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High Altitude Platform (HAP): Feasibility Studies in Thailand

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Abstract

This research is focused on the feasibility study of High Altitude Platform (HAP) in Thailand. The project is initiated and funded by Geo-Informatics and Space Technology Development Agency (GISTDA). The work prepares for High Altitude Platform development project in future. It aims to study the technical feasibilities of HAP on part of the vehicle (platform) with the capacity to operate at a height of 20-40 kilometers from the earth's surface for at least 15 days. The technical feasibility of this research consists of three sections: type and dimension, material selection, and suitable propulsion system of vehicle.

There are two main vehicle types in this study, lighter and heavier than air vehicle. The platform can be presented by airship, balloon, and fixed-wing unmanned aerial vehicle. The study found that the most appropriate type of platform is a zero pressure balloon. This is by the reasons of production cost and ease of reaching the required altitude that can be done automatically with a lighter than air gas. The study of material selection shows that Polyethylene with the thickness of 20.3 µm is best suited for production in Thailand. The platform can be propelled by natural wind speed and direction varied which vary along the altitude above the earth's surface. The dimension and size of the platform is calculated with two assumptions: Firstly, the platform has a spherical shape throughout the operation with fixed payload of 12 kg. Secondly, the weather information had been taken from the Thai Meteorological Department by 5 stations over Thailand dating back decades. The analysis using basic concepts of science, theory of ideal gas, and equation of standard gravitational constant shows the feasible altitude is about 24 kilometers. The size of the helium or hydrogen filled balloon is slightly different. The on ground volume of 79.28 and 63.12 cubic meters are required respectively.

***Keywords**:* Airship, Balloon, High Altitude, High Altitude Platform, Unmanned Platform.

1. Introduction

When stepping into the twenty first-century, there are many things that would be difficult to deny that technology has evolved and has become part of the living of mankind. They come in a form that is both directly and indirectly in everyday life. The evolution of technology has broad implications for mankind which could not deny that space technology is in the upper rank that affects the lives of human beings in the present and near future. Space Affairs, or to narrow down called “satellite” affect the well-being of mankind in many ways, such as communications, travel, environmental disaster, and defense [1, 6]. The satellite is easy to be defined that the eyes that can see in the distance, especially from a high view and angle. That means a chance to see the events on Earth more clearly. Besides, there is a possibility to make a prediction and decision when the situation becomes worse in advance of a day, a month or even a year, for example, the ability to see the storm, the travel route of the storm several days in advance, the ability to predict agricultural production for more than a month in advance, the ability to extend the communication in rural area, etc. Nowadays, city people would be difficult to deny who do not bring technology to life. At least they use for connectivity, travel plan, and weather forecast. All of these are linked to space technology, especially satellite technology. The trend of exploring the world is developed by satellite technology. However, many countries have tried using alternative technologies such as HAP to reduce manufacturing and development cost which is quite high for a satellite. HAP is recently one of technology on the worldwide attention and focus.

High Altitude Platform (HAP) is an aerial platform or sky station situated at high altitude from earth’s surface or stratosphere. Its range is generally from 17 to 22 km [3, 10]. The platform can operate specific function as a satellite with more interests in delivering communication services and cost consumption. It can also provide various missions including remote monitoring, surveillance, observation, data transferring, positioning and navigation as well as scientific experiment in near space or zero gravity environment. All missions can be performed by on-board modules.

However, the apparent study and development of HAP in Thailand are still not as widely known from literature survey. This study will be a good starting point for the technical feasibilities of HAP. To meet the requirements of GISTDA, main emphasis of this work is the platform that could be operated at altitudes between 20-40 kilometers range above the earth's surface and stay aloft over Thailand for at least 15 days. This paper describes the status of research on the technology for HAP in Thailand about three issues: survey on platform type and dimension, selection of material, and study on suitable propulsion system.

2. Platform Type and Dimension

According to worldwide literature survey, it is obvious that aerial platform can be classified into two broad categories: Lighter Than Air (LTA) and Heavier Than Air (HTA) as shown in Fig. 1.

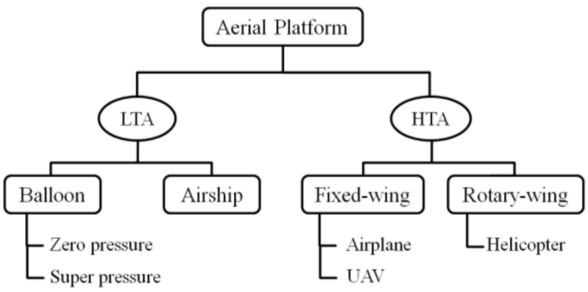

Fig. 1 Aerial platform classification

2.1 Lighter than air platform

The LTA platform is a vehicle that filled inside the main body by lighter than air gases such as hydrogen or helium gas. The buoyancy force obtained from the gas generates lift instead of aerodynamic effect on the body like the HTA. This means that the LTA platforms do not require the movement all the time to stay aloft. The volume of the lifting gas is the most important issue to discuss about the success of reaching required altitude for this platform.

Balloon and airship are generally expressed in the LTA platform; both of them are distinguished by with and without propulsion system.

2.1.1 Balloon

Balloon is the easiest platform that can be fabricated and launched with inexpensive cost. It is customary to be divided into two types zero and super pressure balloon - both indicated by the pressure of the balloon's surface. At the expected altitude, size of the balloon must be estimated from the environmental parameter such as pressure, temperature, gravitational force, etc. Zero pressure balloon is no stress into balloon’s skin. It is necessary to be equipped with a venting duct to release the lifting gas once it is fully inflated contrast to the super pressure. One example of balloon that shows the success is project loon (Fig. 2). The existing information described that the balloon can reach at altitude approximately of 20 kilometers above earth's surface and its dimension is the size of tennis court, about 11- 24 m [5].

2.1.2 Airship

Airship is basically a balloon equipped with motor and movable control components for maneuverability. This type of platform is needed for the specific mission over the limitation of balloon such as endurance, station-keeping capabilities, and maneuvering requirements, etc. [6]. In Thailand, it appears only Abhakorn-airship (Fig. 3) that had been developed since 1993-2005 but low altitude [8]. In worldwide, the use of airship began in 1930s for passenger-carrying purpose but it had also been operated at low altitude. The airship operating at high altitude has been taken an interest in the early of twenty first-century for the effectiveness of wireless communication. Many countries, such as Japan, South Korea, Malaysia, UK, USA, Europe, etc. have been agreed to work together with the objective of participating in research and development on HAP but few publications shows obviously on its success. A technical report for the US army shows the concept of HAP operating at 21.33 kilometers for the maximum duration of six month with the estimated size of 130-200 meter long, 43-46 meter in diameter, and 104,772-161,406 cubic meter in volume [6]. Airship is generally more sophisticated than balloon in overall structure and fabrication method. Moreover, the required airship volume is mostly greater than the one of balloon. Thus, it would be less feasible to use airship on the absence of reliable parameters at this stage of the beginning.

Fig. 2 Project Loon [11]

Fig. 3 Abhakorn-Airship [8]

2.2 Heavier than air platform

The HTA platform is simply defined by fixed-and rotary-wing: the former can be described by manned or unmanned aircraft, and helicopter is an example of the latter. It is impossible to fly helicopter at high altitude because it is low density condition, thus, no enough lift to reach that height. A number of fixed-wing crafts have been proven by the US government to fly at high altitude since 1950s, e.g. Dragon lady (U-2), Canberra (B-57), and Blackbird (SR-71). Recently, a lot of progress is focused to unmanned aerial vehicles (UAVs) in the design and development of HAP in UK and US on communication and military purposes, for example, Heliplat, Helios, Proteus, Predator, and Global Hawk [2, 4, 6] with a wing span of 70, 75, 23.65-28 (including winglet), 14.8, 39.8 meters, respectively. The fixed-wing platform requires advanced technology and a lot of budget to design, manufacture, and test from prototype to be reliable in service.

Fig. 4 Global Hawk [7]

With regard to altitude achievement, endurance, cost, ease of fabrication, and dimension are summarized between balloon (B), airship (A), and fixed-wing aircraft (F) in Table. 1. The dimension shows the longest or largest length of each platform.

Table. 1 Comparison of different platforms

Description	Platforms		
	B	A	F
1. Altitude ach.	+	N/A	+
2. Endurance	±	N/A	+
3. Cost	-	+	++
4. Ease of fab.	++	+	-
5. Dimension (m)	11- 24	130-200	14.8-75

- Low, ± Variable, + Medium, ++ High

The above table shows the shaded box highlighted for the technical feasibility of HAP in Thailand. The airship and fixed-wing aircraft are obviously indicated on the requirement of many fields of knowledge to be the first step to achieve high altitude flight. They require more efforts and budget than balloon. In the long run, a series of developments based on various experiments from lab scale to prototype with a trial-and-error process is needed for the absence of human risk. It seems that balloon could be the most appropriate HAP for Thailand in this stage.

3. Material Selection

The fixed-wing aircrafts are constructed with the most combination of material comparing to the other two platforms. The five basic structural components are wings, fuselage, empennage, engine, and others. All components must be designed and assembled with care for obtaining an adequate strength for the whole structure with particular attention to weight for obvious reason on performance. The weight optimization is the main issue for each component, thus it is result in different material used for aircraft structure fabrication. The choices of material for this kind of platform are metal, plastic, composite materials, and others.

The material for airships needs higher strength than zero pressure balloons to keep its shape during operation. The lifting gas filled in the main body generates stress applying to the airship's skin like super pressure balloons. It is usually made by a multilayer laminate of environmental protection, gas retention, structural, and adhesive layer [12].

Generally using, polyethylene films is a material selected to fabricate zero pressure balloons. Their advantages are on physical and mechanical properties which are light weight, sufficient strength, stretching performance, high tear strength, and adequate low brittleness temperature. The last property plays an important role on the ascending condition while the balloon travels up through troposphere to stratosphere, thus it must withstand a wide range of temperature change. The film thickness of 20 μm is recommended for large size balloon. The small one, used for light payload (few kilograms), might be constructed by the film with thickness of 6 and 3 μm for reason of mass reduction [12]. In Thailand, it is possible to find polyethylene films with the thickness of 20.3 μm and density of 0.925 g/cm^3 in order to fabricate the HAP. The thinner thickness requires more research on the fabrication technology to be manufactured in Thailand.

4. Propulsion System

A conventional fixed-wing aircraft has many systems presented in an airship, such as flight control, propulsion, avionics, etc. Propulsion can normally rely on fossil fuel, nuclear, or solar energy [6]. It is convenient to classify propulsion system used on the three different platforms by motorized and non-motorized group - the former is mostly used on airships and fixed-wing aircrafts; the latter is generally used on balloon.

Some examples would be described on different propulsion system for each platform. Firstly, solar panels are installed on the upper surface of the Helios's wing to provide adequate power at high altitude. Recent development has been studied by adding hydrogen-air fuel cell system on the platform for power. These concepts are equally used on the stratospheric airship. Secondly, Global Hawk uses a turbofan engine to propel itself. Lastly, most balloons are non-motorized platform. It is the simplest propulsion system because of no additional payload to be installed on this kind of platform. Once launched, it can freely float to the expected altitude by natural wind speed and direction. Weather will be a risk factor and might be concerned on its operation. Although it is a mercy of existing winds on the possibility to complete the mission for balloon, many demonstrations are proven and realized on the success as telecommunications platforms [9]. The advantages of balloon are listed as follows: low cost, able to mount heavy, bulky payloads, recovery and reuse of the payload, short preparation time, pilot experiments for space technologies and means to develop the next generation of researchers [12]. For Thailand, it is very important to understand the environmental conditions from ground level to 40 kilometers to approach ceiling and endurance as indicated in the objectives.

5. Environmental Conditions

As the selected platform or High Altitude Balloon (HAB) is launched, it will pass through various weather conditions. Its size can be estimated by the environmental conditions from its assigned station located in Thailand. A single source being reliable that can provide such information is the Thai Meteorological Department. The weather data for the ten years 2005-2014 had been collected by many rubber balloons, known as weathering balloon from five stations located at Bangkok, Chiang Mai, Ubonratchathani, Songkhla, and Phuket. The collective data is scattered and not generally straightforward, especially at high altitude. It is probably from the failure of the balloon with uncertainty altitude about 18-30 kilometers before reaching the expected altitude. The results are extrapolated to cover the required altitude, 40 kilometers. A group of the data were averaged and shown related to altitude in Fig. 2.

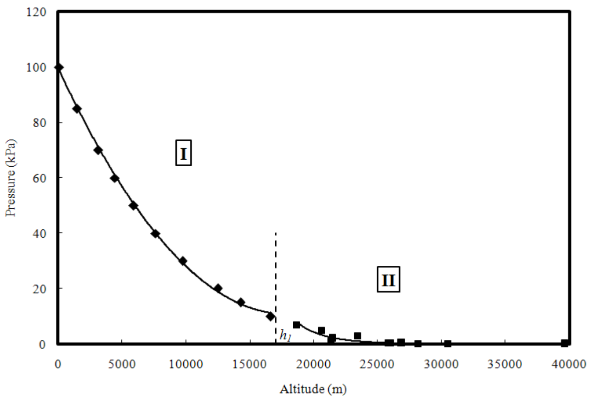

Fig. 2 Pressure and altitude

When the altitude increases, pressure decrease rapidly but becomes stable about 20 kilometers. The relation is discontinuous at altitude h_1, about 17 km. Two trend lines represented by I and II were added into the graph and might be represented by the equations as follows:

$$P = 2.7799\times10^{-7}h^2 - 9.9311\times10^{-3}h + 99.496 \quad (1)$$

and

$$P = 2.5798\times10^{38}h^{-8.7829} \quad (2)$$

where P is pressure and h is altitude. Eq. (1) is used when the altitude is less than 17 km while Eq. (2) is applied for the rest.

Fig. 3 shows the relationship between temperature in Celsius and pressure in mbar obtained by the same manner. Two equations are separated at P_1, 100 mbar as shown by I and II. The temperature decreases rapidly to -83°c while the pressure is less than 100 mbar but the inverse relation is obtained when the pressure is increased when the pressure is greater than 100 mbar.

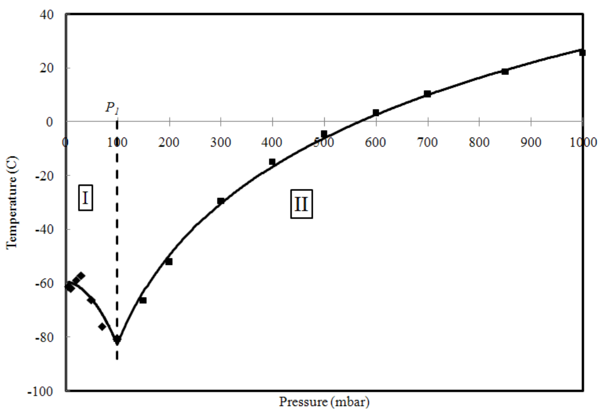

Fig. 3 Temperature and pressure

Both equations are listed as follows:

$$T = 47.72\ln P - 302.69 \quad (3)$$

and

$$T = -2.095\times10^{-3}P^2 - 2.1899\times10^{-2}P - 59.539 \quad (4)$$

where T is temperature. Eq. (3) is applied for low pressure, less than 100 mbar (I) and Eq.(4) is applied for the rest (II).

The previous information on pressure and temperature shows how material must withstand the severe temperature change and they are uniquely data obtained in Thailand's sky. More information on environmental conditions is to be tested by more reliable weathering balloon as long as the platform is still at the beginning stage to confirm the feasibility of high altitude flight in Thailand.

6. Methodology

The design experience on these kinds of platforms is still limited only to the LTA at low altitude. An overview of methods for technical feasibilities of HAP that can stay at 20-40 kilometers over Thailand's territory for at least 15 days is described within two assumptions: platform always remaining circular form and attaching 12-kg payload.

For overall methodology in this section, the analysis uses basic concepts of science, theory of ideal gas, principle of buoyancy, equation of standard gravitational constant, and spherical volume formula. All formulae mentioned above are shown as listed below:

$$\rho = \frac{M \cdot P}{R \cdot (T + 273.15)} \quad (5)$$

$$G = \frac{g}{\left(\frac{R_E + h}{R_E}\right)^2} \quad (6)$$

$$M_{total} = M_{hull} + M_{gas} + Payload \quad (7)$$

$$B = \rho g V \quad (8)$$

$$V = \frac{4}{3}\pi r^3 \quad (9)$$

where ρ is density, M is gas molecular weight, R is gas constant, G is standard gravitational constant, g is gravity of Earth (9.81 m/s^2), R_E is Earth radius, M_{total} is total mass of platform, M_{hull} is hull mass, M_{gas} is mass of lifting gas, B is buoyant force, V is balloon volume, and r is balloon radius,

The calculation also includes the relation obtained from previous section and variation of standard gravitational constant related to altitude. The spherical balloon size is estimated by two kinds of lifting gas, hydrogen and helium. The design flow is given by the following lists:

1. Define the payload (12 kg), and the float altitude (40 km).
2. Calculate the air, hydrogen, and helium properties at the float altitude: pressure, temperature, and density, using Eqs. (1) – (6)
3. Select the material type (PE) and thickness (20.3 μm).
4. Estimate the hull weight with the given payload, using Eq. (7)
5. Determine the required balloon volume from the given float altitude, using buoyancy to weight ratio (BWR) is 1, using Eqs. (8) – (9)
6. Calculate the air, hydrogen, and helium properties on ground: pressure, temperature, and density, using Eqs. (1) – (6)
7. Determine the required balloon volume on ground, using Eq. (9)

There are three items to be noted on the procedure above. The forth item use 20 percent addition on the hull weight, multiplied by 1.2. The sixth and seventh item indicates “on ground” in the calculation which means 3-meter altitude was taken into account.

7. Results and Discussions

This paper is studied based on the selected material (PE thickness 20.3 μm) and Thailand’s environmental conditions. The results show that the size in term of the required balloon volume on ground is very large for attaining at the altitude 40 kilometers. That is 1.188 x10^5 and 1.646 x10^8 m^3 when the balloon is filled by hydrogen and helium into the gas-tight compartment, respectively. It is quite difficult and expensive to be realized in order to find such a volume of lifting gas for being the first step to learn how its characteristic is. Moreover, it is most important to reduce the hull weight, and lightweight PE is needed. This makes the material playing the most important role in the study but it requires the advanced technology to produce very thin PE which is not currently available to be obtained from industries in Thailand. The analysis remains on the selected material.

However, the objective is at altitude between 20-40 kilometers, so the analysis had been done at this range. The most possible to fly the balloon is at the altitude of 24 km which the required volume on ground is 79.28 and 63.12 m^3 for hydrogen and helium fill balloon. It is reasonable to be attempted and fly by far the largest HAP built in Thailand.

8. Conclusion

The goal of this paper was to be an initial single-source document for a basic understanding of the HAP technology related to the environment conditions of Thailand, and possibilities enabled by high altitude or near-space platform. The design experience on this paper is referred from the low altitude airship, Abhakorn-airship, which had been proven in public that it is possible to fly over Thailand’s sky so many times from north to south during 1993-2005 in both military and civil purposes. However, there are still numerous challenges including environmental research, material study, aerodynamic database by wind tunnel test, stability, structural strength, manufacturing processes, and prototype test.

9. Acknowledgement

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10. References

[1] Alsamhi, S.H., Yemen, I., and Rajput, N.S. (2015). An intelligent HAP for broadband wireless communications: developments, QoS and applications, *IEE Electronic and Communication Engineering Journal*, vol. 3, no.2, April 2015, pp. 134 – 143.

[2] Capello, E., Guglieri, G., and Quagliotti, F.B. (2009). UAVs and simulation: an experience on MAVs, *Aircraft Engineering and Aerospace Technology*, vol. 81, iss.1, April 2009, pp. 38 – 50.

[3] Chauhan, T.H., Agarwal, S., Purohit, S. and Kumar, A. (2013). Wireless communications from high altitude platforms, *International Journal of Emerging Technology and Advanced Engineering*, vol.3, issue 4, April 2013, pp. 220 – 223.

[4] Falletti, E., Mondin, M., Dovis, F., and Grace, D. (2003). Integration of a HAP within a Terrestrial UMTS Network: Interference Analysis and Cell

AME0007

Dimensioning, *Wireless Personal Communications*, vol. 24, iss.2, February 2003, pp. 291 – 325.
[5] GoogleX (2016). *Project Loon*, URL: https://www.solveforx.com/loon/technology/, accessed on 24/07/2016
[6] Jamison, L., Sommer, G.S., and Porche III, I.R. (2005). High-Altitude Airships for the Future Force Army, TR-234, RAND Corporation: United States Army.
[7] Official United States Air Force Website (2014). *RQ-4 Global Hawk*, URL: http://www.af.mil/AboutUs/FactSheets/Display/tabid/224/Article/104516/rq-4-global-hawk.aspx, accessed on 20/08/2016
[8] Siribodhi P. (2016). *Abhakorn-Airship*, URL: http://www.libazz.com/DSCN/article.php?aid=65462, accessed on 19/08/2016
[9] Tomme, E.B. (2005). *The Paradigm Shift to Effects-Based Space: Near-Space as a Combat Space Effects Enabler*, Research paper 2005-01, Air Power Research Institute, Maxwell AFB, URL: http://www.au.af.mil/au/awc/awcgate/cadre/ari_2005-01.pdf, accessed on 20/08/2016
[10] Tozer, T.C. and Grace, D. (2001). High-altitude platforms for wireless communications, *IEE Electronic and Communication Engineering Journal*, vol. 13, no.3, June 2001, pp. 127 – 137.
[11] Wikipedia (2016). *Project Loon*, URL: https://en.wikipedia.org/wiki/Project_Loon, accessed on 24/07/2016
[12] Yajima, N., Izutsu, N., Imamura, T., and Abe, T. (2009). Scientific Ballooning: Technology and Applications of Exploration Balloons Floating in the Stratosphere and the Atmospheres of Other Planets, English edition, ISBN: 978-0-387-09725-1, Springer Science+Business Media, New York.