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Freewing Tilt-Body™ "Scorpion" Applicability to the 1997 U.S. Joint & Maritime Requirements

Introduction

For several decades the operational communities have recognized numerous requirements amenable to cost-effective solutions by Unmanned Aerial Vehicles (UAVs). Resolution of these varied requirements into a single vehicle, or even a small family of vehicles with a high level of commonality, has defied the efforts of every procurement agency. Probably the most significant challenge in the reconciliation of competing demands is that of platform (air vehicle) performance. While avionics and sensor architecture and interface requirements are relatively adaptable (if sometimes expensive), aerodynamic performances have remained a singularly intractable problem among the UAV communities. In simple terms, the selection of sensors and other avionics systems and/or their modular inclusion within a given vehicle have not sparked nearly the difficulties of the basic performance (including launch and recovery requirements) of the platform itself.

The intractability of the problem stems directly from the unavoidable inflexibility of both fixed wing and rotary wing design mandates (and from the cost/complexity issues of traditional hybrids). The Freewing Tilt-Body, beginning as it does from an entirely different paradigm, offers both the flexibility and modularity absent from conventional approaches and the "forced union" of the fixed and rotary wing. In this document, we plan to present a convincing case for this proposition.

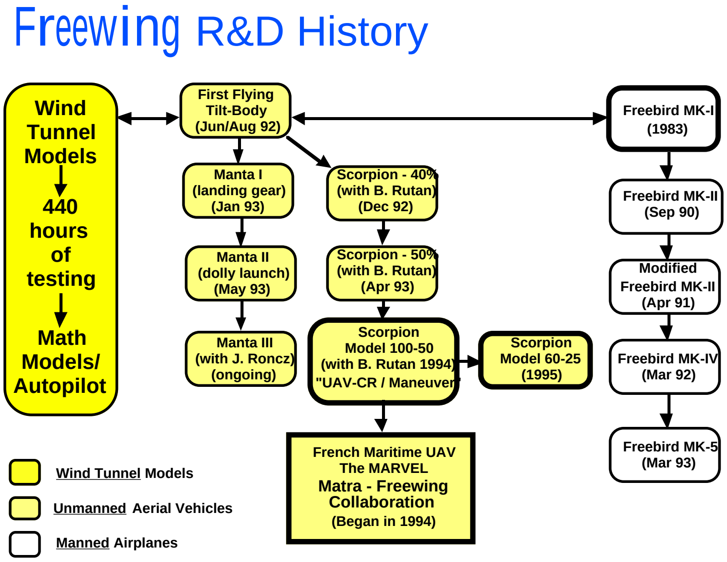

Figure 1

Freewing Tilt-Body Concept

The Freewing Tilt-Body™ Scorpion, with its current production airframe and carrying a 57 pound payload, meets all the aircraft performance requirements of the Joint mission (and therefore also of the 50 km Land mission) and has an endurance margin of 1 hour. Without changing the air vehicle this extra endurance margin may be traded for an increase in payload weight of 83 lb. for a total payload weight of 140 lbs.

Through the numerous Freewing air vehicles developed (see figure 1), and our own as well as independent studies (NASA and others) the following basic advantages have been demonstrated:

Summary of Advantages for the Freewing Tilt-Body Vehicle

- ESTOL (or near-VTOL) at a fraction of the cost and complexity of tilt-rotors;
- Inherently stable camera/sensor platform, better image resolution, laser accuracy, etc.;
- Center of gravity of fuselage very flexible, without affecting basic longitudinal stability, since torque cannot be passed through a hinge. Thus payload is more flexible (i) from mission to mission and (ii) over life of system to accommodate changing requirements;
- Reduced need for sensor stabilization = lower cost;
- Wing and fuselage intrinsically modular; can mix & match according to mission needs;
- Can pitch fuselage independently of flight path;
- Can launch, recover, do mission in gustier conditions than fixed wings or rotary wing vehicles;
- G-loading in turbulence reduced significantly;
- Extended sensor and avionics life due to reduced aerodynamic shocks to airframe;
- Reduced maintenance costs due to intrinsically simple structure; and
- Thrust-vectoring performance; in a simple (just a few moving parts associated with thrust-vectoring) and autostable system.

The Scorpion Model 100 is designed to be an inherently modular air vehicle. To meet the needs of any given mission (i.e. greater payload or range) the base vehicle can be easily modified to meet these needs. For example, to meet maritime needs, the only item that must change from the existing air vehicle is the engine.[1] To obtain more fuel for a higher fuel consumption engine or to increase range or endurance, one can add stub wing fuel tanks (a plug-in option). The increased weight due to more fuel or heavier payloads is handled by extending the wing span (higher aspect

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[1] Upgrading to a more powerful engine in a freewing is relatively trivial (compared to this process in a fixed wing) because the freewing is much less sensitive to CG location than fixed or rotary wings. By contrast, doing so in a fixed wing changes the CG in a way that can cascade iteratively through the airplane, causing a weight spiral and requiring fundamental changes to the vehicle’s design.

ratio wings are also a plug-in option). Furthermore, the air vehicle could be changed back to its original size with relatively little effort; this takes just a few minutes and can be done in the field. It is feasible to have a baseline Model 100 that can be changed to meet the needs of the user at any time throughout the life of the air vehicle.

1. System Development Status

1.1 Tactical Air Vehicle

The Scorpion Model 100 was developed according to the requirements of the Maneuver/Tactical UAV. The emphasis was put both on the mission capability and the take off and landing characteristics.

Parameter	Joint Mission	Joint Scorpion (Baseline)	Maritime Mission	Maritime Scorpion (see §8, below)
Range	200 km	200 km	200 km	200 km
Endurance @ Range	3 Hr. @ 200 km	4 Hr @ 200 km	3 Hr @ 200 km	3 Hr @ 200 km
Payload	EO/IR	EO/IR	EO/IR	EO/IR
TLE	< 100 m	< 100 m	< 100 m (<80 m)	< 100 m
Data Link	Analog (Digital)	Analog	Analog (Digital)	Analog
IFF Transponder		Mode IIIC	Mode IIIC (Mode IV)	Mode IIIC
Propulsion	As Provided (HFE*)	Gas	HFE	HFE
TCS Compatible	Yes	Yes	Yes	Yes
Launch & Recovery	Unprepared surface/ Large Amphib Ship	ESTOL Unprepared Surface/ Large Amphib Ship	Shipboard Helipad	Shipboard Helipad
Autonomous Landing	Yes - UCARS Option	Yes - UCARS Option	Yes - UCARS Option	Yes - UCARS Option
Deployability	1 C-130	1 C-130	All Air Capable Ships	All Air Capable Ships
Mobility / Footprint	2HMMWVs w/ 1 Trailer	2HMMWVs w/ 1 Trailer	Shipboard Compatible	Shipboard Compatible
Remote Video Terminal		200 km w/ metadata	200 km w/ metadata	200 km w/ metadata
Air Vehicle Cost	$350K/33rd Unit $300K/100th Unit	$380K/33rd Unit $300K/100th Unit		$344K/33rd Unit $243K/100th Unit (excluding payload)

A freewing vehicle takes advantage of the fact that its wings are not hard-jointed to the fuselage but freely hinged to it: a more stable and safer flight is then possible as air turbulence is not transmitted to the fuselage that carries the mission payload. In a Freewing Tilt-Body vehicle, the decoupling between fuselage and wing is used in a reverse way as well: fuselage trim surfaces (placed on the long moment arm created by the booms) serve to generate a fuselage pitching moment. In this way the thrust vector can be pointed away from the velocity vector. Thrust-vectoring with its many advantages (extremely short take off and landing, extended speed range, etc.) is thus achieved at a reduced cost and with only a few moving parts.

Although the Scorpion is a thrust-vectored capable machine, it is nonetheless autostable – even during transition into and out of thrust-vectored mode. Other thrust-vectored vehicles are unstable, especially during transition or in hover, and therefore require an aggressive autopilot for flight; a loss of the autopilot in these vehicles can mean the loss of the airplane. By contrast, the Scorpion's autostability greatly reduces the workload on both autopilots and human pilots, which can be expected to beneficially affect service life and attrition rates. The Scorpion can also survive the catastrophic loss of more of the air vehicle and still complete a mission, since stability and control are principally in the freewings, with the tail surfaces serving to maintain the chosen thrust vector.

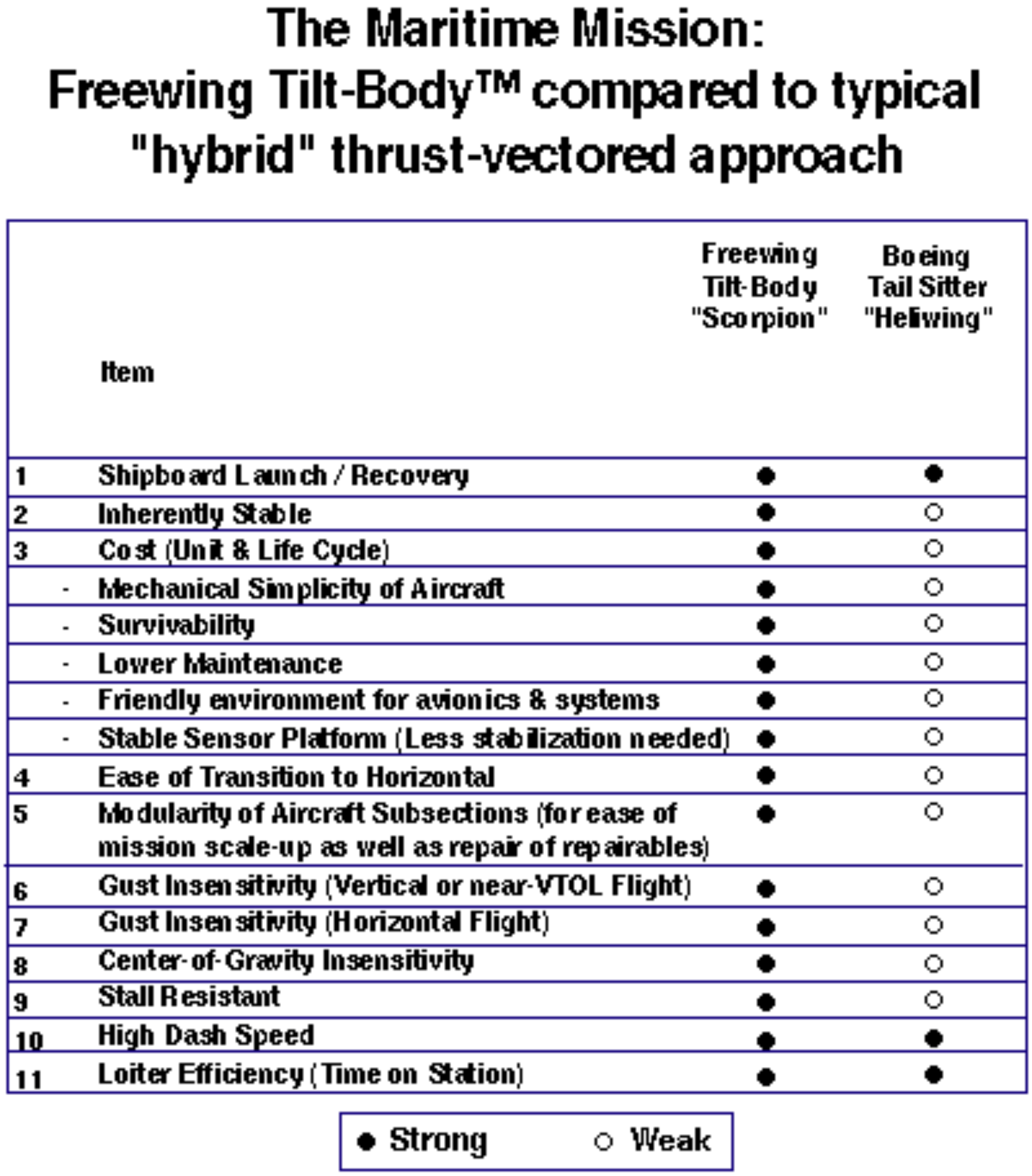
1.1.1 Air vehicle specification

1.1.1.1 Physical specification

Figure 2 shows the Scorpion Tilt-Body Model 100 in cruise configuration. Figure 3 shows the Scorpion Tilt-Body in take off/landing configuration (hereafter referred to as Tilt-Body mode). It is to be noted that only the wings carry actual control surfaces. As no coupling exists between the fuselage and the freewing, any control surface on the fuselage/tail will not permit control of the vehicle. The control surfaces on the freewing are used both as ailerons when deflected differentially and as elevator when deflected together, thus their application as elevons. The angle between the tail boom and the main fuselage can be adjusted in flight. It is not considered a control surface, but only as a way to change the air vehicle configuration. In both cruise mode and tilt-body mode, all flight controls are achieved by activating the elevons. The table below gives the main geometric characteristics.

1.1.1.2 Propulsion

Propulsion is achieved by means of a single engine, driving a single, adjustable-pitch propeller. The engine installed is a general aviation dual ignition 2 cylinder engine that has a TBO of 500 hours. (However, the heavy fuel Maritime requirements indicated in the RFI are leading us towards a turboprop for a heavy fuel growth path, as explained later.)



The Maritime Mission: Freewing Tilt-Body™ compared to typical "hybrid" thrust-vectored approach

	Item	Freewing Tilt-Body "Scorpion"	Boeing Tail Sitter "Heliwing"
1	Shipboard Launch / Recovery	●	●
2	Inherently Stable	●	○
3	Cost (Unit & Life Cycle)	●	○
-	Mechanical Simplicity of Aircraft	●	○
-	Survivability	●	○
-	Lower Maintenance	●	○
-	Friendly environment for avionics & systems	●	○
-	Stable Sensor Platform (Less stabilization needed)	●	○
4	Ease of Transition to Horizontal	●	○
5	Modularity of Aircraft Subsections (for ease of mission scale-up as well as repair of repairables)	●	○
6	Gust Insensitivity (Vertical or near-VTOL Flight)	●	○
7	Gust Insensitivity (Horizontal Flight)	●	○
8	Center-of-Gravity Insensitivity	●	○
9	Stall Resistant	●	○
10	High Dash Speed	●	●
11	Loiter Efficiency (Time on Station)	●	●

● Strong ○ Weak

As can be seen from §8 hereunder, the Scorpion is arguably a strong contender for maritime UAV missions, a notion obviously agreed to by Matra BAe Dynamics, since they have purchased the rights to use the Freewing-manufactured Scorpion airframe in their "Marvel" UAV program, which is focused on launch and recovery from the helipad of the Lafayette class frigate.

By contrast, the "traditional" hybrid air vehicles, which are essentially combinations of the fixed wing and the rotary wing vehicles, can be accurately viewed compared to the Freewing Tilt-Body™ approach as expensive, unreliable, complicated and heavier by a factor of 2 or more to carry the same payload as the Scorpion.

See APPENDIX 1 for a discussion of the comparison points of the above chart, with an expanded discussion of the Scorpion as a maritime UAV.

Air Vehicle Specifications

Total length	11.8 ft
Span	16.1 ft
Wing area (total) Freewing area Stub wing area	37.3 sq ft 61% sq ft 39% sq ft
Total height (cruise mode)	4.1 ft
Total height (tilt body mode)	6.75 ft
Maximum take-off weight	383 lbs (466 lbs., cf. top of pg. 2)
Empty weight	253 lbs
Nominal payload weight	57 lbs (140 lbs, cf. top of pg. 2)
Maximum fuel load	72 lbs
Power	52 hp
Max RPM	7000 (3000 output shaft)
SCF	.52 - .57 lbs/hp/hour
Propeller (diameter * pitch)	60" x variable pitch
Direction of rotation	CW (facing propeller)
Static thrust	270 lbs

1.1.1.3. Performance

The air vehicle as defined in paragraphs 1.1.1.1 and 1.1.1.2 has been tested since March 1994. The flight test results together with more than 450 hours of wind tunnel testing have resulted in the development of an accurate mathematical model of the vehicle aerodynamics. The development of the math model is at a point where it can be easily adapted to any size of Tilt-Body configuration. From the flight tests and the math model calculations, the performance stated in the following table has been demonstrated.

Joint (Baseline) Scorpion Performance

Max speed	150 kt
Loiter speed	55 kt
Take off speed	21 kt
Landing speed	29 kt
Take off roll	< 100 ft
Take off over a 50 ft obstacle	167 ft (calculated)
Landing over a 50 ft obstacle	195 ft
Best range speed	65 kt
Rate of climb	2400 fpm
Ceiling	15,000 ft

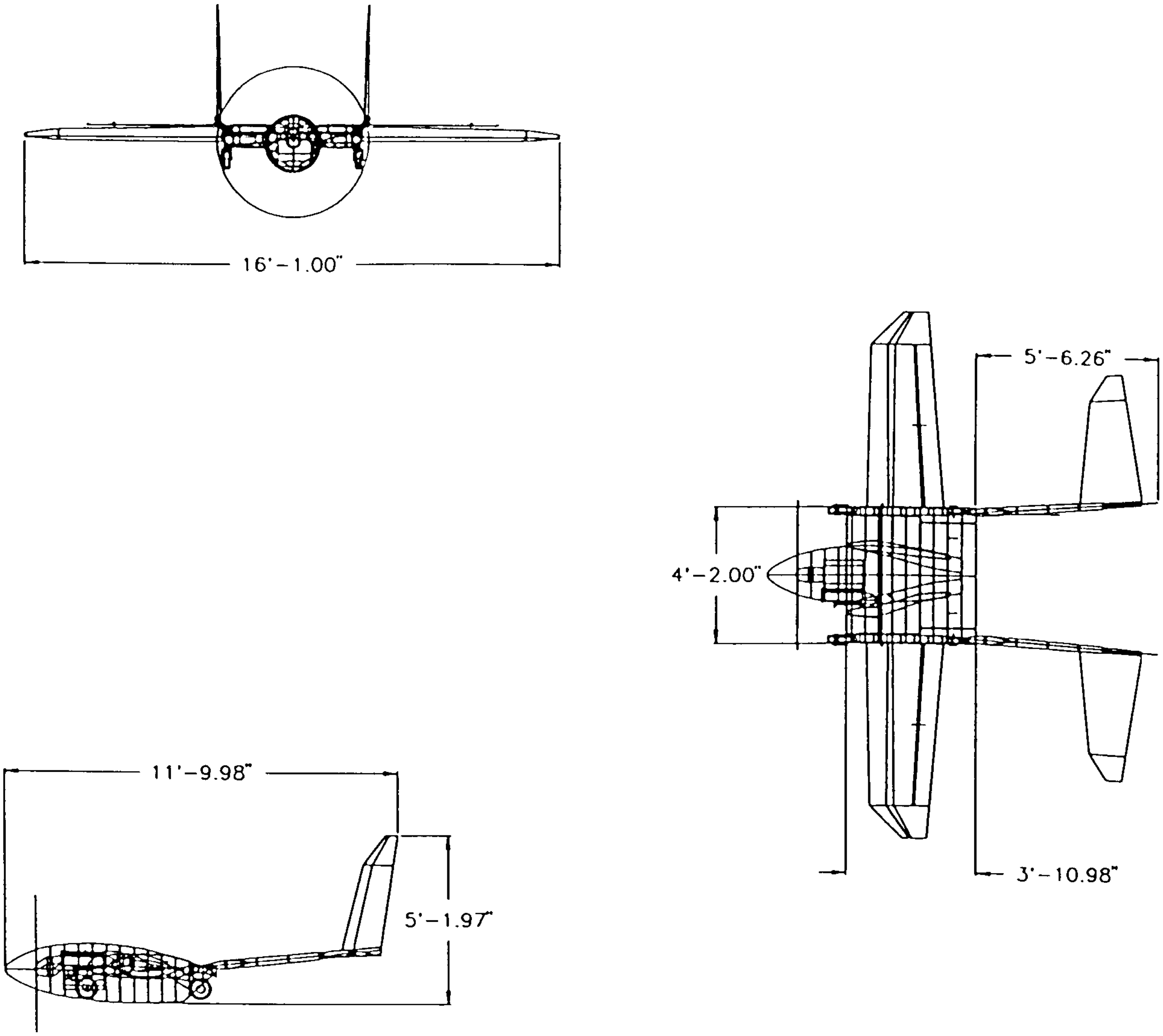


Figure 2: Scorpion Model 100, Cruise Mode

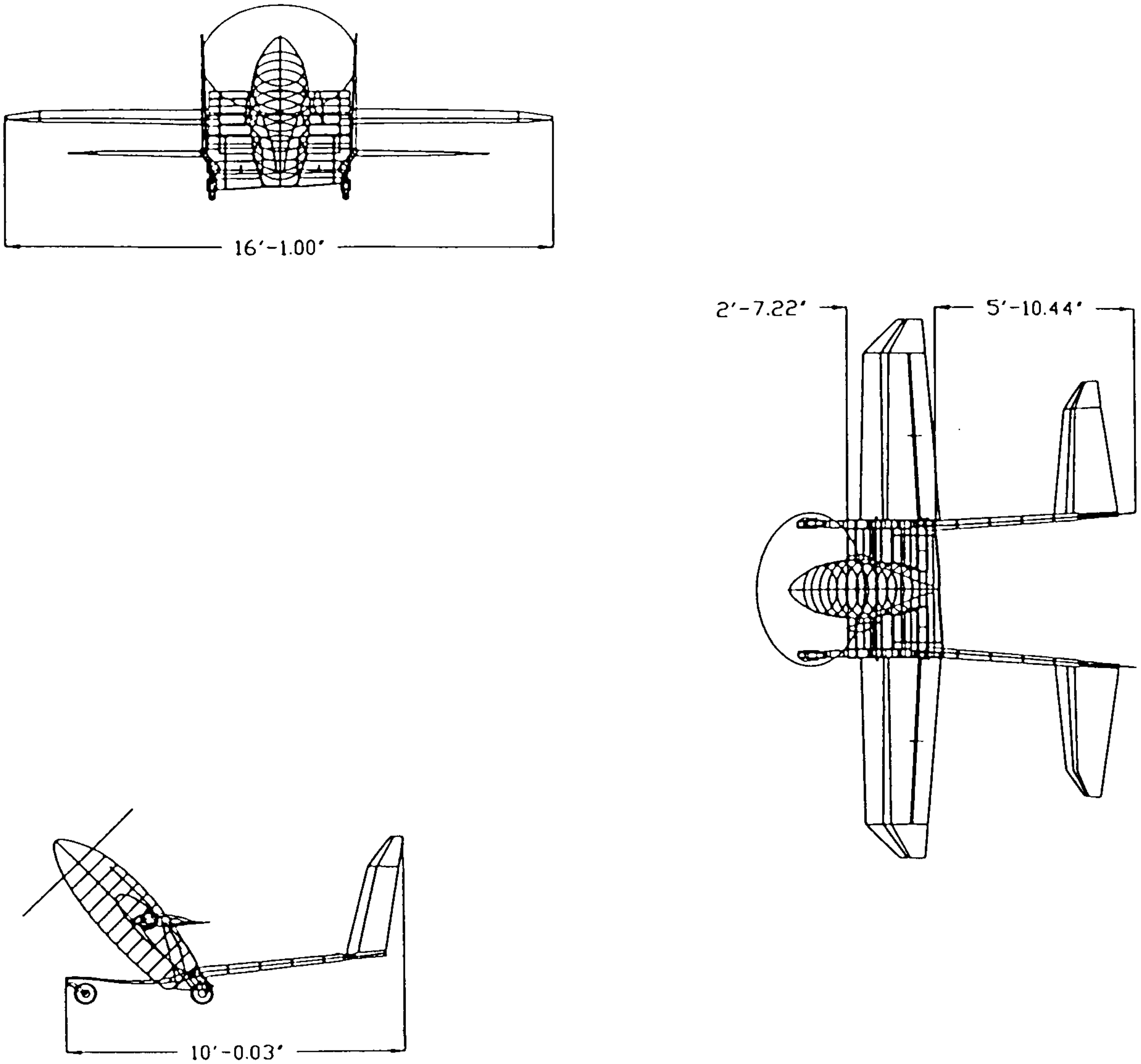


Figure 2: Scorpion Model 100, Tilt-Body (Near-Hover) Mode

1.2 System definition

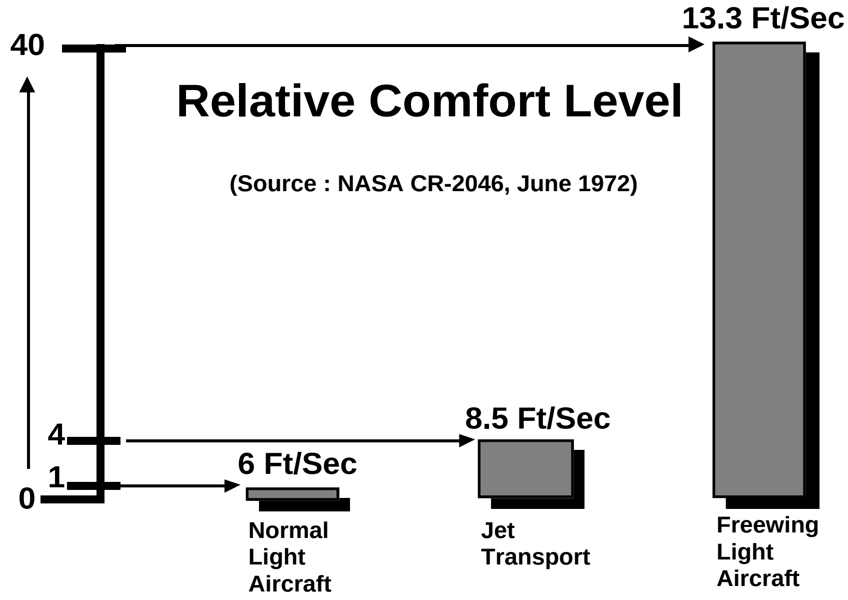
The system architecture contains two main components: the ground segment and the airborne segment. Both subsystems can be integrated into various systems according to the mission requirements. As the system components are defined, 4 vehicles, 2 Ground Control Stations, 2 Remote Data Terminals and 1 Remote Video Terminal could be packed in a basic mobile unit constituted by 2 HMMWV and 1 trailer.

1.2.1. Airborne segment.

Due to the modularity of the Scorpion 100 airframe, only minor changes are needed to meet both the Joint and Maritime requirements. Freewing is utilizing all commercial off-the-shelf (COTS) items for its proposed system. The natural stability of the Scorpion will increase the life of onboard systems because of the ability to dampen gusts and turbulence (cf. figure 4). Also, this stability will reduce the cost and complexity of the gimbal stabilization system for payloads.

2. Production Status

The Freewing Tilt-Body Scorpion Model 100 is in limited production at this time with four airframes delivered, including to Matra BAe Dynamics for development of a French Navy shipboard version. Production tooling is nearing completion with formal opening of the production line scheduled for the second half of 1997. The Freewing air vehicle family has completed over 200 hours of flight testing in approximately 400 flights. A total of 8 air vehicles have been produced and tested in the Freewing Tilt-Body family with a total test time of 80+ hours.


Relative Comfort Level

(Source : NASA CR-2046, June 1972)

Figure 4

3. Design & Support Documentation

The first three Freewing Scorpions were built at Burt Rutan’s facility in Mojave, California. AutoCad drawings are available of the Scorpion airframe as currently produced. Blueprints are available of air vehicle systems including: electrical, engine installation, fuel system and actuator installation. Technical manuals including airframe maintenance and Pilots Operating manuals are in work.

4. Datalink

Freewing has used a variety of datalinks from Futaba and BTA. Freewing and Tadiran have an agreement by which Tadiran datalinks are planned to be integrated with the Scorpion vehicle during the summer of 1997. Matra BAe Dynamics is providing the datalinks for the Marvel system in France. NASA is supplying its own (based on digital cellular telephone technology) for the Scorpion in the Mission to Planet Earth UAV project. For DOD contracts Freewing plans to defer to whoever the prime contractor happens to be for any given program. Freewing does not plan to offer to serve as prime contractor for DOD UAV programs at this time, electing to serve as vehicle subcontractor to an integrator. Freewing has arrangements with aerospace firms such as Boeing, Battelle that could have them serve as prime contractor / systems integrator.

For commercial UAV applications, Freewing will of course provide to the customer its own datalink (probably Tadiran) and GCS (probably the VCS from CDL Systems).

5. Payloads

Since the freewing neutralizes most turbulence (cf. figure 4), the platform stabilization needs are reduced for any given sensor for any specific image resolution, allowing a reduced cost/complexity stabilization unit; conversely, for any given commercial stabilized imaging system, a greater resolution will result when used on the Freewing Tilt-Body as compared to any similar fixed-wing UAV. With the Scorpion vehicle in the cruise configuration, the landing gear is in a retracted position, allowing a full 360 degree field of view unobstructed by landing gear or other airframe components.

Freewing Aerial Robotics Corporation has been in contact with various FLIR manufacturers over the past year. As a system design requirement, we can accommodate any payload (contracted or GFE) up to 57 pounds that can be interfaced through an RS-422 interface for the command and control part and through an RS-170 interface if a video signal is outputed. An estimate for the cost of an EO/IR payload is included in 6.1.1.

6. Production Costs

6.1 Cost proposal

6.1.1 ROM for Joint Scorpion and for Maritime Scorpion

Joint Scorpion	Air Vehicle	EO/IR Payload	Total
33rd Production	$247K	$133K	$380K
100th Production	$174K	$126K	$300K

Maritime Scorpion	Air Vehicle
33rd Production	$344K
100th Production	$243K

6.1.2 Influence of vehicle growth on the cost

The two air vehicles described in this paper share a common core vehicle. The principal changes to take the baseline Scorpion to the maritime version are (i) the plug-in stub wing fuel tank extensions, (ii) plug-in higher-aspect-ratio freewings and (iii) turboprop engine. *Only the change to turboprop affects the baseline vehicle.* Due to the relative insensitivity of the Freewing Tilt-Body to CG changes, this change would not require mass redistribution within the vehicle and other such major design issues. Not only can one argue that the re-engining process itself is comparatively inexpensive, but the result is a very high degree of commonality among the various Scorpions, no matter which Service is using it.

6.2 Life cycle cost

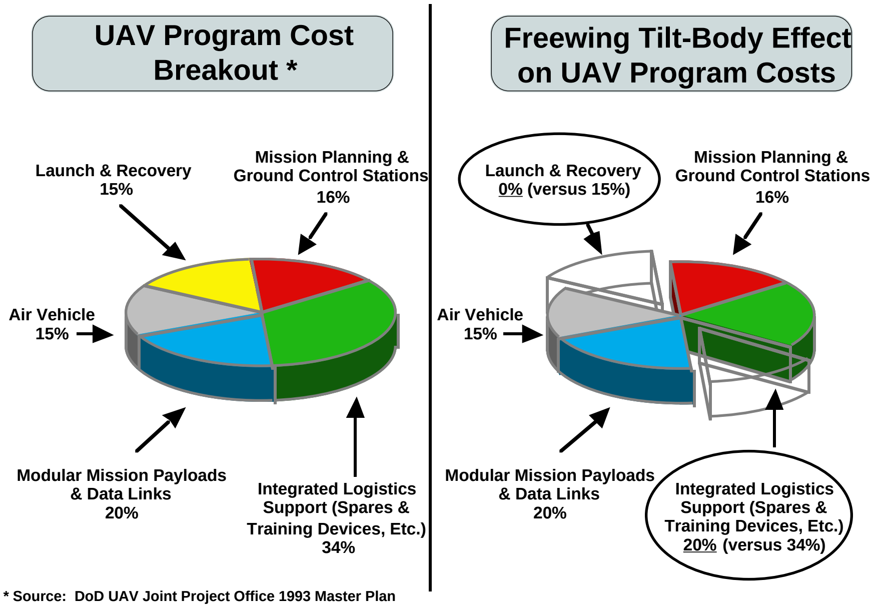
As the actual mission is not defined at this time, a detailed life cycle cost cannot be done accurately. A qualitative comparison between the life cycle cost of a fixed wing UAV and the life cycle cost of the Freewing Tilt-Body Scorpion is provided.

Figure 5 shows a typical life cycle cost for a fixed wing UAV (source: DoD UAV Joint Project Office 1993 Master Plan). For the comparison, we consider:

- The price of a freewing tilt-body vehicle is similar to a fixed wing vehicle.
- No launch and recovery devices are required for the Joint Scorpion, and no ship alts are needed for the Maritime Scorpion (cf. §8.1.3). As the Scorpion is near-vertical takeoff and landing capable, provision for such devices are not necessary. Only the cost advantage is presented here, but in terms of mission capabilities, the device-free launch and recovery has a big impact on the turnaround time, as no reconditioning is required between missions.

- As an estimate, Integrated Logistics Support is reduced to half the cost of a comparable fixed wing vehicle. As the takeoff and landing are done in a non-assisted mode, the airframe is less subject to high stress (on assisted take off) or potential damage in the case of a parachute assisted landing. Moreover, due to the turbulence mitigation characteristics of the freewing, the airframe, avionics and payload are not subjected to the same stress during normal flight, thus increasing their life span.

With these considerations in mind, the chart here presents the life cycle cost chart for a freewing tilt-body UAV. A rapid comparison between both charts shows a 30% cost reduction in favor of the freewing technology, compared to a similar size fixed wing. A similar comparison between Freewing and another thrust-vectored vehicle can be expected to be even more dramatic.



* Source: DoD UAV Joint Project Office 1993 Master Plan

Figure 5

7. System Reliability & Maintainability

Through the selection of high reliability components and utilizing a design approach that emphasizes simplicity, the Freewing Scorpion provides a highly reliable system with excellent maintainability. The table below shows the predictions for reliability and maintainability performance in terms of Mean Flight Hours Between Unscheduled Maintenance (MFHBUM), Mean Time To Repair (MTTR), and Maintenance Manhours per Flight Hour (MMH/FH). For a thrust-vectored aircraft system, the following figures may seem counterintuitive; it is important to remember that the Scorpion has only three moving parts associated with thrust-vectoring, and that it is autostable in all flight modes.

MFHBUM	MTTR	MMH/FH
7.65	0.21	1.06

8. Growth Plans

8.1 200 km Maritime Vehicle

The current Freewing Scorpion vehicle meets the 200 km Maritime requirements with the exception of a heavy fuel engine and the ability to operate from a helipad, the growth paths to which are discussed below.

8.1.1 Heavy fuel engine

As no rotary or other internal combustion heavy fuel engines are available today, a turboprop powerplant is the only viable option for meeting the heavy fuel requirement of the maritime vehicle with any certainty. An engine change such as this is not a problem for the Scorpion Model 100 because of the inherent CG insensitivity. The main drawback of the turbine is lower fuel efficiency. Freewing has received proposals from two developers for a turboprop powerplant of 90-100 hp for the Scorpion UAV. Both systems are flying successfully on civilian experimental aircraft.

8.1.2 Increased Fuel Load

The turbine engine's increased fuel consumption necessitates an increased fuel load to meet the requirement for a 3 hr time on station at a range of 200 km. The modularity of the Freewing Tilt-Body provides a simple solution to this requirement. Figure 6 shows various components that can be used to increase fuel load and to increase available lift. Specifically, stub wing fuel tanks, rigidly attached to the Scorpion main fuselage, carry the additional fuel needed for the turbine engine. To maintain takeoff and landing performance, the Maritime version of the Scorpion uses higher aspect ratio freewings, providing wing loading similar to the current vehicle.

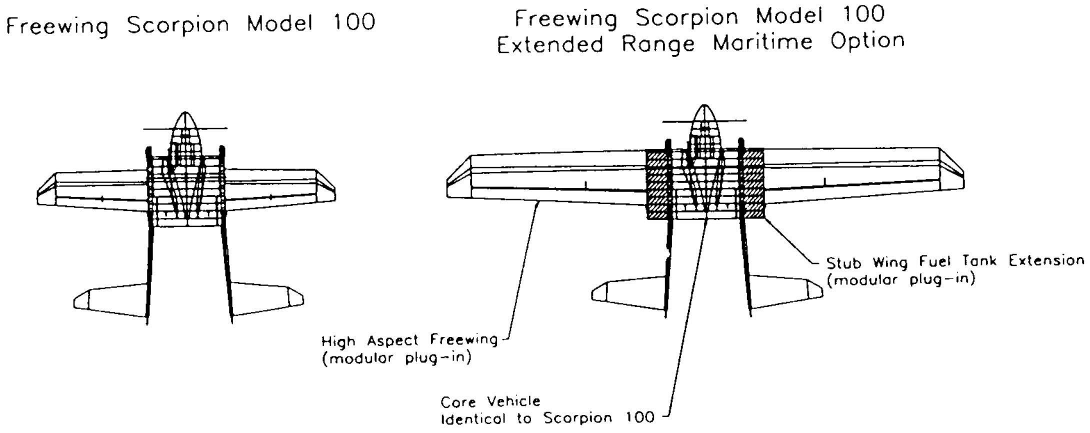


Figure 6: Freewing Scorpion Model 100 Modular Growth

Parameter	**200 km Maritime Scorpion**	**Joint Scorpion (Baseline)**
Total length	11.8 ft	11.8 ft
Span	28 ft	16.1 ft
Wing area (total) Freewing area Stub wing area	78.95 sq ft 70% 30%	37.3 sq ft 61% 39%
Total height (cruise mode)	4.1 ft	4.1 ft
Total height (tilt body mode)	6.75 ft	6.75 ft
Maximum take-off weight	573 lbs	383 lbs
Empty weight	343 lbs	253 lbs
Maximum payload weight	100 lbs	57 lbs
Maximum fuel load	130 lbs	72 lbs
Power	95 hp	52 hp
Max RPM	2600 output shaft	7000 (3000 output shaft)
SCF	.7 lbs/hp/hour	.52 - .57 lbs/hp/hour
Propeller	60" variable pitch	60" variable pitch
Direction of rotation	CW (facing propeller)	CW (facing propeller)
Static Thrust	493 lbs	270 lbs
Thrust to Weight (static/max TO)	.86	.70

8.1.3 Landing and take off

Landing and take-off distances for the Maritime Scorpion are below the size of a helipad (40 by 40 feet), assuming a 20 kt wind over deck. Resizing the modular, plug-in freewing for the Maritime Scorpion was done to maintain the same landing and take off performance. To maintain the same performance, use of a more powerful engine is planned (95 HP rather than the 52 HP already in use).

It is to be noted that maneuvering around a ship introduces problems not only due to the confined space (landing and take off distances) but also due to the turbulent air induced by the superstructure of the ship. As the Scorpion vehicle benefits from the turbulence mitigation characteristics of the freewing concept, the vehicle is more stable than any comparable fixed wing or rotary wing air vehicle. Figure 4 shows the results of a NASA study on freewing turbulence mitigation. As made clear in this graph, freewings can be so efficient at neutralizing turbulence that passenger versions using this technology would have to fly through the middle of thunderstorms in order to even experience discomfort, let alone danger. The implications for UAVs are clear: platform stability, and therefore stability and accuracy of the sensor data, can be of unprecedented quality.

Both these characteristics of the Scorpion Tilt-Body (turbulence mitigation and ESTOL take off/landing distance) have resulted in the selection of the Scorpion Tilt-Body by Matra BAe Dynamics to propose to the French Navy as their future ship-based UAV vehicle. Annex I shows a commercial brochure of the Marvel system jointly proposed by Matra BAe and Freewing Aerial Robotics Corporation to the French Navy.

8.1.3.1 Shipboard landing specifics

Landing any airplane requires a controlled dispersing of the residual kinetic energy in the vehicle. Since the remaining stored energy is reduced as the square of the velocity, if an airplane can be slowed to 1/4th of its normal approach speed, then one is faced with dispersing only 1/16th of the normal kinetic energy value. This is the case with the Scorpion, so therefore many specific landing and capture methods become available to the Scorpion that are not available to fixed wing vehicles. Three of these have been considered by Freewing and its partners.

8.1.3.1.1 Matra BAe Dynamics and the Marvel system

Matra BAe plans to modify the landing gear of the Scorpion (or Marvel, as they call it) such that for landing it can present spring-loaded clamps to the ship’s deck at impact. The deck would have a metal grid, and upon penetrating the grid the clamps would open and lock themselves. This is similar to a system employed at one time by the CL-227.

8.1.3.1.2 Hook & loop airbag landing system

Freewing has been granted a U.S. patent on a system that uses an airbag (carried on the airplane). The airbag would be covered with female Velcro™, and before landing aboard ship a male Velcro™ mat would be unrolled and secured on deck. (Chemical adhesive coatings could be used in lieu of hook & loop.) This method has the advantage of making heavier sea-state landings easier, since the UAV could maintain a higher closing velocity than in other methods, with the airbag finishing the job. The Velcro or other adhesive coating on the airbag is to hold the vehicle in place until sailors can properly secure the vehicle.

8.1.3.1.3 "Conventional" landing and roll out

Equipped with a propeller capable of full reverse and, as said before, assuming a 20 kt wind over deck, a landing with extremely short roll out is another method that becomes available, given the very slow closing velocity made possible by the Scorpion's thrust-vectoring.

8.1.4 EMI

The shipboard electromagnetic environment will be challenging. In anticipation of this, the Scorpion vehicle uses extensive shielding for all of the internal electronics and avionics. Servos and servo control signals lines are individually shielded, as are electrical power lines. Receivers and power supplies are housed in grounded metal boxes. RFI filters are employed on all power buses.

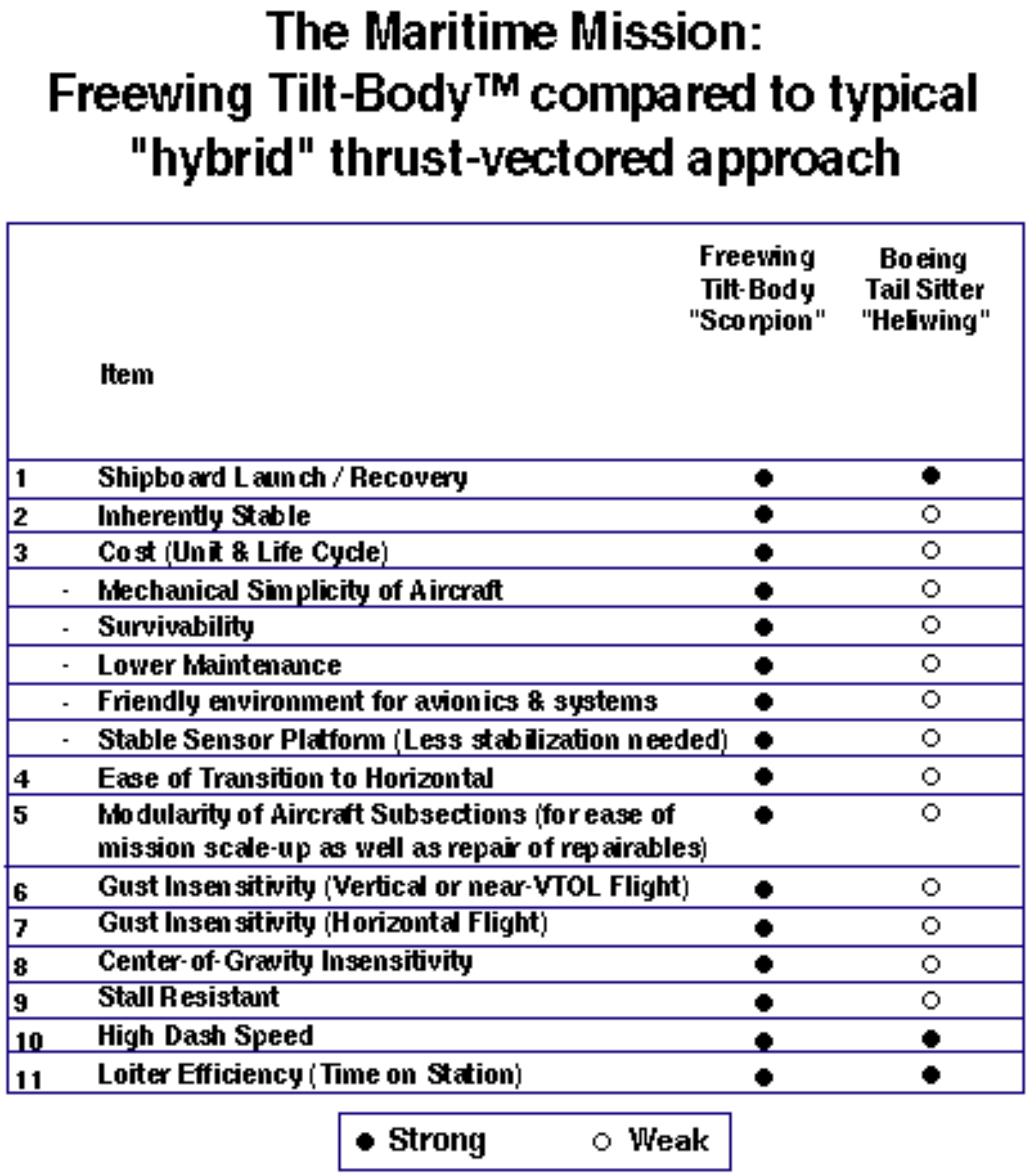
9.0 Existing Customers

The production tooling for the Scorpion has been built, and the first four preproduction vehicles have been pulled from the molds. Freewing Tilt-Body vehicles will be in use for scientific research and military UAV research this summer. The current customers for the Freewing Scorpion series include:

- Matra BAe Dynamics
  37 Ave Louis Breguet, 78140 Velizy-Villacoublay-France
- NASA
  Dr. Pat Coronado, Goddard Space Flight Center, Greenbelt, MD

Please see Freewing's Web site for additional information, including a hyperlink to the site that NASA Goddard maintains about the Scorpion project.

APPENDIX 1



The Maritime Mission: Freewing Tilt-Body™ compared to typical "hybrid" thrust-vectored approach

	Item	Freewing Tilt-Body "Scorpion"	Boeing Tail Sitter "Heliwing"
1	Shipboard Launch / Recovery	●	●
2	Inherently Stable	●	○
3	Cost (Unit & Life Cycle)	●	○
-	Mechanical Simplicity of Aircraft	●	○
-	Survivability	●	○
-	Lower Maintenance	●	○
-	Friendly environment for avionics & systems	●	○
-	Stable Sensor Platform (Less stabilization needed)	●	○
4	Ease of Transition to Horizontal	●	○
5	Modularity of Aircraft Subsections (for ease of mission scale-up as well as repair of repairables)	●	○
6	Gust Insensitivity (Vertical or near-VTOL Flight)	●	○
7	Gust Insensitivity (Horizontal Flight)	●	○
8	Center-of-Gravity Insensitivity	●	○
9	Stall Resistant	●	○
10	High Dash Speed	●	●
11	Loiter Efficiency (Time on Station)	●	●

● Strong ○ Weak

The Freewing Tilt-Body is a novel approach to thrust-vectoring. There have been numerous attempts over the years to combine the benefits of helicopter-like flight with the high-speed efficiencies of fixed wings in a hybrid fixed-wing/rotary-wing. These approaches generally try to literally combine the two types of vehicle, so that it can function as a rotorcraft and then change into a fixed-wing vehicle by moving the thrust line through a transition to the horizontal.

Examples of this hybrid approach are the tilt-rotor, tilt-wing, tilt-ducted-fan and the tail-sitter. Some 45 of these attempts over the last 50 years are identified in a chart by ANSER[2], yet only three of these were developed for operational use. And only one, the Harrier jet, is in service today.

The Freewing Tilt-Body is a fundamental departure from this "hybrid" paradigm. It is neither fixed wing nor rotary wing, and numerous (often profound) advantages accrue as a result. For comparison purposes, the Boeing Heliwing can be used as a representative of the tail-sitter class of "hybrid" vehicles. The tail-sitter type of vehicle shares virtually all of the deficiencies of the other "hybrid" types. Additionally, the tail-sitter is a flying wing while in horizontal flight mode. The comparison chart, above, is self-explanatory; however, some less obvious comparison points are enumerated below.

Stability & Control. The Heliwing is inherently unstable in thrust-vectored flight mode as well as in transition. In fact during transition the hybrid machines are particularly vulnerable, since the vehicle is acting precisely as neither fixed wing nor rotary wing. During transition and hover, the hybrids' aerodynamics are characterised by dramatic changes in the parameters most crucial to stable flight and control. First order aerodynamic coefficients become less and less important and second and third order ones predominate. Ultimately, certain parameters, e.g.α (angle of attack), ß (yaw angle), and $Ø_j$ (thrust angle), become paramount. The operational flight envelope in these regions is narrowly constrained by the magnitudes of these parameters and combinations thereof, and the flight envelope is mathematically difficult to define and predict. Traditional flight difficulties such as stall and spin are always present, while others such as yaw-roll coupling may also suddenly be threatening in an overwhelming manner. By contrast, the Scorpion is inherently stable throughout its design envelope — even during transition. This is precisely what permits the Freewing Tilt-Body to linger in near-hover flight without risk of stalling and falling.

CG Sensitivity. The Scorpion is up to an order of magnitude less sensitive to CG shifts than a normal fixed-wing vehicle. But the Scorpion's advantage here is even more striking compared to the Heliwing. Hybrid thrust-vectored aircraft generally are more sensitive to CG than fixed-wing vehicles, but since the Heliwing is a flying wing while in horizontal flight, its allowable CG range is even more restrictive than a conventional fixed wing's. Thus when compared to the Heliwing, the Scorpion advantage is even more pronounced. Payloads with, say, an aft-biased center of mass that the Scorpion could take in its stride might have to be redesigned for the Heliwing.

Modularity of Aircraft Subsections. The Scorpion is intrinsically modular, which gives a four-fold advantage against the Heliwing: (i) transport, (ii) stowage or deck spotting, (iii) repair of the vehicle and (iv) mission growth potential of the vehicle. Obviously, since the Scorpion has quick-disconnect freewings and booms, its transportation parameters are more flexible, as is its impact on stowage. Deck spotting — always a premium concern in maritime operations — is very favorably affected, since Scorpion vehicle center bodies can be readied for flight (including engine

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[2] ANSER (Analytic Services, Inc.) is a not-for-profit, public service research institute founded in 1958 to serve the national interest. Their "V/STOL Aircraft and Propulsion Concepts" chart was developed for the JAST program, and can be found on the ANSER Web site, http://www.anser.org.

warm up and system initialization) without wings or booms, which can be attached just before launch. By contrast, the Heliwing must remain fully assembled.

If the wing of a Heliwing sustains significant damage during handling or operations, there is a clear impact on the system as a whole, since the Heliwing’s wing is pregnant with mechanical and electronic devices necessary for flight. Moreover, repair of such wing damage is not trivial, and would typically require depot-level action. By contrast, the Scorpion’s wings and booms are quick-release and modular by design, so a damaged wing or boom can be replaced in a few minutes in the field.

Regarding growth potential the Heliwing, being a flying wing, is not easily amenable to misson growth. Adding fuel tanks to it is not a simple action. Upgrading the engine or increasing the aspect ratio of the wing is a major design initiative, and extremely costly. So once designed for a given mission, a flying wing is by its nature resistant to growth paths. The Freewing Tilt-Body, by contrast and by deliberate design, is quite the opposite. Wings, booms and vertical and horizontal stabilizers are all modular, each attached by a quick release system. The Scorpion can accept high-aspect ratio wings in a matter of minutes. Stub wing fuel tank extensions (cf. §8.1.2) can be easily added or removed, depending on mission needs. And re-engining the Scorpion is a much less daunting task than with fixed wings (let alone a flying wing) because of the CG insensitivity of the vehicle. **The importance of the following phenomenon cannot be overemphasized: the stability and control of the freewings are largely independent of the Scorpion’s fuselage.** Most of the advantages of the Scorpion, including its unique method of thrust-vectoring, follow from this.

Shipboard Launch / Recovery. This is absolutely central to the maritime mission., and recovery is by far its most difficult aspect, for any vehicle. In §8.1.3, above, there is a short discussion of the frigate-helipad recovery method designed by Matra BAe Dynamics, as well as two alternate methods investigated by Freewing. Actual demonstration of these and other methods is planned by Freewing, and this is *not* seen as a trivial task for any vehicle. However, even here there is reason to believe that a freewing-equipped air vehicle may have some advantage over the Heliwing. In addition to the basic problem of landing any vehicle on a square that moves in three dimensions, there is the problem of turbulence. The air environment during the final approach to a helipad at sea is a kind of boiling cauldren of gusts and intermixed hot gasses. One of the freewing’s hallmarks is its ability to automatically dampen gusts. The Heliwing on final is by contrast a flying billboard, very sensitive to horizontal gusts during the most critical phase of flight. In closing, this is not to imply that the Scorpion will necessary have an easy time in the maritime environment, but rather that each vehicle will have its own special problems to be worked out.

Cost. Whether in terms of developmental costs, unit flyaway costs, operations & maintenance, or life-cycle costs, there is simply no fair comparison between the Scorpion and the Heliwing (or other hybrid thrust-vectored vehicles). With only three moving parts associated with its autostable thrust-vectoring, the Scorpion’s simplicity and modularity cascades through all aspects of cost.