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Overview of recent endeavors on personal aerial vehicles: A focus on the US and Europe led research activities

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ABSTRACT

Personal aerial vehicles, an innovative transport mode to bridge the niche between scheduled airliners and ground transport, are seen by aviation researchers and engineers as a solution to provide fast urban on-demand mobility. This paper reviews recent research efforts on the personal aerial vehicle (PAV), with a focus on the US and Europe led research activities. As an extension of the programmatic level overview, several enabling technologies, such as vertical/short take-off and landing (V/STOL), automation, distributed electric propulsion, which might promote the deployment of PAVs, are introduced and discussed. Despite the dramatic innovation in PAV concept development and related technologies, some challenging issues remain, especially safety, infrastructure and public acceptance. As such, further efforts by many stakeholders are required to enable the real implementation and application of PAVs.

1. Introduction

Since the first flight of the Wright Brothers in 1903, aviation has experienced dramatic progress especially in civil sectors. For example, in 2015 Airbus and Boeing predicted annual growth rates for world airline traffic of 4.6% and 4.9% in terms of passenger kilometers over the next 20 years, which could result in 15.2 trillion revenue passenger kilometers (RPK) in 2034 [1,2].

Apart from the increasing demand of commercial airliners (hub and spoke air transportation system), a new aviation mission with on-demand mobility is evolving [3], i.e. the so-called medium distance gap in transport systems defined by Bouladon: "Medium distances (connections between towns) where there will be rivalry between ultra-fast trains, air-cushion land and sea vehicles, and short or vertical take-off planes" [4]. As defined by NASA (Rohn 2015 [5]), on-demand mobility refers to "personal transportation capabilities in which the specifics of a trip (origin, destination, and departure time) are chosen by the user". While scheduled mobility refers to "public transportation services aggregating the needs of many users with the specifics of a trip (origin, destination, and departure time) determined by service providers (e.g. bus, rail, airline operators)" [5].

A major reason of calling for on-demand aviation is that the ground on-demand mobility modes (mainly private cars) are losing their agility due to the long commute distances and time in modern urban life. In the US cities, 23% of the total commuters have a daily commuting distance longer than 20 miles and 8% have a commuting distance longer than 35 miles [6]. The lengthy commuting distance together with the congestion lead to a yearly delay per commuter of more than 40 h [6], which result in substantial more fuel consumptions, carbon emissions and costs. In addition to the traditional ways, such as to control or to manage the mobility demand, to operate the existing road system more efficiently, or to add more capacity to road infrastructure, on-demand aviation can serve as an alternative to develop new transport modes to extend the urban transportation from one and two dimensions to three dimensional, i.e. from ground traffic to air traffic. In the meantime, this new aviation transport mode has aroused great industrial interest from both traditional and emerging giants, such as Airbus Group [7] and UBER [8]. In addition to the increased demand and enthusiasm, technology innovations such as flow control, advanced materials for airframe and engines, radical new energy storage and conversion systems also provide new opportunities for this aeronautical revolution.

In this paper, the focus is given to personal aerial vehicles, a common type of on demand mobility aviation, which is seen by NASA as "Dawn of a New Era" [5,9]. Most relevant basic concepts of the personal aerial vehicle will be firstly introduced. Then, some representative historical developments of the personal aerial vehicle (PAV) will be reviewed. The enabling technologies as well as the remaining challenges of PAVs will also be discussed in this paper.

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2. Basic concepts of personal aerial vehicles

2.1. Definition

Broadly speaking, all aviation modes that allow individual or personal mobility can be termed as personal aerial vehicle or personal air vehicle [10]. In some documents, PAVs are also called flying cars or roadable aircraft [11,12].

PAVs were firstly explicitly mentioned by NASA within the NASA/Langley Personal Air Vehicle Exploration (PAVE) and the DARPA Dual Air/Road Transportation System (DARTS) projects [13]. NASA engineers Moore el al. [14] have formulated the definition of PAVs, i.e. “PAVs are defined as self-operated aircraft, capable of use and affordable by a large portion of the general public. The goal of these vehicles is to provide a breakthrough in personal air mobility, through dramatic time-savings and increased reach, and therefore a greatly improved quality of life”. According to this definition, the most important features of PAVs are:

a) high journey speed for personal air mobility
b) affordable and usable for a large portion of the population
c) satisfying personal transportation needs of customers

Within the system of systems modeling of PAVs, DeLaurentis et al. [15] have considered the connotation of PAVs in the larger transport system and paid special attention to the future orientation of PAVs, i.e. in contrast to today's General Aviation (GA) aircraft, PAVs were projected into real implementation around 2030. The most important goal of PAVs was also seen as to dramatically improve individual mobility.

In order to achieve automobile-based on-demand acceptance, PAVs need to fulfill the following top level objectives [16]:

a) Ease of use: PAVs need to be easy to fly (as easy as driving a car), i.e. reduced vehicle operating skills and low pilot training expenditure to achieve more customers or in other way (fully autonomous when needed)
b) Safety/reliable: Comparing with other modes of transport systems, such as automobiles or GA, PAVs should be much safer and more reliable (as safe as commercial airlines)
c) Community friendly: PAVs need strict noise control to meet local noise restrictions without excessive infrastructure
d) Environmentally friendly: PAVs need to have a very low emission level by alternative energy use
e) Affordable: The operating costs of PAVs need to be competitive as compared to other modes of travel
f) Door-to-door or doorstep-to-destination (DtD) capability: To achieve the real individual mobility and to achieve the DtD speed, PAVs need to have very low requirements for take-off and landing infrastructure.
g) On demand mobility (ODM): As one of the core features, PAVs need to be capable to allow users specifying and choosing individual trips with no or very low time and space constraints.

2.2. Classification

According to the functionary orientation, PAVs can be classified to two different groups, namely the Intra-city ODM and the Thin-haul Commuter [17]. To clarify the difference of Intra-city ODM with Thin-haul Commuter, some significant aspects are selected and listed in Table 1.

Table 1
Comparison of two ODM aviation missions: Intra-city ODM and Thin-haul Commuter (Hansman and Vascik [17]).

Category	Intra-city ODM	Thin-haul Commuter
Application domain	Intra-city	Inter-city
Seat capacity	1–4 passengers	4–9 passengers
Take-off and landing capability	Vertical take-off and landing (VTOL)	Standard runway or short takeoff and landing (STOL)
Propulsion requirement	Quiet electric or hybrid/electric propulsion	Distributed electric or hybrid/electric propulsion
Range capacity	Mission range 5–100 miles	Mission range 100–300 miles
Autonomous level	Enhanced autonomy	Hybrid autonomy

3. Historical development of personal aerial vehicles

As an old dream of human beings, inspirations about personal aerial vehicle (PAV) could be traced back to the early 20th century [13,18]. The Cierva autogyro was found in the literature to be an initial successful attempt of a PAV that was developed in 1923 [13]. In the 1930s, Whatman and Waldo attempted to develop PAVs with conventional takeoff and landing (CTOL) capabilities, such as Whatsit in 1935 and Arrowbile in 1936. Harold Pitcairn also made notable contributions regarding PAVs in the 1930s by developing the Autogyro and Pitcairn Arrowbile with roadable competence. Using free wing technology, Daniel Zuck built the Pland-Mobile in 1947. During that period, the Fulton Airphibian and two prototypes of Convair Model 116 & 118 were built and flown, in which the former, the Fulton Airphibian, was considered as the first certificated roadable aircraft. However, due to technology barriers, accident, and lack of enthusiasm, most PAV models never achieved production status.

70 years later, technology advancement and market growth have generated a revitalization for PAVs. Considerable amounts of PAV concepts have been introduced or invented. Online website “roadabletimes.com” has collected over one hundred different PAV designs from the early 1900s to today, in which many designs are initiated very recently. Fig. 1 presents a selection of some PAV concepts developed in history and under current development. As can be observed in Fig. 1, worldwide many PAV concept demonstrators are being built and some of them have even been certificated [17,18]. Table 2 shows some features of a selected number of PAVs. As shown in the table, many concepts are possible for PAVs, though some of them are still in the early prototype stage.

Comparing with the abundant practical attempts and inventions of PAV concept designs and the worldwide extensive distribution of the activities aforementioned, most systematic research endeavors concerning PAVs have been carried out mainly in the US since 1990s [19] and in the EU since 2000s [20] (cf. Fig. 2). In this chapter, the PAV related research projects will be reviewed.[1]

3.1. NASA PAV-related projects

3.1.1. AGATE alliance (1994–2001)

To strengthen the nation's knowledge-based industrial expansion, the U.S. started the Advanced General Aviation Transport Experiments (AGATE) consortium in 1994 [23,24]. The main motivation was to release the pressure on existing air and ground systems, i.e. hub-and-spoke airlines and highway systems [25,26]. Under the leadership of NASA's General Aviation Program Office (GAPO), the AGATE alliance involved many industrial, university and government sector participants. The AGATE project focused on the following perspectives of next generation near all-weather single pilot small aircraft with 4–5 seat capacity:

[1] Note that the recent PAV research efforts led by NASA are not included in this chapter, but in the following chapter for the discussion of individual enabling technologies.