Aeromobile Air Transport System Design and Testing

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Abstract

This paper is primarily concerned with the design and manufacture of a flying car and problem of traffic management in the world today. A possible solution to this problem would be to design a flying or hovering car which will take the problem away from the overcrowded roads. Given technological advances in aircraft construction, navigation and operation; flying cars or personal aircraft is not only a possibility but a necessity for the future. The feasibility and viability of such a concept was investigated in terms of producing a conceptual design for a two-person carrying flying vehicle, manufacturing prototype, ground and in-flight testing.

Flying cars have featured heavily in science fiction writing and films for many years, however the idea, of actually building such a vehicle only came into fruition at the start of the twentieth century. The design was somewhat unsuccessful and therefore research was discontinued.

Production of other flying cars in US has been reported over the next three decades until recently.

Traffic congestion on roads all over the world is becoming an overwhelming problem. Larger roads and motorways are especially overused which causes the average speed of vehicles at peak times to be reduced to around 35 miles per hour in some countries. This, in turn, means that extra fuel is wasted and the exhaust emissions in the atmosphere increase rapidly.

One solution to the problem would be to merely build more roads, however this is a very expensive process and is not very viable in large built up areas.

An alternative to expanding current traffic networks would be to develop a new system of highways in the sky for a future flying cars.

Much like the cars of today flying cars will require similar rules as used by automobiles at present, and this is where the development of virtual “highways in the sky” present themselves. These skyways would be a network of predetermined routes controlled by the flying cars air traffic control and management. The computer system will also maintain the flying cars motion in terms of speed and direction so that they all remain suitably spaced in the air. The systems could be made up of a series of computer networks which can control all of the flying cars in the area it covers, instead of one world-wide system. Rules and legislations will have to be developed.

This paper also is intended to summarize the literature review carried out in the context of flying car design. It outlines the main features and work done in this field in order to gain a relevant and comprehensive background. The final aim of the project is to create a flying car design concept and flying prototype and system for transport infrastructure. Therefore, all the information contained in the project has the purpose of setting the initial design requirements as well as looking at the feasibility of the production of such a vehicle.

Introduction and history overview

Since the beginning of flight in 1903, there have been many attempts to successfully develop flying cars. Most of them have never met technological success, and the development of those which have, has not gone further than a prototype stage. In fact, the hurdles of designing a successful flying car are enormous, mainly because the design requirements of a ground vehicle are so different of those of an airplane. Therefore, trying to merge the two sets of requirements into a craft have lead to important challenges in the past, and presented problems that had no solution at that time. The most significant designs are shown in Figure 1.

Figure 1- From top left to bottom right. Watreman aeromobile, 1937. Fulton airphibian,1946. Aerocar, 1949. Aerauto PL.5C, early 50s. Ave mizar,1973. Gwinn aircar, 1935.

Note that 4 of the 6 prototypes shown above are modular designs. That is, the flight component lifts off, so that it can be left behind or carried away. The first prototypes developed were all either modular or integrated designs. In the latter case, the flying components are folded and stored aboard. Whereas the integrated designs offer the advantage that conversion from road to air mode is fast and handy, modular designs have the drawback that, since flight components must be decoupled from the ground component, mobility is constraint in the sense that the vehicle will always have to come back to the last spot it was landed. Eventually, the flight component will have to be moved from one place to another (a pretty rough task, considering the size of the wings). However, it may become clear that modular designs generally have better on-road performance specifications. The third flying car category includes those flying cars with VTOL capabilities. They lead on more complexity and it has not been since the recent years that some VTOL prototypes have been designed. They might seem, at a first glance, the most likely to success design provided their ability to land and take off almost "anywhere".

By the use of technological advances (composites materials, fly-by-wire control systems or new engines with lower power to weight ratio, for instance) design difficulties are beginning to be overcome and flying cars are nowadays progressing faster than ever. In fact, in the last 10 years, some prototypes have been proved to fly properly, and at the same time have a customer demand. The most relevant of them might be *Terragufia* aircar, which first flew in March 2009 and it is expected to go into the market at some point in 2011. Despite of this progress, the goal of mass produced flying car still seems to be far from reality due to several reasons which will be later discussed.

Market potential

A comprehensive market analysis has been as a preliminary work. This analysis will provide a rough idea of in which stage flying car design is set nowadays and how it is expected to develop in the next future, mainly regarding customers and investors. This is therefore supposed to be the first step which will define the basic design lines of this conceptual project. The process is indeed complicated by the fact that flying car is a new class of vehicle and so there is no historical data available on its market potential. Furthermore, almost no successful design work has been done, and it therefore becomes felly complicated to find which would be the potential customers, or rather, if there would be any investors interested.

Some of the already existing flying car projects are used to define a basic market environment. From there, the market niche of the design could be described using suitable assumptions and predictions. With regard to the customers, they may fall under the following categories:

- *Private customers*: In a short term period, a customer profile would be those of any person who is willing to experience different feelings when flying, who wants to go beyond the flying design standards as are set out nowadays. Basically, these are adventure minds or collectors. At the beginning, the product will be expensive and only available for "higher economies". However, as the flying car design goes into more consolidated stages and the costs are reduced, they are likely to be used for fast doorstep to doorstep transportation, easy and fast mobility in congested traffic and mobility in countries with poor infrastructure.
- *Institutional customers or enterprises*: They would include any corporation, administration or army. Flying car could be useful in many tasks, such as fire brigade, park rangers, industrial scouting for pipelines, electricity lines, railways, etc. custom checking for coastal and border protection, defence surveillance and transportation, first aid, delivery services or bridge inspection, to name just a few.

With regard to the investors, as it may become apparent, they are the only way of funding the flying car in the early stages of production and design (apart from particular funding) when there already are no sales which may generate enough incomes to be reinvested. Investment is basically required for completion of a working prototype, FAA/EASA certification, publicity and promotion and establishment of an initial production facility. Once the technologic hurdles of the prototype are overcome, the project funding becomes the main problem. There actually are a few prototypes whose commercial progress has been frustrated due to the lack of funding, along with other issues such as government certification rejection.

In EU there were 15,943,287 cars sold in 2008. The number of new personal aircraft registered the same year was 3,348. So, aviation represents a modest 0.019% of the global personal vehicle market. However, even if only a third part of this potential market was captured, this would mean a demand of 1,115 flying cars per year (only in EU). This justifies the flying car to be a saleable product, because although it would cover only a minuscule percentage of the global personal transportation, this is such a massive market that the absolute number of units likely to be demanded is far from negligible. Nevertheless, as any other new technology hitting the market, flying car is likely to be expensive at the beginning. However, if a product proves to be desirable, it might sell regardless the price. Therefore, it could be firstly sold in a minor scale basis to either institutional or particular customers with enough economic means. Once the product is settled and proved to be economically viable, the production could be raised and in turn its price reduced, hence attracting an ever expanding group of costumers. Thus, the product could be expanded out to the general public. In a relatively far future, it could even become a substitute of the nowadays personal vehicles for anyone who requires travel quickly within a long distance radius. Although imagine a society where flying cars have substituted conventional transportation may seem a frivolity, in has happened many times in the past that a new technology which apparently was constraint to a few people, has then become a basic tool for the society dynamics. The list is endless: computers, mobile phones, cars, aircraft, etc.

Therefore, the flying car as a product seems to be saleable at a first glance, and it definitely fills a particular need: To travel further, safer and faster than cars, avoiding traffic congestions. It is important to recall though, that in order to adapt traffic management to this new sort of transportation, a lot of progress is to be done in terms of certification and ATM mechanisms. In fact, if ever flying cars achieve any level of success, the next major hurdle to overcome will be, with no doubt, how they are managed so that minimum level of safety and airworthiness is ensured. In this sense, a curious example of a project being developed is those of Neuera 200. Neuera 200 flight management system constrains its flight such that it does not enter regulated airspace, and thereby eliminates the requirement of governmental oversight for either its construction or operation.

Table 1 shows a summarized list of the most significant existing flying car projects that have gone far enough so that an initial cost of production can be estimated. These are either done nowadays or in the past. Most of them have just been a frustrated attempt, some have been produced, and only a few are expected to go into commercial production.

Model name	**Initial cost of production, per unit. ($)**[1]	**Investors**
Parajet Skycar	90000	Parajet corporation[2]
Wernicke Skycar	100000	No investors found so far
Terrafugia	194000	University fundings. Sponsorships: Ansys, Garmin, Telex, Airgrahpics, etc.
Labiche aerospace	175000	No investors found so far
Haynes skyblazer	1M	Looking for investors
Milner aircar	500000	Milner company
Moller skycar	-	Moller international and looking for more investors so far
Pal-V	160000	Carver engineering, Tudeft, Tacston. University funding: universities of Gent and Leuven
Macro skyrider	100000	No investors found so far

Table 1- Initial cost and potential investors (the above data might out of date at time of going to press)

[1] Some of these costs are only estimated since the design has not already been produced.

[2] Parajet is an enterprise producing engined paragliders.

Some surveys have been done in US in order to explore deeper the market potential. The most important findings are summarized below.

- The vehicle appearance on ground is fairly important.
- Automatic conversion from aircraft to ground mode is highly desirable (i.e integrated vehicle)
- 85% of the time the vehicle would be used as a car.
- Average trip is 600 miles.
- Average trip includes 2 destinations.
- 76% of the potential customers are married or have multiple family members.
- 81% of the potential customers polled own a high performance car.
- Minimum flying speed at least needs to be 3 times faster than the average car speed.
- 55% of the potential customers polled wanted at least 4 seats.

Whereas these conclusions should be accounted when approaching the concept of a flying car, it is also important to bear in mind that these are not the result of a comprehensive analysis. In fact, the participants of the survey are only a part of the individual potential customers of US. However, many other individuals from other countries or corporations might have a different view about the flying car concept as a product. Consider, for instance, the average trip distance: it seems to be very high for European application. As it will be seen later, the average trip mileage for the design will be considerably lower.

Configuration of design parameters

When considering the flying car as a concept, the designer is left with plenty of configurations to choose from. In fact, despite of the over 70 designs built, there is no a clear tendency in the design configurations. However, some of them are either likely to be more appropriate or become obsolete. In this section, the basic design options are discussed.

The concept: The ultimate aim of the flying car is to develop the function of a personal vehicle which serves as a complement or substitute of the nowadays conventional cars. On this basis, any flying car may fall into one of the following descriptions. A roadable aircraft (an aircraft which is certified to circulate on roads), a personal air vehicle only (it is only able to fly) or a car which is able to fly (the design is closer to the conventional car and it deploys the lifting components when it has to go on flight).

Modular/Integrated frame: The features of these two different configurations have been briefly discussed above. Modular configuration is clearly cheaper to produce. Nevertheless, the drawbacks of leaving behind a part of your personal vehicle when landing become self-explanatory. No one imagines that a vehicle which forces the pilot to come back to the last spot where the vehicle was landed is going to have any success. Therefore, it is clear that for the design to be successful, the integrated frame is a mandatory configuration. The lifting components might either be folded or stored aboard.

Engine: Flying cars are light, compact vehicles which require relatively high manoeuvrability. Due to the performance requirements, the propulsion system becomes a critical component and actually represents one of the main challenges in the whole design process. The conventional piston engine can be used in a propeller driven flying car. Provided with pusher propeller configuration, the takeoff distance will be similar to those of a general aviation light aircraft powered by a reciprocating engine. If the vehicle requires VTOL capabilities, the piston engine is not likely to lift the desired amount of payload at reasonable fuel consumption so that the design becomes efficient enough that it can be produced. In this case, another option is the use of a reaction engine. Whereas they would probably produce the thrust required for good VTOL capabilities to be developed, the efficiency of this kind of engine is optimized for high flight altitudes and speeds which do not apply to flying cars requirements. Hence, the fuel burn would be tremendously high. Furthermore, the noise level of the reaction engine is well above the minimum standards set by the urban environment in which the flying car is supposed to operate.

The Wankel rotary engine is an interesting alternative. Here, the four stroke of the Otto cycle occur in the space left in between a three-sided symmetric rotor and the inside of a housing. The way how this engine operates (the mechanism of which goes beyond the scope of this report) provides it with a higher thrust to weight ratio than its reciprocating counterpart. In addition, the elimination of the most stressed parts prone to failure existing in the piston engine gives the rotary engine high reliability and a smoother flow power, due to which it is very quite in operation. The latter feature represents a great advantage, since low noise is a basic design requirement for the flying car. It is also immune to catastrophic failure. On the other hand, it has some penalties to take into account: basically, low fuel efficiency and engine life expectancy. These problems along with sealing deficiencies between the housing and the rotor have led rotary engine to a minor use in general aviation. However, it is coming back in the recent years and there are some updated versions. This is the case of Moller International. This company has developed an enhanced rotary engine version which has very low emissions and is very powerful for its weight and size. Moreover, it is said to be as efficient as the best turbo-charged diesel (the “gold standard” of fuel efficiency), giving fuel consumptions as high as 70mpg.

*VTOL/conventional takeoff***:** Whether the flying car is provided with VTOL capabilities or not, will define its major design features. Without regard to the complexity of the technology used, it becomes fairly clear that VTOL capabilities have plenty of advantages. For instance, no airport infrastructure is needed any more and the vehicle is able to operate pretty much everywhere. It has indeed the same advantages than a rotorcraft, plus the additional safety given by the ducted fans (if used). Hence, provided its ability to hover almost in direct contact to vertical surfaces (buildings or bridges), a ducted fan VTOL flying car would be useful in specialized tasks in which rotorcraft cannot operate safely such as bridge inspection or specific rescues. However, VTOL introduces a lot of penalties such as high vibration, mechanical problems when tilting the rotors to go into forward flight from hovering, excessive fuel consumption and hence reduced range, etc. If ever these technological hurdles are successfully overcome along with a cost reduction, VTOL will definitely be spread out in flying car design. Finally, autogyros are the intermediate solution between VTOL and conventional takeoff, with takeoff distances as short as 40 to 50 m. There is an autogyro personal vehicle being developed in Europe which will be discussed in later sections. Therefore, the choice of takeoff technology is far from trivial. Whereas with VTOL capabilities the design will reach improved performance and has more chances to success as a product, it might entail a risk in terms of reliability and safety if the mechanism by which VTOL is achieved is not mature enough.

Analysis of some existing designs

The most reliable designs of flying cars are described below along with their specifications in order to show the different existing approaches to the personal flying car concept. These data could be useful when performing the initial sizing in the design stage of flying car project.

Following are 12 designs for initial data collection: cost, maximum speed, cruise speed, payload, range and maximum take-off weight

Figure 2- Parajet skycar

Figure 3- Terrafugia transition

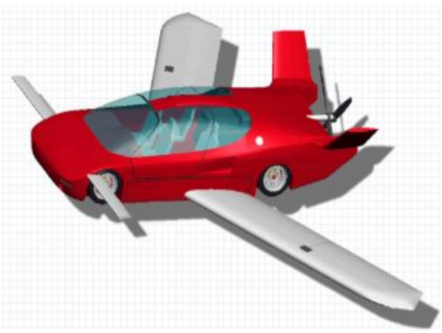

Figure 4-FSC-1; Labiche aerospace

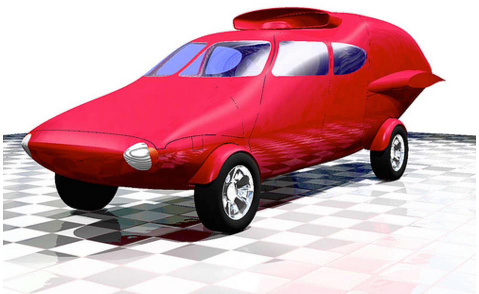

Figure 5- Haynes Skyblazer. On road mode

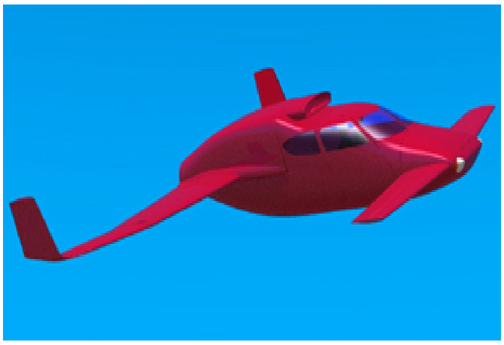

Figure 6- Haynes Skyblazer. On flight mode

Figure 7- Milner aircar

Figure 8- PAL-V

Figure 9- Wernicke skycar

Figure 10- Moller Skycar

Figure 11- Autovolantor

Figure 12- Macro skyrider

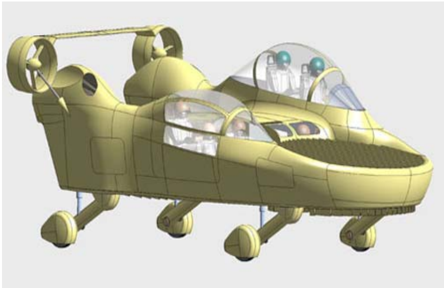

Figure 13-x-Hawk

Below are the basic technical specifications of the models described above.

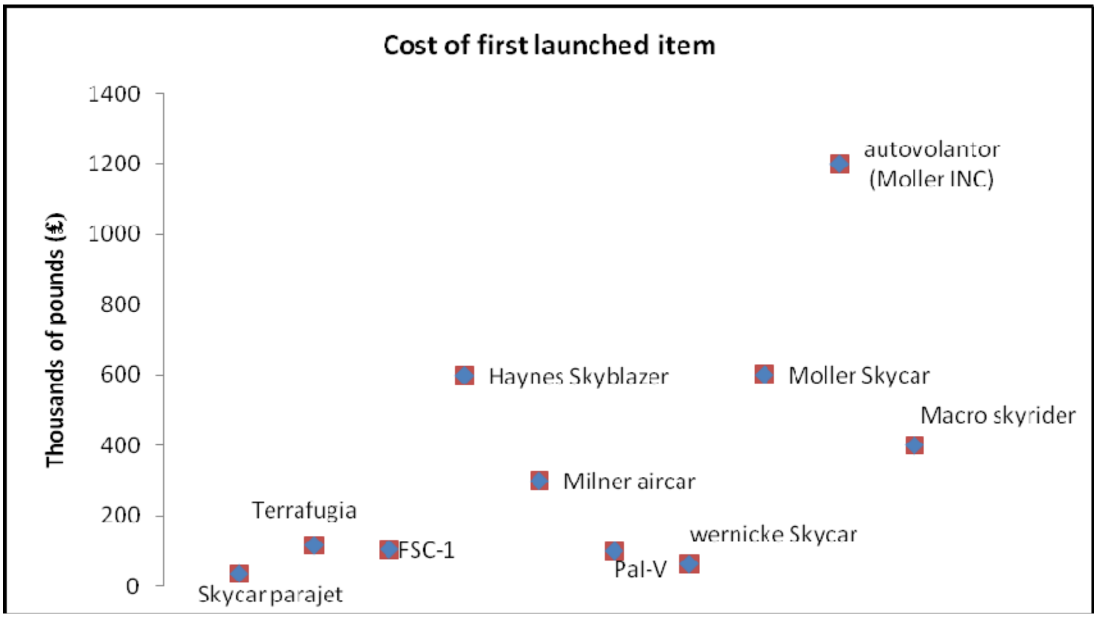

Figure 14- Cost of production per item

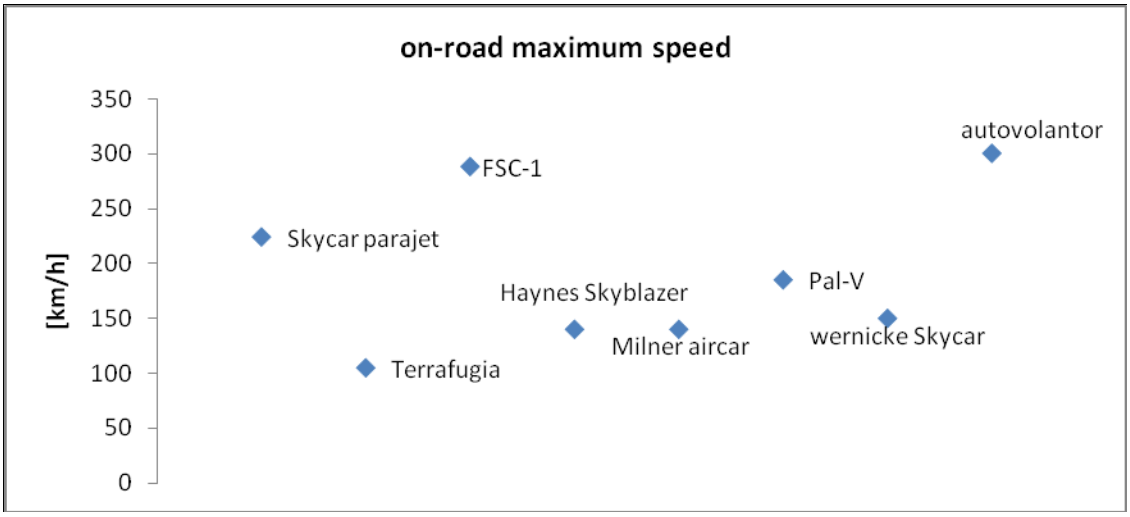

Figure 15- on road maximum speed

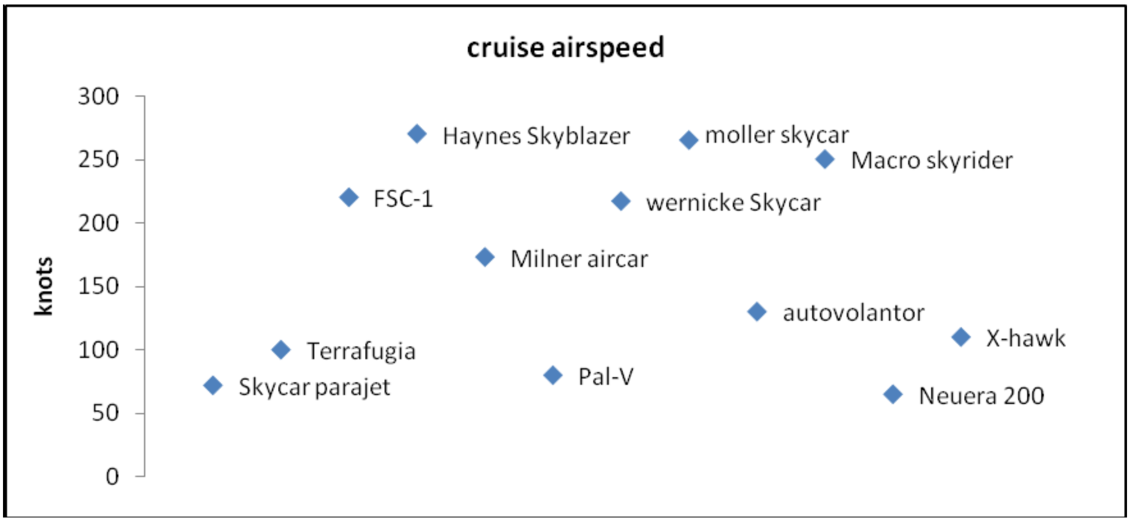

Figure 16- air cruise speed

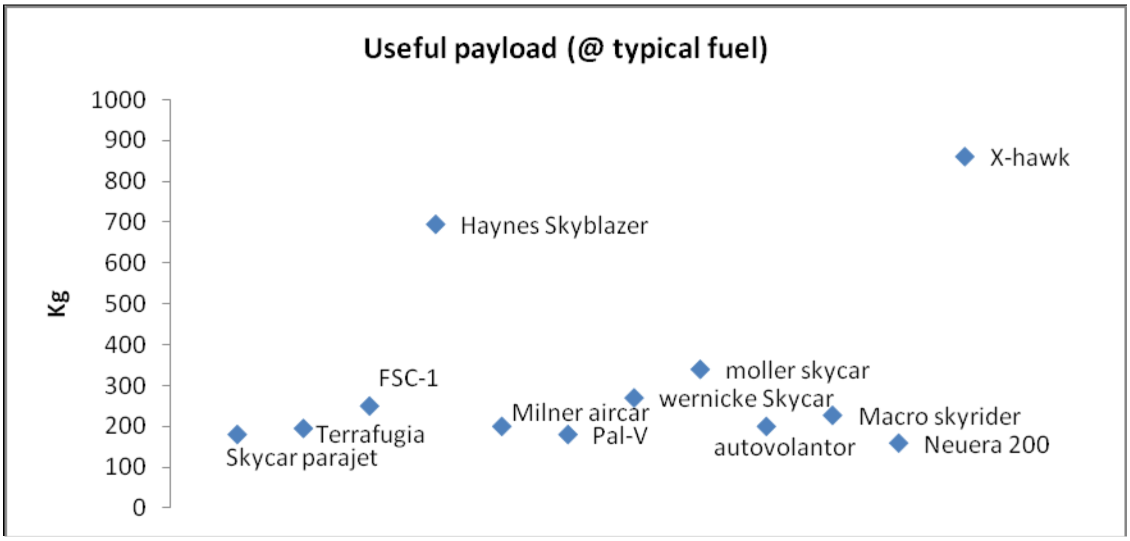

Figure 17-Useful payload at typical fuel (máximum range)

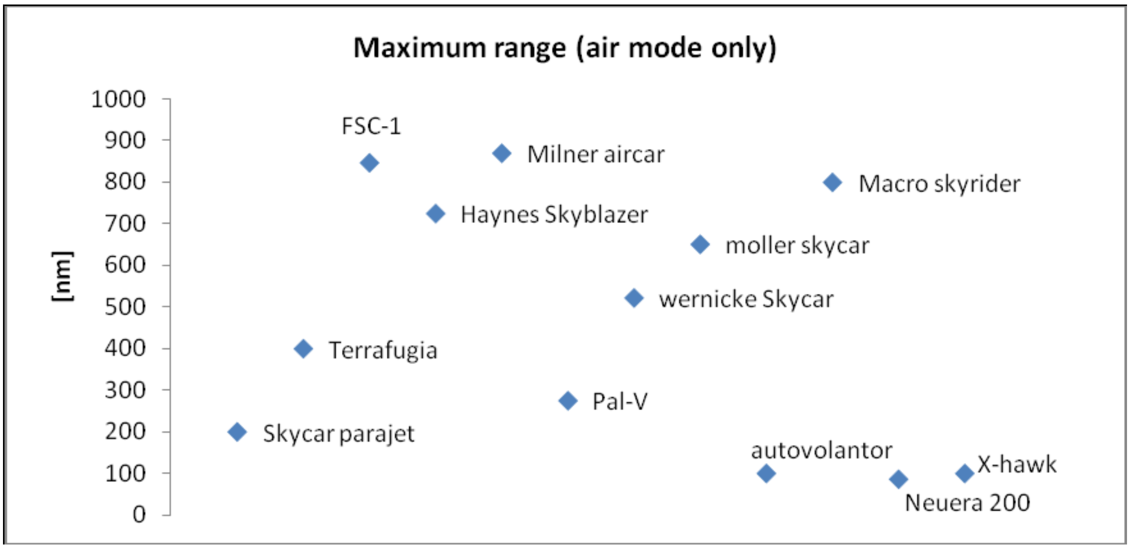

Figure 18- Maximum air range

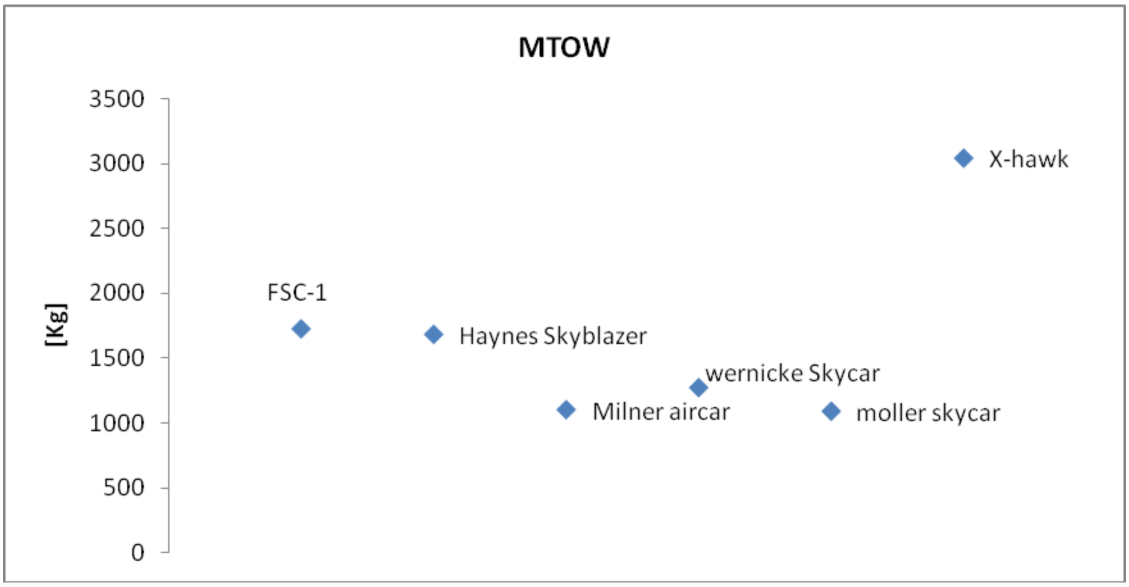

Figure 19- Maximum takeoff weight

Note from above that all designs provided with VTOL capabilities are priced equal or above 400000 pounds per unit It is important to recall, though, that this price is to be reduced as production is raised up. Regarding airspeed, speed on road and range, these parameters vary quite a lot depending on the model being considered. Concerning payload, the standards are between 150kg and 300 kg. That is, between 2 and 4 pax. plus baggage. Skyblazer and x-hawk designs, both are beyond these values. Finally, all models analyzed have about the same MTOW (excepting, again, the x-Hawk. This is due to its carrying purposes).

Concept design approach

Once the market potential has been briefly studied and the most important designs have been analyzed, we are led with a general idea of which are the needs demanded by the market, the main technological hurdles and hence the general requirements for the concept to be developed can be set. This will be a first approach and, of course, these design objectives are prone to be modified during the actual conceptual design process.

Therefore, according to the conclusions obtained from the market research there is a potential market which would be interested in a flying car understood as a *personal transportation vehicle: an integrated, compact* *size flying car*. In order to open the market chances and to make the product as polyvalent as possible, the flying car will be also designed for other uses apart from personal transportation. For instance, it will also be used for rescues, civil or even military carriage. Thus, although mainly directed to personal transportation, the design will be understood as an all-use flying car concept. The outer appearance will be worked to be attractive, as it seems to be a major customer demand. It will also have good performance qualities in both on road and air mode. Although VTOL capabilities have plenty of operational advantages, when integrated in a flying car supposed to operate among many other vehicles, it is difficult to imagine how such a vehicle will be able to fit in nowadays urban traffic organisation. In fact, since being such a new product, adaption of its operation to the already existing transport structure is of major importance. Hence, on road certification for VTOL in the middle of a crowded city is likely to be difficult to achieve nowadays. For this reason, although provided with VTOL capabilities, they will be used only in certain cases. In addition, VTOL fuel burn is extremely high, and so its use reduces the range. Therefore, conventional takeoff and landing will be also considered. Ducted fans will provide enhanced safety and propeller efficiency. However, this dual operational capability introduces a technological challenge which will have to be solved during the design process. In turn the flying car will need to have a reasonable cost, low enough to make the product saleable. Table 2 shows the basic design requirements.

General initial specifications for the design	
Take off technology	Both VTOL/conventional takeoff and landing
Maximum cost of production	400000£/unit
Engine	Rotary Wankel engine: Moller rotary engine
Airspeed	175 knots
Maximum road speed	150 km/h
Range(using conventional takeoff/landing)	400nm
Payload @ maximum range	350 Kg
MTOW	2000 Kg
Dimensions	Maximum dimensions: Lenght:6; Height:2.2; Width (wings folded): 3 m

T*able 2- General basic technical specifications (BTS) for the flying car based on market research.*

The concept of a flying car as described in this paper has been shown to have a place in the actual market and to fill a need demanded by the potential customers. The flying prototype automobile developed by S. Klein will have to fulfil the basic design requirements stated in table 2. Nevertheless, new vehicle usage means that several technological hurdles have to be solved. The main of these, follow below:

- Proper c.g setting to meet good on road and on air performance.
- Design roomy enough for practical everyday purposes yet aerodynamic enough to fly at high airspeeds.
- Reduce engine noise and emissions, in order to fulfil urban standards. In addition, achieve a demanding thrust to weight ratio.

- Integrate VTOL and conventional takeoff & landing capabilities in a single vehicle.
- Be light-weight but at the same time ensure safety on road mode (crashworthiness).
- Achieve good engine performance on road and on air modes. Note that whereas constant airborne power is required on flight, variable ground power is more suitable on road. So, engine optimization for these two different environments becomes a difficult task.
- Adequate handling capabilities and suitable aircraft/car controls integration.
- Suitable lifting components storage and minimisation of side winds effect on road mode.

Moreover, for the flying cars to achieve fully success in the future, many collateral improvements must be done in terms of systems (autopilot technology, for instance) and traffic management (virtual highways will be required).
The aim of this project is to create a conceptual design of a flying car prototype in accordance to all the considerations and requirements stated in this paper.

Proposed Concept Design Process Diagram

Design process which has been adopted based on light aircraft design step by step process is as follows:

- Market studies and basic technical specifications (BTS).
- Analysis of BTS and establishment of ways for solution (priorities, empirical and statistical data, calculation).
- Solution for concept design and redesign for it's selection (including propulsion).
- Main geometry and operation parameters (statistics, calcutation).
- Weight engineering (mass characteristics).
- Aerodynamics characteristics.
- Performance calculation.
- Analysis of BTS targets.
- Changes if necessary and corrections.

Aeromobile flying car concept and flying prototype

Design development of folded wing flying car, Aeromobile, as one solution for the future flying car concept is presented in the paper.

Back in 1993, Professor Stefan Klein from the Academy of Fine Art and Design in Bratislava began work on the 'Aeromobile'. The Aeromobile is a 5.5m long 'Batmobile' like car which can be transformed into a 7.8m wide aircraft. Its super light weight wings are concealed on its back, somewhat similar to a bird. The Aeromobile is powered by a Honda motorbike engine with a rear mounted propeller, capable of propelling the aircraft to a cruise speed of 220kph (137mph). On the ground, in car mode the vehicle can reach speeds of up to 140kph (87mph).

The unique aspect of the design of the Aeromobile is the design process its self. It is more common nowadays to do as much maths and calculations as possible prior to the build. In this case, the designer opted for the opposite strategy of building a prototype soon after initial calculations, refining and learnig what they can from the prototype, doing more and more calculations and iterating to a final concept. This process is being incorporated to ultimately save money and time on the design.

Aeromobile Base Technical Specification:

- Empty Weight: 400 kg
- Two seats/Payload: 200 kg
- Wing span: 7.8 m
- Wing area: 10.3 m^2
- Length: 5.5 m
- Width: 1.8 m
- Height: 1.80 m
- Engine: Honda Blackbird 1200 ccm, 140 HP, 9500 rpm
- Propeller: 3 blades, ϕ = 1.45 m (fixed pitch)

- Max ground speed: 140 km/h
  Cruise speed: 220 km/h

Aeromobile base airworthines requirements CS-VLA

Aeromobile II (S. Klein)

Conclusion

The concept of a flying car as described in this paper has been shown to have a place in the actual market and to fill a need demanded by potential customers. The conceptual design and flying prototype of the flying car developed in this project (Aeromobile) will have to fulfil the basic design requirements. Nevertheless, new vehicle usage means that several technological hurdles have to be solved in order to obtain full airworthiness and road use certification.

Moreover, for the flying cars to achieve fully success in the future, many collateral improvements must be done in terms of systems (autopilot technology, for instance) and traffic management (virtual highways will be required) and new road infrastructure.

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