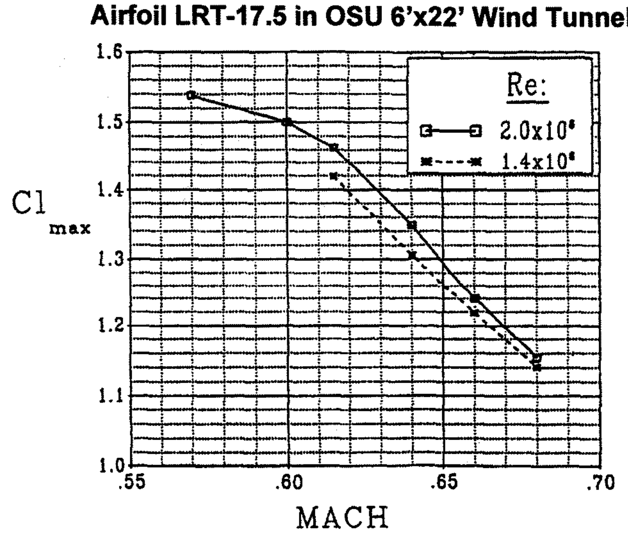


Figure 3.8: Maximum Lift

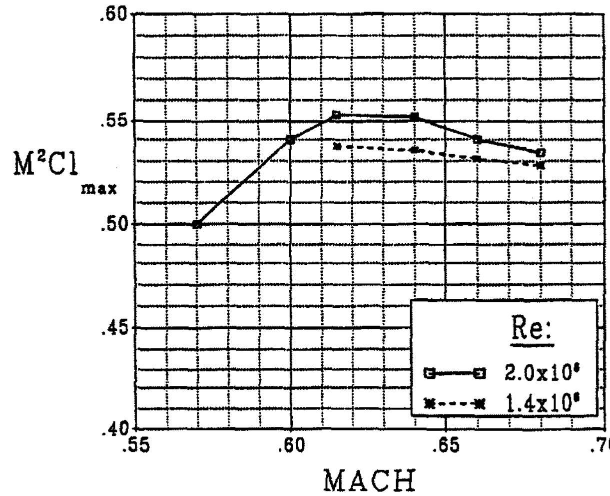


Figure 3.9: Ceiling Parameter

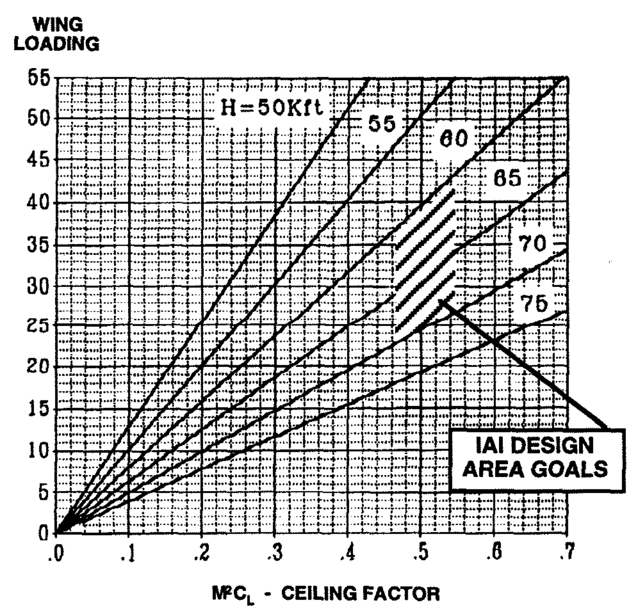


Figure 3.10: Wing Loading vs Ceiling Factor

3.2.2 Endurance

An additional common requirement of the HALE UAV is long endurance. Endurance is determined by the Breguet equation for constant power which is a close approximation to [1] :-

$$E = K\frac{1}{SFC}\frac{C_L^{3/2}}{C_D}\left(\frac{\rho S}{W_{TO}}\right)^{1/2}\left[\left(\frac{1}{1-\frac{W_F}{W_{TO}}}\right)^{1/2}-1\right]$$

K = Constant
C_L = Lift coefficient
C_D = Drag coefficient
SFC = Specific fuel consumption (lb./bph.hr.)
W_{TO} = Takeoff weight
W_F = Maximum fuel weight.
S = Wing surface area
ρ = Density

Here the requirement is for L/D to be as high as possible, just as required by flight ceiling.

Specific fuel consumption TSFC should be as small as possible.

The ratio of fuel weight to takeoff weight is extremely important to long endurance. The FUEL FRACTION can be increased by choosing an appropriate structures technology. Increase in takeoff weight allows to some limited extent an increase in this ratio.

3.3 Structure.

The principle target of structural design is to produce a wing with a high aspect ratio, while maintaining the strength and rigidity required to prevent aero-elastic adverse phenomena.

The significance of this is an increase in stress at the root of the wing. A material having a high strength to weight ratio is required. Thus, in designs of HALE UAVs it is usual to construct the wings from graphite epoxy. This material has a clear advantage in strength to weight ratio over that of aluminum or fiberglass.

This allows a wing structure having a specific weight of 2 lb./ft^2, 1/10 of a 747 and 1/2 that of a U2.[5]. In spite of this, it is usual that considerations of strength will limit the wingspan.

The use of bonded composite materials provides the following advantages :-

- Production of large components which saves assembly labor.
- Use of adhesives without bolts - important for low drag, low weight and labor savings.
- Prevention of wingspan flexing - important for high aerodynamic efficiency.
- High structural rigidity - prevents flutter.
- Improved vibration absorption compared to metal.
- Improved fatigue behavior.

Fig. 3.11. shows the structure of the HERON UAV. The wing is divided into three parts, where the central section comprises an integral fuel tank. The fuselage consists of a single integral part with covers for the engine cowling and access panels. The boom is manufactured together with the vertical stabilizers as a single part. The horizontal stabilizer is manufactured as a separate single part.

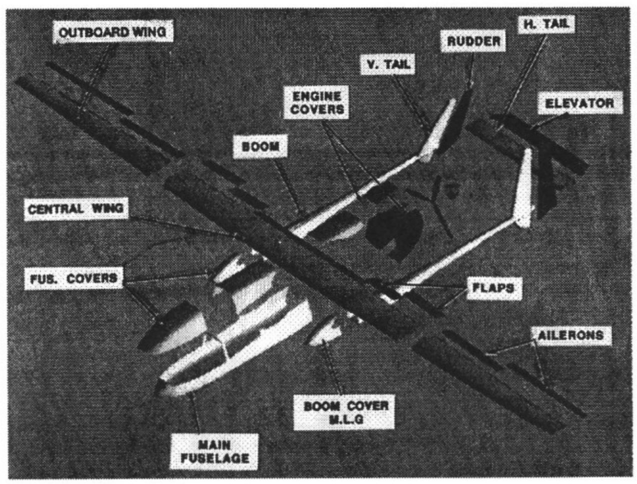


Figure 3.11 Heron Structure

As stated in the previous paragraph one key to long endurance is that the ratio of fuel weight to takeoff weight should be as high as possible. I.A.I. design goals are in the region of 0.50 - 0.65.

3.4 Cooling of Engines and Systems.

Flying at altitudes of 60,000 ft. and above causes a significant reduction in the ability to provide cooling from the outside air, due to the reduction in air density.

With respect to the cooling of turbofan and turboprop engines the problem is less severe, since the quantity of air passing through the engine is adequate to cool it. Adapting these engines for high altitude usually requires enlarging the oil heat exchanger.

At high altitude, electrical generators also require liquid cooling, and usually we must use brushless, oil cooled generators, that require oil-air heat exchangers.

Cooling of the avionics systems, communications and payloads is also problematic at high altitude. The traditional solutions are as follows:-

- Liquid cooling using liquid-fuel or liquid-air heat exchangers . In event of using the fuel as a heat-sink, one must check that the temperature to which the fuel is expected to rise is below its boiling point. It must be remembered that the fuel located in the wing cools via the skin of the wing. If there is a danger of boiling then a heat exchanger must be added to air cool the fuel. Fuel at a high temperature contributes somewhat to the efficiency of the propulsion system.

- Pressurizing the avionics and payload bays allows them to operate under similar conditions to those of low altitude. Pressurization also has a positive influence in preventing interference caused by low pressure e.g. discharge in the communications system.

3.5 Reliability, Redundancy and Autonomous Control.

For HALE UAVs with high endurance, reliability is very important. If a 95% probability of mission completion is required, for a mission of duration 20 hr., then it is required that the Mean Time Between Mission Abort MTBMA > 400 hr.

This goal appears to be quite ambitious. As can be expected, the propulsion system is the most critical in determining UAV mission and overall reliability. In fig. 3.12 mission reliability (or probability of mission completion) is plotted against endurance. A configuration which is propelled by a turbofan engine achieves a reliability of 90% on a 24 hr. mission, whereas a configuration which is propelled by a piston engine with two stages of turbocharger, achieves a mission reliability of 78% with a 24 hr. endurance, or 60% on a 48 hr. mission.

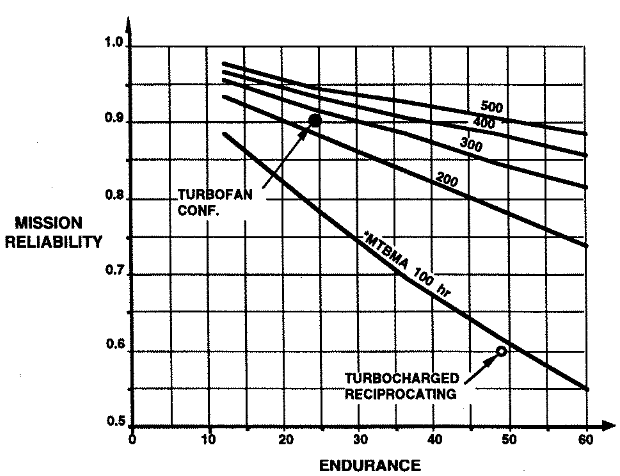


Figure 3.12: Typical UAV Mission Reliability

The HALE missions require autonomous flight control of the UAV. For this it is necessary to develop avionics systems having double or triple redundancy, with corresponding software. The software must have the capability of identifying with almost 100% certainty, the component or system which failed and provide backup, without any human intervention. It is desirable to have automatic control during the takeoff and landing stages, which are the critical phases of the flight. I.A.I. has developed two automatic landing systems based on laser and radar (CARLS), and is now developing an automatic landing system based on DGPS.

3.6 Integration with Air Traffic Control (ATC)

HALE UAVs for civilian and military missions are designed in certain missions for thousands of hours of operation and for performing hundreds of takeoffs and landings per year. In order to maintain air traffic safety regulations, i.e. the US flight regulations (FAR), or the European (JAR), it is necessary for the UAV to integrate into the air traffic as if it were a manned aircraft. For this purpose the UAV is equipped with a transmitter / receiver which permits speech between the ground station and the Air Traffic Control (ATC). In addition to this, it is equipped with a transponder which allows the ATC to identify it with secondary radar. In the ground station the operator is required to act as a pilot following the instructions of ATC, changing radio frequencies etc. (See fig. 3.13.)

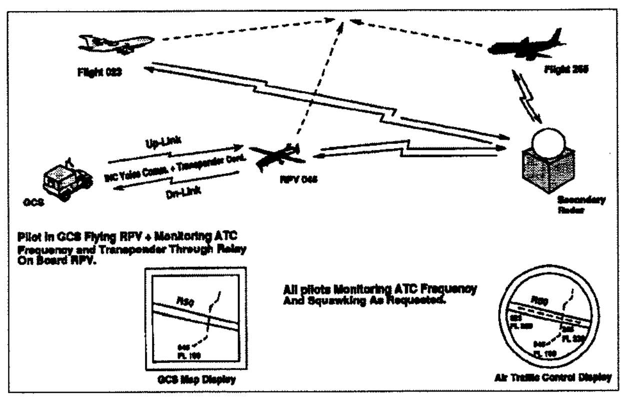


Figure 3.13: UAV Integration with Air Traffic Control

3.7 Survivability

HALE UAVs for military roles perform their missions above friendly territory or above enemy territory. When flying above hostile territory a situation can occur that the UAV flies within the envelope of enemy threats.

High altitude flight has an advantage from the point of view of survivability. Fig. 3.14. demonstrates this clearly. At this altitude the only threat is long range Surface to Air Missiles (SAM), and intercept aircraft.

At these altitudes the SAM envelope is considerably reduced. Prior intelligence on the location of SAM batteries makes them avoidable, by proper mission planning, so the UAV can remain outside their envelope. Use of ECM could allow the UAV to fly within the firing envelopes of the missiles.

Survival from interceptors is likely to be more difficult, since they could be anywhere. Modern intercept aircraft are able to fly at an altitude of 50,000 ft. However, at this altitude they are very limited in maneuverability and endurance. This imposes strict limitations on their ability to detect, lock, the missile, and launch it towards a UAV which flies several tens of thousands feet above them, at a much slower speed.
Reducing the radar signature and IR signature can further reduce the probability of engagement.

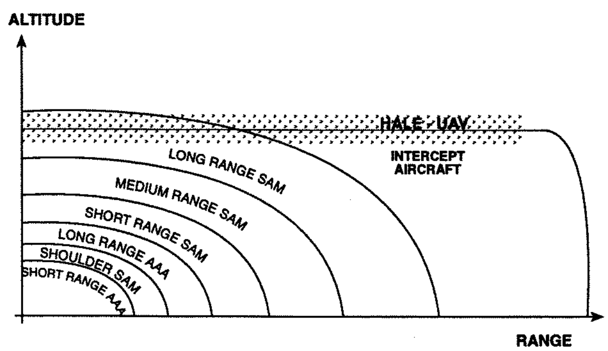


Figure 3.14: Threat Envelopes

4. Configurations for High Altitudes.

Two configurations for military intelligence missions have been examined at the stage of preliminary design. The UAVs have been designed to meet the following performance requirements:

65000 ft operational ceiling
24 hr endurance
600 lb payload
> 90% mission reliability

Comparison of configurations include aerodynamic performance, reliability, costs and development risk. The configurations examined are :-

- Configuration with two wing mounted piston engines.
- Configuration with two turbofan engines attached to the fuselage.

4.1 Description of Configurations.

4.1.1 Configuration with Piston Engines.

Fig 4.1. describes the configuration. The wing is trapezoidal with a span of 36.5 meters. The fuselage is 13 meters long. The UAV is equipped with two wing -mounted, twin-turbocharged, liquid-cooled, piston engines. Engine type is Teledyne Continental TSIOL-300. The engine power is 175 hp, and the turbocharging system critical altitude is 60,000 ft. The engines drive 3.5 m variable - pitch propellers, via a reduction gear. Takeoff weight is about 9,100 lb.

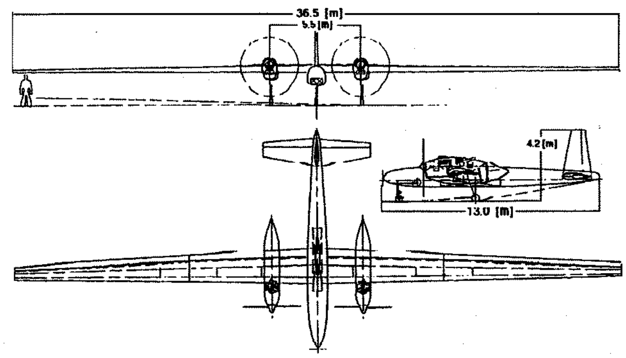


Figure 4.1: Trubocharged Piston Engine Configuration

4.1.2 Configuration with Turbofan Engines.

Fig 4.2. describes the configuration.
The central wing is trapezoidal with a span of 26.5 meters. The fuselage is 13 meters long. The UAV is equipped with two Williams FJ-44 engines, each having a static thrust of 1,900 lb, which are nacelle-mounted on the aft fuselage. The takeoff weight is approx. 10,900 lb.

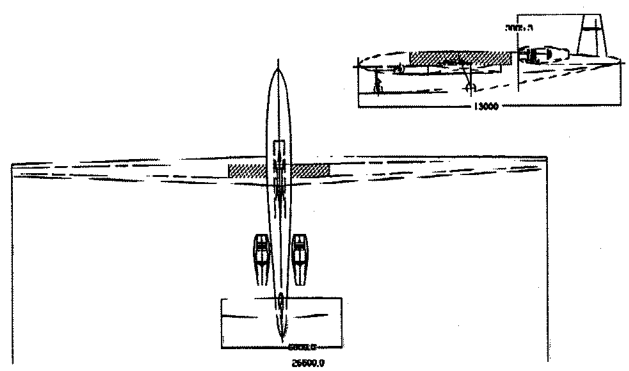


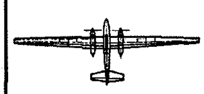
Figure 4.2: Turbofan Configuration

4.2 Effectiveness of Configurations.

The main parameters of the configurations are indicated in table 4.1.

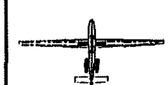
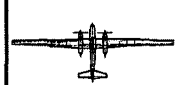
The piston configuration has the lowest wing loading since it is designed for low speeds.
A comparison of thrust / weight (T/W) as it appears in table 4.2, compares the thrust at sea level to the weight. At 55,000 - 65,000 ft. the thrust of turbofan engines is reduced by 80 - 90% compared to that at sea level. In contrast to this, a piston engine with two turbochargers is able to maintain a fixed power output from sea level to 60,000 ft.

Table 4.1: Key Specifications of the HALE Configurations

	CONVENTIONAL TURBOFAN 	CONVENTIONAL PISTON 
SPAN [ft]	87	120
Sref [ft ^{2}]	301	530
Swet [ft ^{2}]	1,300	1,800
Swet/Sref	4.32	3.39
$b/\sqrt{\text{Swet}}$	2.41	2.8
L/D	31	33
Wempty [lb]	5,460	5,540
Wfuel [lb]	4,830	3,000
Wpayload [lb]	600	600
TOW [lb]	10,890	9,140

A comparison of performance in table 4.2 shows an advantage for the piston configuration, mainly due to its superior fuel efficiency.

Table 4.2: Comparison of Performance, and Reliability

	CONVENTIONAL TURBOFAN 	CONVENTIONAL PISTON 
T/W OR P/W	0.35 [lbf/lb]	0.038 [hp/lb]
W/S [lb/ft ^{2}]	36.2	17.2
OPERATIONAL CEILING [kft]	60	~65
FLIGHT VELOCITY [M]	0.6	0.35
ENDURANCE [hr]	~21	~32
AERODYNAMIC DEVELOPMENT SCOPE & RISK	LOW	LOW
MISSION RELIABILITY @ 20 hr MISSION	0.93	0.82

The mission reliability of the jet configuration is about 93% for a 20 hr. mission, due to the reliability of the propulsion system. In comparison the piston configuration achieves a reliability of only 82% under the same conditions.

4.3 Costs.

A comparison of configurations must include cost in addition to effectiveness, in order to evaluate them on a common basis of cost effectiveness. The cost is comprised of the development and pre-production costs, the production Unit Fly away Cost (UFC), and also operation, maintenance & support, which add-up to the life cycle cost. .

The technology involved in the development and production process has considerable impact on the development cost and on the UFC.
Normally, there is a direct link between UFC and the empty weight of the UAV. Fig. 4.3. presents a typical example of Fly Away Cost versus weight. This is the cost of the aircraft only, without payloads, communication systems and avionics. The addition of these components could double the cost.

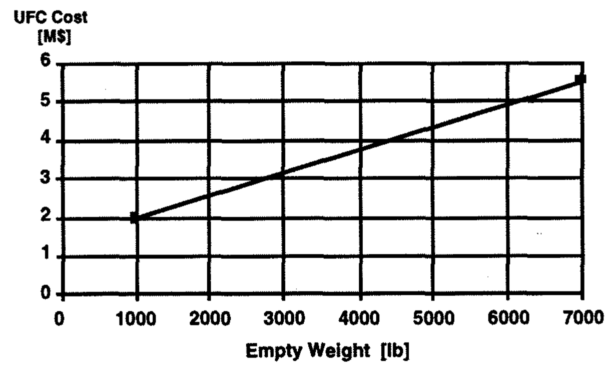


Figure 4.3: Typical Fly Away Cost of HALE UAV

In order to choose a configuration it is necessary to perform an analysis which includes mission, threats, number of UAVs required and the life cycle costs of the UAV system.

5 Conclusion.

I.A.I. involvement in UAV projects for High Altitude Long Endurance (HALE) has accumulated experience and knowledge in the field of technology and in the field of operations of these systems.

This paper reviews the typical missions of HALE UAVs in the civilian and military fields and describes the principal technologies required by these UAVs.

Two different configurations for High Altitude Long Endurance, were presented, The selection of a particular configuration is dependent on the requirements.

HALE UAVs are not yet in use but the number of programs existing indicate a growing interest. In the near future we will see a number of HALE UAVs in use for civilian and military missions.
IAI is involved in the development of different technologies for HALE UAVs. The greatest

challenge is the integration of these technologies into a single system. (See Fig. 5.1)

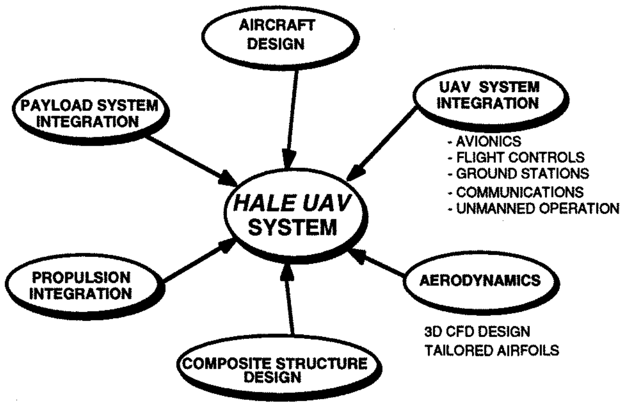


Figure 5.1: Technologies and infrastructures of HALE UAV

Acknowledgments

The authors would like to thank Ms. Eti Mizrachi for assistance with the graphics.

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