Market Overview of the Vertical Take-Off and Landing Vehicles

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***Abstract*— Vertical Take-Off and Landing (VTOL) vehicles is a special class of Unmanned Aerial Vehicles (UAVs). This paper summarizes the current stage of VTOL design and market, and discusses VTOL growth and technical performance comparison. A database is presented to provide information concerning VTOL technical characteristics (maximum speed, payload, range, endurance, propulsion configurations), and VTOL market characteristics (major manufacturing countries, real and potential applications, developing stages and current status). Conclusions may be drawn regarding VTOL usefulness in diverse application domains.**

***Index Terms*—UAV, VTOL, market analysis, performance characteristics.**

I. Introduction

An Unmanned or Uninhabited Aerial Vehicle (UAV) is a flying vehicle without a pilot, its flight being controlled remotely from a ground control station (GCS), having also the ability to operate semi-autonomously or autonomously or in any combination of the above modes. The vehicle is equipped with diverse sets of sensors and other electronics necessary to complete desired and specialized goals, whose plan and duration are specified according to the requested mission [1].

Vertical Take-Off and Landing (VTOL) unmanned aerial vehicles are a special class of UAVs, designed and utilized for highly specialized missions because of their advantages comparing to traditional UAVs: VTOLs *can take off and land vertically*, having the ability to land in difficult and restricted-size areas (ship deck); VTOLs can *hover* over specific areas of interest, serving as ideal platforms for target inspection and identification.

The central objective of this paper is to survey the current status of the VTOL market and technology, leading to the creation of a valuable database, useful for future VTOL design specifications justification and choice. As such, two aspects of the VTOL market have been studied and reviewed, *VTOL market characteristics* and *VTOL technical characteristics*.

This work was partially supported by a research grant from the Greek General Secretariat of Research and Technology (G.S.R.T.) and the EADS-3 SIGMA S.A.

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VTOL market characteristics present dominant geographic regions for VTOL production identifying type and range of missions. Since the VTOL market has yet to mature from the design specifications and technical characteristics point of view, a large percentage of existing VTOL vehicles is still in the first phases in terms of development; this is identified in the presented market analysis.

VTOL technical characteristics evaluation includes specific technologies used to design VTOL propulsion, engines, performance capabilities such as payload, maximum speed, ceiling, endurance and range of flight. Technologies used identify flying performance limitations too, providing helpful insight for future developments.

The data used have been collected from special catalogs [2], journals and the internet. Seventy-four VTOL vehicles have been identified worldwide and have been reviewed. The list of the reviewed VTOL UAVs is presented in the Appendix. However, it is essential to understand that since the primary use of such vehicles is in military applications, there may be designs not openly available for evaluation due to proprietary information and confidentiality agreements between the involved parties. This issue is extended even to partial data availability concerning technical and performance characteristics such as maximum speed. In every case, the unavailable amount of data is indicated as "unknown". Nevertheless, in most cases more than enough amount of information has been acquired, sufficient to draw required conclusions.

II. Market Characteristics

Market characteristics are summarized in terms of manufacturing countries, VTOL application domains and VTOL development status.

A. Manufacturing Countries

As shown in Fig. 1, America accounts for 68.5% of the vehicles developed worldwide, while Europe and Asia contribute 21.9% and 9.6%, respectively.

The vast majority of VTOLs manufactured in the American continent is contributed by the United States. US alone manufacture 64.4% of the total number of VTOLs worldwide as shown in Fig. 2; Fig. 3 illustrates the amount of money invested by the US Department of Defense (DOD) in 2000 in programs involving research and development of UAVs and VTOLs [3], mostly for military applications.

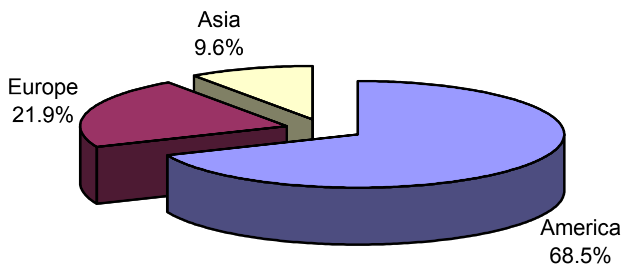

Fig. 1. Percentages of the number of VTOL UAVs produced over the world by region.

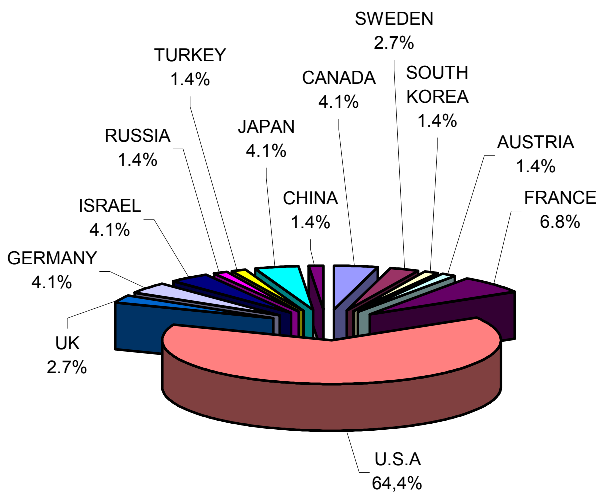

Fig. 2. Percentages of the number of VTOLs produced over the world.

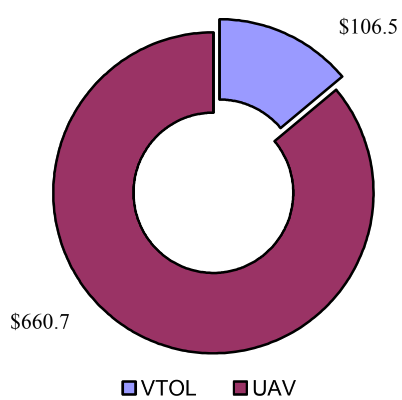

Fig. 3. Money given by the US government for the R&D of UAVs and VTOLs (in millions of dollars), in 2000.

B. VTOL application domains

VTOLs may accomplish many types of missions and tasks, including those of the ordinary UAVs. VTOL applications may be classified as military (mostly desirable), and civilian.

Current and potential use in non-military applications include pipeline and power lines inspection and surveillance, police patrol, media, border patrol, rescue missions, research for oil and natural gas, fire prevention, topography and natural disasters, as well as agricultural applications, but mostly in Japan [4]. The Yamaha Motor Company VTOL model RMAX is an excellent example of the VTOL application potential in civil applications.

VTOL military applications include surveillance and reconnaissance, combat uses and testing for new weapon systems.

C. Development Status

VTOL development stages have been classified as: concept phase, design phase, prototype phase, demo phase and production phase. Fig. 4 presents the percentage of vehicles corresponding to each phase. The first three phases account for 37% of development status.

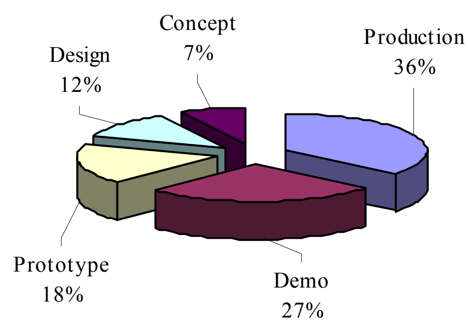

Fig. 4. Percentages of the number of VTOLs per development phase.

III. Technical Characteristics

VTOL development stages have been classified as: concept phase, design phase, prototype phase, demo phase and production phase. Fig. 4 presents the percentage of vehicles corresponding to each phase. The first three phases account for 37% of development status.

A. Type of Propulsion

In the VTOL vehicles the type of propulsion used to produce the required forces to fly, take off and land are mostly different rotor configurations. These are the single rotor, co-axial rotor, tandem rotor, intermeshing rotor and VSTOL (Vertical Short Take Off and Land). All these configurations use rotary blades to produce the needed propulsion. Other configurations also exist, using jet streams, in fan rotors or other technologies such as the Canard Rotor/Wing, currently under development by Boeing, in order to fly the vehicle. These cases form a special category and they are placed in the figures as *Other*.

Fig. 5 presents percentages responding to the number of vehicles use the configurations referred before. The vehicles for which the configuration could not be identified are referred as *Unknown* and correspond to the 26% of all. The most commonly used are the single rotors, with 34% leaving second the co-axial rotors (16%), which are also used in many models of VTOLs.

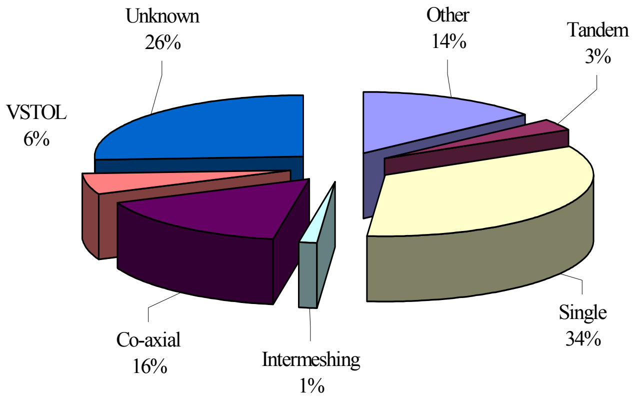

Fig. 5. The rotor configurations used for the propulsion of VTOLs.

B. Payload

Payload indicates the weight of special equipment that can be carried in missions. According to its payload a vehicle can have extended applications since additional equipment can be placed on it. Fig. 6 presents the payload capabilities for 46 out of the 74 VTOLs examined. The average value is found to be 80 Kg.

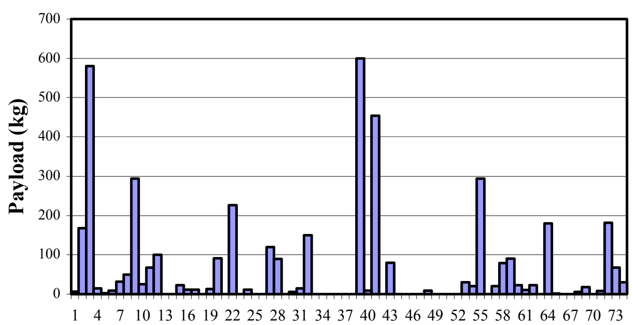

Fig. 6. Payload capabilities of the vehicles (X-axis corresponds to Table I in Appendix).

As it can be seen, most of the vehicles have payload below 100 Kg, some between 2.7-600 Kg, and just three have values above 300 Kg. These three indicate a special category of VTOLs used for heavy-duty missions, where increased maximum take off weight is needed.

C. Speed

The maximum speed a vehicle can reach during the flight can be crucial in the time completion of a mission and sequentially in its capability to take a mission. In Fig. 7 the maximum speeds of 26 vehicles is presented. Their average value is calculated at 204.7 Km/h. This value is overestimated since some of the vehicles are in primary stages of production and so the values given by the manufacturers are just expectations. Also, in this category the percentage of the unknown values is really big, reaching 65% of the total. Nevertheless, the popularity of the vehicles shows speeds between 100 - 150 Km/h.

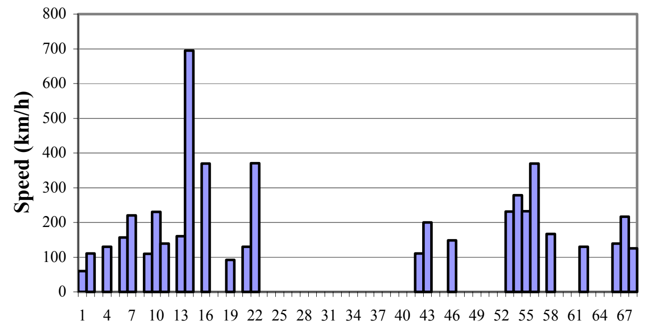

Fig. 7. Maximum speed per VTOL (X-axis corresponds to Table I in Appendix).

D. Ceiling

The maximum altitude VTOLs can reach is shown in Fig. 8 and ranges from 300 to 6700 meters. The average value is 2961m. The VTOLs that are in primary stages of development, doesn't show an increasing possibility of this technical characteristic.

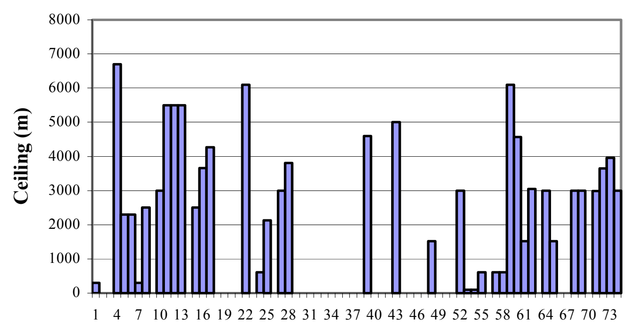

Fig. 8. The ceiling limit per VTOL (X-axis corresponds to Table I in Appendix).

E. Endurance

The endurance of VTOL corresponds to the time the vehicle can stay flying. Fig. 9 presents this flight time per vehicle. The only vehicle that distinguishes from the others is the iFF-4 (Number 73, Table 1, Appendix) vehicle with 24 hours of flight time. This vehicle is in the design phase and shows a trend for increased endurance in the future. However, this trend is not verified by other VTOLs in the Design phase. It is sure that all manufacturers are milling to extend the endurance time, but it becomes hard because of the lack of spaces for bigger fuel tanks and the limitations of the total weight that can be lifted.

The average calculated endurance (excluding iFF-4) is about 3.19 hours.

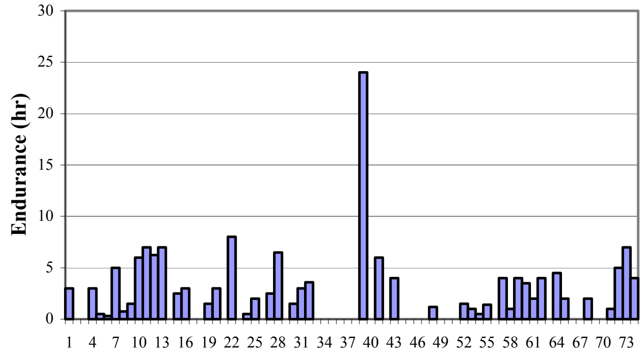

Fig. 9. Flight time per VTOL (X-axis corresponds to Table I in Appendix).

F. Range

The range indicates the radius of action of the vehicles. This technical characteristic depends heavily on the electronic equipment carried by the vehicle and capabilities of the ground control station. Most of the vehicles have ranges over 100 kilometers (Fig. 10). This value is also limited by the endurance performance of the vehicle.

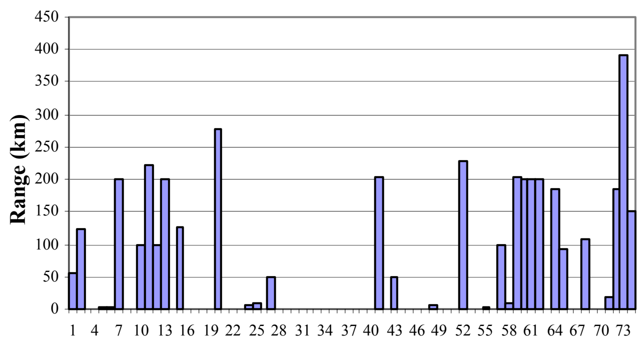

Fig. 10. Range per VTOL (X-axis corresponds to Table I in Appendix).

G. Power Plants

The engine is the most important part of a VTOL UAV. It is the part that influences all the performance characteristics and at the same time, is the most expensive one.

Several kinds of power plants can be used, either these are piston or jet or even electric. As piston, are categorized the 2-stroke, 4-stroke and rotary (Wankel) engines and as jet, the turbo shaft, turboprop and turbofan engines.

Generally, piston engines are the most popular and they are used by the 63% of the vehicles, mainly because they are cheap, effective and easy to repair. Just a few VTOLs use electrical engines (5%) because of the low power produced and the rest 32% use expensive high-powered jets (Fig. 11).

The piston engines used produce horsepower between 4 to 115 hp, conversely to jet engines, whose performances range between 100 to 420 hp. The high horsepower produced by the jet engines limit their use in vehicles from which special capabilities are needed, and thus special design and propulsion configurations are used.

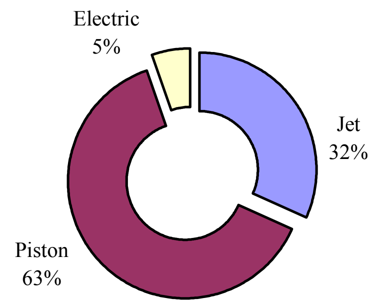

Fig. 11. Categories of engines used on VTOLs.

Piston engines are usually 2-stroke and rotary engines while the 4-stroke seems to be almost out of the market (Fig. 12). For some of the vehicles (17%), was found that they carry piston engines but not of a registered specific type, and they are listed as *Unknown* in Fig. 12.

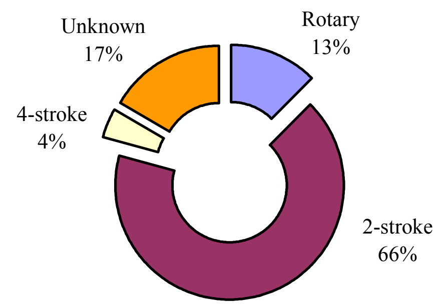

Fig. 12. Types of piston engines used.

In the jet engines, the most popular type is the turbo shaft (Fig. 13) suiting better at this type of vehicles. In this market, the three companies which supply the VTOL manufacturers are: Williams, Rolls Royce and Allison. Over the half of this market (56%) is taken by Williams, leaving the rest divided to the other two companies (Fig. 14).

A classification can be made in the horsepower of all the engines used. Three categories are used to represent low, medium and high power needs, as presented in Fig. 14 and point out that more than half of the VTOLs use medium power engines ranged between 16 to 100 hp.

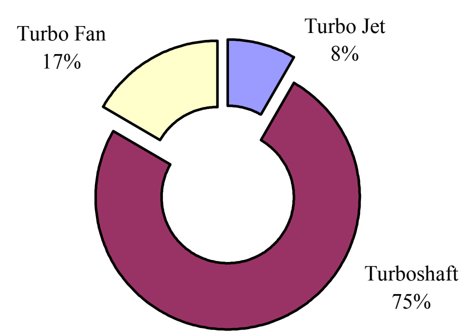

Fig. 13. Types of jet engines used.

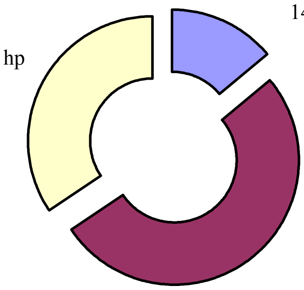

Fig. 14. Power ranges of VTOL engines.

IV. CONCLUSION

From the data collected in this survey, two major topics have been discussed: VTOL market analysis and technology characteristics. It has been shown that this special market of UAVs is a growing one. Many manufacturing companies develop new products, trying to cover more application and mission goals. For this purpose the manufacturing companies use many different technologies, designs and production strategies. Some of them develop a base model, which is used as a platform and move on to the production of alternative models of this vehicle, by just replacing the electronic equipment and power plant.

The engines used are of great importance for the performance characteristics and the price of the vehicles, so the majority of manufacturers use piston engines. Single rotor configurations are the oldest but also the most trusted type of propulsion, showing that ease of construction and tested technologies are preferred. The need of extending the capabilities of these vehicles moves many companies in researching alternative technologies, which have not reached yet the higher stages of production.

APPENDIX

TABLE I

	Model Name	Manufacturer
1	ACRW	BOSTAN RESEARCH INC.
2	Aerobot	MOLLER
3	Aerodyne	GERMAN MINISTRY OF DEFENCE
4	Aerohawk	AERONAUTICS UAV SYSTEMS LTD
5	23F	AEROCAM
6	60F	AEROCAM
7	Apid	SCANDICRAFT SYSTEMS
8	Arch 50	DAEWOO HEAVY INDUSTRY
9	Argus	SCHWEIZER
10	Camcopter	SCHIEBEL
11	CL-227 Sentinel	BOMBARDIER AEROSPACE
12	CL-327 Guardian	BOMBARDIER AEROSPACE
13	CL-427 Puma	BOMBARDIER AEROSPACE
14	Cycloprop	BOSCH AEROSPACE
15	Cypher	SIKORSKY
16	Cypher II	SIKORSKY
17	CVG 2002	COPTERVISION
18	D'HovRBot	D-STAR ENGINEERING
19	DP-4	DRAGONFLY PICTURES Inc.
20	Dragonfly	BOEING - DARPA
21	Dragonwing	BOEING
22	Eagle Eye	BELL
23	Firefly	AERO-K AVIATION PRODUCTS
24	FLYRT	NAVAL RESEARCH LABORATORY
25	HELI 25	B.T.A. AUTOMATIC PILOTING
		INTERNATIONAL
26	Helicam	MLB CO.
27	Heliot	CAC SYSTEMS DRAGON FLY
28	Heliwing	BOEING CO.
29	Heliplane	CARTERCOPTER
30	Hetel Light	ECT INDUSTRIE
31	Hetel Standard	ECT INDUSTRIE
32	Hetel Large	ECT INDUSTRIE
33	High Point	NAVAL RESEARCH LABORATORY
34	Hummingbird	MOLLER INTERNATIONAL
35	Hummingbird	NAVAL SURFACE WARFARE CENTER
36	Hummingbird A115	FRONTIER SYSTEMS
37	Hummingbird A160	FRONTIER SYSTEMS
38	Hovtol	JOHNNY SWINSON
39	iFF-4	IMAR GMBH
40	Istar 29	MICRO CRAFT
41	JAG	VICTORY SYSTEMS
42	Ka-37	KAMOV
43	Ka-137	KAMOV
44	K-Max Burro	KAMAN
45	Manta	FREEWING AERIAL ROBOTICS CORP.
46	Manta	GEORGIA TECH RESEARCH INSTITUTE
47	Maple Seed	MLB CO.
48	MiniCypher	SIKORSKY
49	Nitro Hawk	CHANNON AIS
50	Pidgeon	ARMY RESEARCH LAB
51	Project Elliott	ORION AVIATION
52	QH-50 Dash	GYRODYNE
53	Rmax	YAMAHA
54	R-50	YAMAHA
55	RoboCopter	KAWADA
56	Rogue	REMOTE INTELLIGENCE SYSTEMS, Inc.
57	RPG Midget Mk III	TECHMENT AB
58	RPH-2	FUJI HEAVY INDUSTRIES
59	RQ-8 FireScout	NORTHROP GRUMMAN
60	Scorpion Model 100	FREEWING AERIAL ROBOTICS CORP.
61	Scorpion Model 60	FREEWING AERIAL ROBOTICS CORP.
62	Sea Bat	ORION AVIATION
63	Sea Spray	PIASECKI AIRCRAFT CORP.
64	Seamos	EADS – DORNIER GMBH
65	Sender	NAVAL RESEARCH LABORATORY
66	Sky Robot	HUMMINGBIRD AVIATION, INC.
67	Spin Wing	THORPE SEEOP
68	SPRITE	AEROBOTICS
69	SteadiCopter	STEADICOPTER
70	VerticalStar	LOCKHEED MARTIN
71	Vigilant F2000	TECHNOSUD – THOMPSON-CSF
72	Vigilante 496	SAIC
73	Vigilante 502	SAIC
74	WZ-1	NANJING UNIVERSITY OF AERONAUTICS AND ASTRONAUTICS

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