The Market for VTOL UAVs

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This article presents the state-of-the-art in Vertical Take-Off and Landing (VTOL) vehicles based on their design, technical performance comparison (maximum speed, payload, range, endurance, and propulsion configurations), and market characteristics (major manufacturing countries, real and potential applications, and developing stages).

VTOL vehicles are a special class of Unmanned Aerial Vehicles (UAVs)[1], designed and utilized for highly specialized missions because of their ability to land in difficult and restricted-size areas (ship decks) and ability to hover over specific areas of interest serving as ideal platforms for target inspection and identification.

This article surveys the current status of the VTOL market from two points of view: VTOL market characteristics and VTOL technical characteristics. VTOL market characteristics reveal information related to dominant geographic regions for VTOL production and manufacturing companies. Technical characteristics lead to potential VTOL mission types and range. As justified by the presented market analysis, 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 are still being improved in terms of development.

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.

Data has been collected from special catalogs[2], journals and the internet. Seventy-three VTOL vehicles have been surveyed. However, considering that the primary use of such vehicles is in military missions, there may be VTOL vehicles not accessible to the public due to confidential agreements between developing companies and the military. When this is the case, unavailable data has been indicated as "unknown" in the graphs. All 73 vehicles found and surveyed are listed in the Appendix at the end of this article.

Market Characteristics

Market characteristics are summarized with respect to manufacturing countries, VTOL application domains, company characteristics, VTOL development status, sales, and prices.

General Information

In 1997 the UAV global market total income, including the VTOL segment, reached $2.27B[5], a 9.5% increase compared to the previous year 1996. Although the demand for VTOL vehicles was limited at that time, intensive research efforts over the past seven years have resulted in commercially available products and increased market share. This is reflected in **Figure 1** which shows the total 2000 year funding of the U.S. DoD[3], where 15% of the funding has been allocated for VTOL vehicle design.

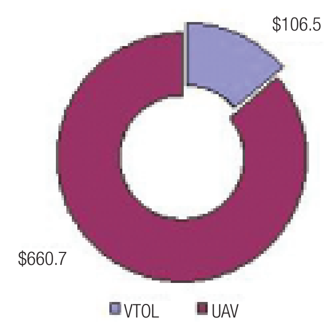

Figure 1: Funds allocated by the U.S. government for the R&D of UAVs and VTOLs (in millions of dollars), in 2000.

Manufacturing Countries

As shown in **Figure 2**, America accounts for 67% of all VTOL vehicles developed worldwide, while Europe and Asia contribute 23% and 10%, respectively.

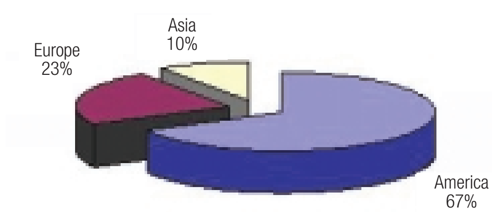

Figure 2: VTOL regional division.

The vast majority of VTOL vehicles manufactured in the American continent are contributed by the U.S. The U.S. alone manufactures 63% of the total number of VTOLs worldwide as shown in **Figure 3**, with most of the VTOLs used for military missions, supporting the high R&D funding investment level as also demonstrated in Figure 1.

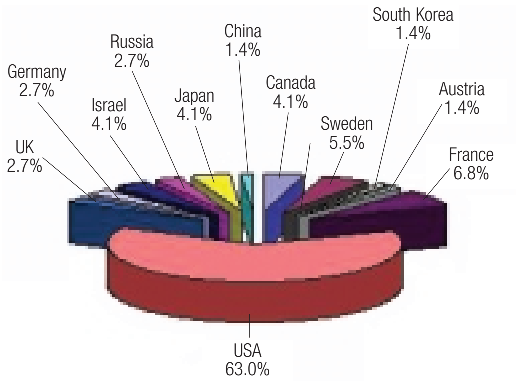

Figure 3: Percentages of the VTOL models produced over the world.

Manufacturing Companies

Based on the collected data, it has been found that 53 manufacturers worldwide design/produce VTOLs. Included in the list are big aerospace companies as well as several smaller ones. There are also research institutes (mostly military research facilities) and universities, shown in **Table 1**, developing six VTOL models accounting for 11% of all manufacturing companies.

VTOL Models	Research Institutes
FLYRT	Naval Research Laboratory
High Point	Naval Research Laboratory
Hummingbird	Naval Surface Warfare Center
Pidgeon	Army Research Lab
Sender	Naval Research Laboratory
WZ-1	Nanjing University of Aeronautics and Astronautics

Table 1: Research institutes developing VTOLs.

VTOL manufacturers use different technologies and production strategies according to the desired application domain. It has been observed that although the same frame may be used, different engines, rotor dimensions, and electric components are placed to build new models in order to satisfy a bigger customer base. Ten out of the 53 companies (19%) follow this strategy.

VTOL Applications

VTOL applications (or missions) may be classified in general as military or civilian.

Non-military applications include pipeline and power line inspection and surveillance, border patrol, rescue missions, region surveillance, oil and natural gas search, fire prevention, topography, and natural disasters, as well as agricultural applications (mostly in Japan)[4].

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

Development Status

VTOL development stages are classified as: concept phase, design phase, prototype phase, demo phase, and production phase. **Figure 4** presents the percentage of vehicles corresponding to each phase.

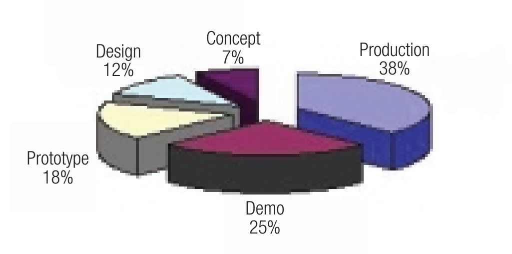

Figure 4: VTOL percentages per development phase.

VTOL Sales and Prices

Data concerning VTOL sales and prices are mostly provided by manufacturers of civilian use vehicles.

VTOL prices depend mostly on their performance characteristics and the applications in which they are used. According to information gathered from the UAV Forum internet page[6], for a single vehicle, the price range is from $25,000 to $350,000. Companies sell their products as a complete system with a ground control station. In such cases the price range is between $250,000 to $1,000,000.

Yamaha's RMAX is the only vehicle for which the number of sales has been reported. **Figure 5** shows the number of registered users in Japan (given by Yamaha's official web page).

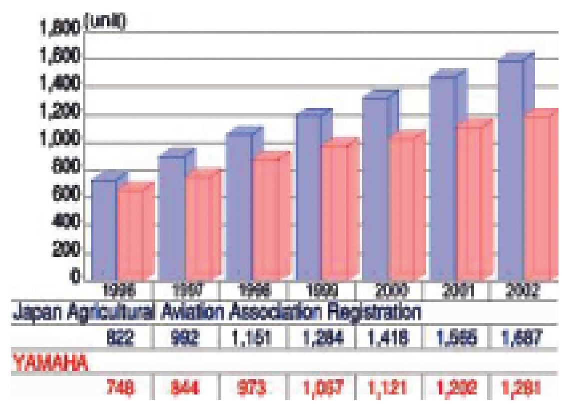

Figure 5: Helicopter registrations in Japan (Adapted from Yamaha's Official internet page[7]).

Technical Characteristics

Technology used in VTOL vehicles follows closely developments made in manned helicopters. The comparative study is performed in terms of propulsion type, payload, speed, flying ceiling, endurance, range, and power, but it is limited by the data availability since performance values may be unpublished by the manufacturers due to competition and confidentiality issues. When this is the case, lack of information for a specific vehicle is reflected in the corresponding figures as "unknown."

Propulsion Type

Propulsion mostly depends on different rotor configurations like single rotor, co-axial rotor, tandem rotor, intermeshing rotor, and the VSTOL (Vertical Short Take-Off and Land) vehicles. Such rotor configurations use rotary blades to produce the needed propulsion. In addition, there exist other configurations using jet streams, in fan rotors, or other technologies such as the Canard Rotor/Wing, currently under development by Boeing. These cases form a special category illustrated as “Other” in the graphs. **Figure 6** tabulates propulsion types for the surveyed VTOL vehicles. The most commonly used propulsion types are single rotors (39%) followed by co-axial rotors (16%).

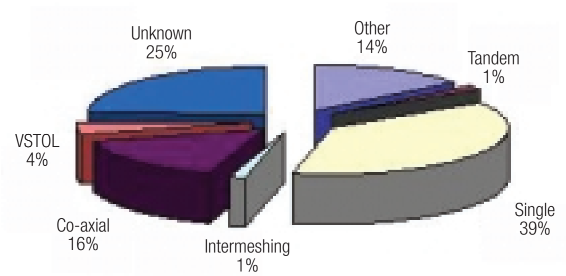

Figure 6: Rotor configurations used for propulsion.

Payload

Payload indicates special equipment weight carried in assigned missions. Most of existing VTOL vehicles have payload capabilities below 100 Kg; two have payload capability above 300 Kg, indicating a special category used for heavy-duty missions. In particular, 15 vehicles can carry over 80 Kg of equipment (32%), the same as those ranging from 20-79 Kg, leaving the rest (17 vehicles) carrying from 0-19 Kg contributing 36% of total. The average payload capability of the VTOLs surveyed was found 82 Kg — including the iFF-4 vehicle (number 39, **Table 2**) — and 70 Kg excluding the same vehicle, which is a high expectations concept.

Payload

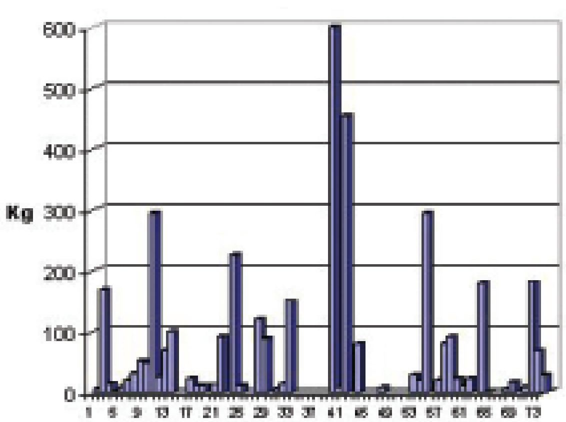

Figure 7: Surveyed vehicle payload capabilities.

Figure 7 presents payload capabilities for 47 out of the 74 vehicles surveyed. The horizontal axis number corresponds to the vehicle number in Table 2.

Speed

Figure 8 illustrates 28 vehicle maximum speeds. Since some of the vehicles are still in their primary production stages, given values by manufacturers most likely reflect “expected” values. Unreported values account for 61% of the surveyed vehicles, a surprisingly high percentage. Nevertheless, the figure shows that most vehicles reach speeds between 100-200 Km/h. Again, the horizontal axis number corresponds to the vehicle number in Table 2.

Speed

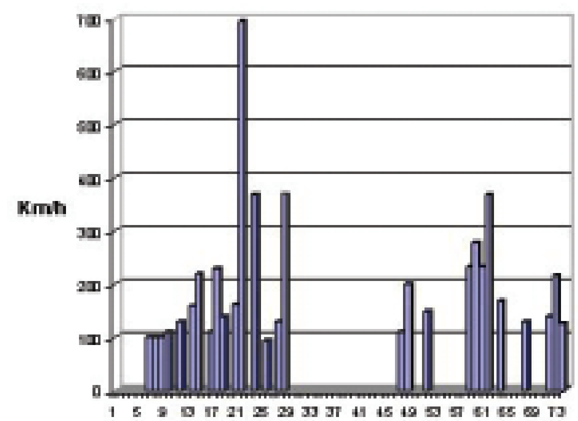

Figure 8: Maximum speed per VTOL vehicle.

Ceiling

The maximum altitude VTOL vehicles can reach is shown in **Figure 9**. It ranges from 300-6700 meters, with an average value of 3017m. The horizontal axis is the same as previously mentioned.

Ceiling

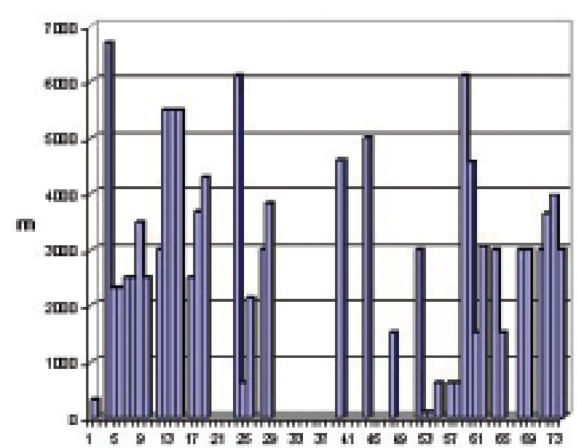

Figure 9: Ceiling limit per VTOL.

Endurance

VTOL endurance corresponds to flying time. **Figure 10** compares vehicle endurance indicating that the only vehicle with considerable better endurance is the iFF-4 (number 39, Table 2) with 24 hours of flight time. This VTOL, which is still in the design phase, is the only one where an increasing endurance trend is demonstrated; therefore, it is premature to judge or even justify future trends.

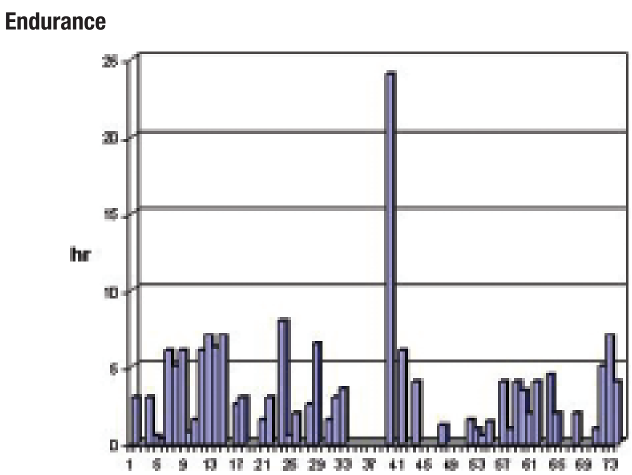

Figure 10: Flight time per VTOL.

Range

Range indicates the vehicle radius of action. It depends heavily on the vehicle electronic equipment and the ground control station capabilities. Most of the vehicles have ranges over 100 kilometers as shown in **Figure 11**. Range and endurance capabilities are coupled.

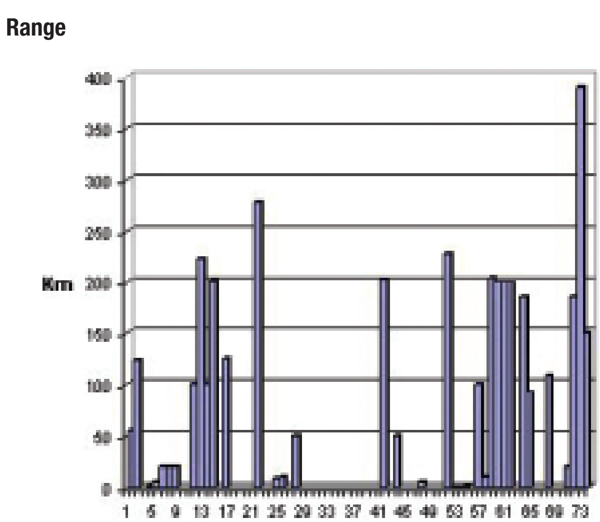

Figure 11: Range per VTOL.

Power Plants

Vehicle engine influences all performance characteristics. Engines may be piston, jet or even electric based. Piston engines may be 2-stroke, 4-stroke, and rotary (Wankel); jet engines may be turboshaft, turboprop, and turbofan engines.

Piston engines are widely used (65%) mainly because they are cheap, effective, and easy to repair. A few VTOL vehicles use electrical engines (5%) because of the low power produced, while the rest (30%) use expensive high-powered jet engines as shown in **Figure 12**.

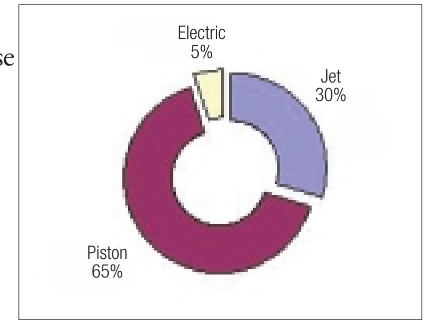

Figure 12: VTOL engine categories.

Piston engines produce horsepower between 4-115 HP. Jet engine horsepower ranges between 100-420 HP requiring special design and propulsion configurations.

Piston engines are usually 2-stroke and rotary engines, while 4-stroke engines "are almost obsolete" (**Figure 13**). Some of the vehicles (15%) are equipped with piston engines but the specific type is not registered — they are listed as "Unknown" in Figure 13.

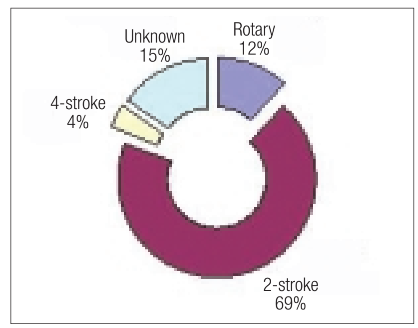

Figure 13: Piston engine types.

The most popular type of jet engines is the turboshaft as shown in **Figure 14**, mostly manufactured by Williams International and Rolls Royce. Williams has more than half of the market (56%), leaving the rest to Rolls Royce (44%)[2].

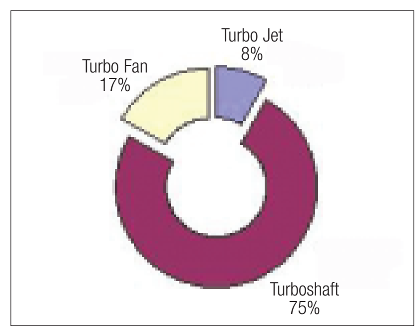

Figure 14: Jet engine types.

Regarding horsepower, a classification is made to represent low, medium, and high power needs as shown in **Figure 15**. More than half of existing VTOLs use medium power engines ranged from 16-100 HP.

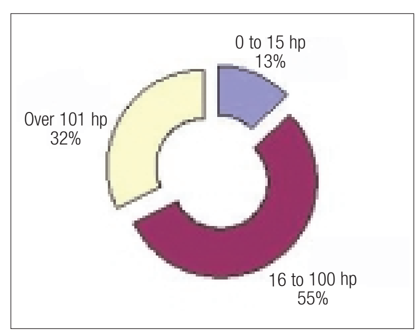

Figure 15: VTOL engine power ranges.

Steady Growth

This survey summarizes VTOL market and technology characteristics based on available data for existing vehicles. It has been observed that companies develop new products and their variations implementing different technologies, designs, and production strategies. A somewhat common theme is to develop a base model that is used as a common platform, and produce alternative models by modifying electronic equipment and power needs.

Performance characteristics and vehicle price dictate the use of piston engines. Single rotor configurations are the most widely used propulsion type, leading to the claim that ease of construction and tested technologies are preferred.

The need to extend VTOL capabilities, endurance, and mission flexibility forces manufacturers to investigate and research alternative technologies, which have not yet reached maturity. However, it is postulated that the VTOL market will grow steadily in the future.

Appendix

References

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	Model Name	Manufacturer
1	ACRW	BOSTAN RESEARCH INC.
2	Aerobot	MOLLER
3	Aerohawk	AERONAUTICS UAV SYSTEMS LTD
4	23F	AEROCAM
5	60F	AEROCAM
6	Apid Mk4	SCANDICRAFT SYSTEMS
7	Apid Mk4-X	SCANDICRAFT SYSTEMS
8	Apid Mk-6	SCANDICRAFT SYSTEMS
9	Arch 50	DAEWOO HEAVY INDUSTRY
10	Argus	SCHWEIZER
11	Camcopter	SCHIEBEL
12	CL-227 Sentinel	BOMBARDIER AEROSPACE
13	CL-327 Guardian	BOMBARDIER AEROSPACE
14	CL-427 Puma	BOMBARDIER AEROSPACE
15	Cycloprop	BOSCH AEROSPACE
16	Cypher	SIKORSKY
17	Cypher II	SIKORSKY
18	CVG 2002	COPTERVISION
19	D'HovRBot	D-STAR ENGINEERING
20	DP-4	DRAGONFLY PICTURES INC.
21	Dragonfly	BOEING – DARPA
22	Dragonwing	BOEING
23	Eagle Eye	BELL
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	Maple Seed	MLB CO.
47	MiniCypher	SIKORSKY
48	Nitro Hawk	CHANNON AIS
49	Pidgeon	ARMY RESEARCH LAB
50	Project Elliott	ORION AVIATION
51	QH-50 Dash	GYRODYNE
52	Rmax	YAMAHA
53	R-50	YAMAHA
54	RoboCopter	KAWADA
55	Rogue	REMOTE INTELLIGENCE SYSTEMS, INC.
56	RPG Midget Mk III	TECHMENT AB
57	RPH-2	FUJI HEAVY INDUSTRIES
58	RQ-8 Fire Scout	NORTHROP GRUMMAN
59	Scorpion Model 100	FREEWING AERIAL ROBOTICS CORP.
60	Scorpion Model 60	FREEWING AERIAL ROBOTICS CORP.
61	Sea Bat	ORION AVIATION
62	Sea Spray	PIASECKI AIRCRAFT CORP.
63	Seamos	EADS – DORNIER GMBH
64	Sender	NAVAL RESEARCH LABORATORY
65	Sky Robot	HUMMINGBIRD AVIATION, INC.
66	Spin Wing	THORPE SEEOP
67	SPRITE	AEROBOTICS
68	SteadiCopter	STEADICOPTER
69	VerticalStar	LOCKHEED MARTIN
70	Vigilant F2000	TECHNOSUD – THOMPSON-CSF
71	Vigilante 496	SAIC
72	Vigilante 502	SAIC
i73	WZ-1	NANJING UNIVERSITY OF AERONAUTICS AND ASTRONAUTICS

Table 2.