

# Thermal Regions for Unmanned Aircraft Systems Route Planning

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**Abstract**—Unmanned Aircraft Systems (UAS) become indispensable parts of modern airpower as force multiplier. One of the main advantages of UAS is long endurance. UAS have to take extra payloads to accomplish different missions but these payloads decrease endurance of aircraft because of increasing drag. There are continuing researches to increase the capability of UAS. There are some vertical thermal air currents, which can cause climb and increase endurance, in nature. Birds and gliders use thermals to gain altitude with no effort. UAS have wide wings which can use thermals like birds and gliders. Thermal regions, which is area of 2000-3000 meter (1 NM), exist all around the world. It is natural and infinite source. This study analyses if thermal regions can be adopted and implemented as an assistant tool for UAS route planning. First and second part of study will contain information about the thermal regions and current applications about UAS in aviation and climbing performance with a real example. Continuing parts will analyze the contribution of thermal regions to UAS endurance. Contribution is important because planning declaration of UAS navigation rules will be in 2015.

**Keywords**—Airways, Thermals, UAS, UAS Roadmap.

## I. INTRODUCTION

INITIALLY, aircraft was used to satisfy the flying curiosity. As the time passed the aircraft began to be produced for specific tasks. Task-oriented add-ons are conducted, weight of the aircraft increased. Up to 90 years, the concepts of war were dominated by Combat aircraft. Unmanned Air Systems (UAS) has been used in active missions after 1990. In the beginning, UAS were manufactured in standard structure, subsequently increased as the type of load. Accordingly, the amount of fuel was required to endure increased.

During the aircraft production, one of the important features that should be considered is endurance. For endurance time of manned / unmanned aircraft, the most important feature is the amount of fuel. The additional drags due to the additional payloads for different tasks reduce the effectiveness of UAS. Some tasks cannot be performed, because the reduction of effectiveness due to drag. In spite of increased payloads, to prevent the reduction of endurance, vertical hot air currents (thermals) occurring in nature is available. Their large wing areas provide better lift when compared to combat aircraft. UAS has the ability to use thermals by means of large wing area. In this way, as well as increasing the rate of the payload, endurance can be increased and UAS can perform the tasks which couldn't be executed due to overloading of UAS. Recently, UAS are used in many different tasks, such as

border patrol. In this study, UAS, the hot air flows (thermals), air routes and relationship between them will be discussed. UAS rules regarding the use of the airways have not reached reconciliation. Studying of the issue that climbing can be done in thermal regions is important because planning declaration of UAS navigation rules will be in 2015.

In the future, thermals are likely to be used as a source of clean energy. While thermal regions can be a solution to route planning, as well as UAS can benefit from the thermals' advantages.

## II. THERMALS

There are many sources of energy that we can find in nature. Some of these (solar, wind) is abundant in nature, others (oil, coal, etc.) only give us energy in chemical reactions. The use of natural energy does not harm the nature, and there is also an advantage of being able to be found easily. Vertical hot air currents found in nature is a natural energy source, birds, gliders and UAS can use this energy.

Thermals were noticed for the first time in 1870 by Lancaster who followed the birds rising from flapping in thermals [1].

### A. Properties of Thermals

Thermals are meteorological events that occur with increasing the altitude of hot air. Thermals found in the warmer regions of the atmosphere. The unbalanced heating of the earth's surface caused by the sun causes the formation of thermals. "Thermals are spatially and temporally localized parts of the atmosphere created by solar radiation heating the ground, typically moving upwards with a speed in the range of 1–10m/s"[1]. "Thermal height varies greatly depending on climate and season but can typically fall between 500 m (1600 ft) and 3700 m (12 000 ft) above ground level" [2].

Barren sandy and rocky surfaces, plowed and stubble fields surrounded by green vegetation or cities are available areas for thermal production. They contain surfaces that absorb heat readily and heat the air from below. Other local sources of surface face heat which may produce thermals include: factories, chimneys, trash or brush fires, etc.

When a flier enters a thermal, turbulence may be noticed. It will normally be followed by a climb indication on the variometer [3]. Previous variometer index compared with variometer index after entry, the difference can easily be observed. If a glider, bird or UAS enters a thermal which vertical speed is 2 m/s, 394 feet additional climb per minute occurs.

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In order to stay in thermals, the aircraft must be flown in a circular pattern or perform some maneuvers. If we increase the payload of the aircraft, the minimum speed (or stall speed) of aircraft requires to create aerodynamic lift. Therefore we have to fly faster, and we'll fly a larger circular pattern. When minimum speed increases, the diameter of circle pattern increases and the occurring lift in the thermals reduces. The width of a thermal region can be about 2000-3000 meter (1 NM). To stay in the thermals, the low speeds (<200 knots) must be utilized.

For the hot air (thermals) rise in the updraft, cool air (downdraft) must be pushed down. Thermals (lift) and downdrafts (sink) coexist side by side. As the air is warmed from below and rises, cooler air must move in from the surrounding area to replace it. Contrary to the thermals, aircrafts lose altitude in cold air. As this cooler air moves in, it carries dust or smoke with it. "Streamers" of smoke and/or dust converging from different directions indicate a probable thermal.

As the air in the thermal rises, it cools as the pressure decreases with altitude. If the air rises high enough to cool the point where the water vapor condenses, a cumulus cloud is formed. Locating clouds with the proper characteristics can assist in finding thermals. If the clouds have sharp outlines, with a flat or concave shape at the base, it can be the sign of a thermal. These are clouds that are still in the process of growing, and indicate an active thermal. In dry regions it is likely that thermals will not contain enough moisture to produce cumulus clouds.

The location of a thermal can be found in known areas, it means that so many people know there. The direction of rotation in the thermal should be known by everyone. All aircraft entering that thermal must turn in the same direction.

#### *B. Thermals Usage of Bird and Gliders*

If an upward force is not available, all objects flying in the air loses altitude because of gravity. For birds, flapping wings provide an upward thrust. For aircraft having engine, engines creates an upward force. Gliders (if non-motorized) to maintain a certain speed at a certain angle must constantly descend. Inside thermals, birds (with wings spread but without flapping their wings) and gliders can gain altitude due to upward flow of thermal air, and all aircraft also can gain altitude with lower engine power inside thermals.

Manmade soaring objects, like gliders, hang gliders and paragliders are able to fly great distances by using only the natural energy of thermals but larger species of birds have also specialized during evolution for this form of flight. Similarly to gliders these birds gain height by circling in thermals with wings spread until the desired height is reached. [1]

Instead of spiraling in one direction to stay with a single thermal, some birds such as peregrine falcons constantly change the direction of their spirals. It allows the flier to sample the volume of the atmosphere more effectively, making it more likely that it will find a better thermal. It is not clear how birds solve this task. [4]

Glider pilots apply Reichmann rules [5] when they are climbing in a spiral due to a thermal. In thermals, the rules are these: If the climb improves, widen the spiral by decreasing the banking angle, if the climb deteriorates, tighten the spiral by increasing the banking angle, and if the climb remains constant, keep the banking angle constant. Pilots by applying these rules can benefit optimally from the thermals.

### III. FLIGHT CHARACTERISTICS OF UAS AND USAGE AREAS

After giving information about thermals, this section will give information about UAS.

#### *A. General Characteristics of UAS*

Historically, unmanned aircraft have been known by many names including: "drones," "remotely piloted vehicles (RPV)," "unmanned aerial vehicles (UAV)," "models," and "radio control (R/C) aircraft." Today, the term UAS is used to emphasize the fact that separate system components are required to support airborne operations without a pilot onboard the aircraft. [6]

UAS can glide with its wide wing surface and stay airborne much more. In UAS, there are no human comforting tools, protection tools and flight indicators, which help the pilots enhancing situational awareness, so these leads to a significant decrease in weight of UAS.

The dimensions of a manned aircraft must be large enough to take at least one pilot. UAS can be produced in dimensions ranging from mosquitoes to a manned aircraft.

For UAS, The constraints resulting from the human limitations do not constitute a problem. G limitations, human health problems and personal needs of people are some of the constraints.

Payloads of UAS vary depending on the task. The resolution of the camera is important for The Recce UAS, whereas the bombardment payload is important for Offensive UAS. For example, Electro-Optical (EO) sensors (cameras) can identify an object the size of a milk carton from an altitude of 60,000 feet [7].

#### *B. Utilizing UAS*

If we are to compare UAS with the manned aircrafts, the dimensions of UAS can be different ranging from mosquitoes to a manned aircraft, so UAS will have much more usage area. UAS are usually used in military operations, but the civilian usage is newly started. Amazon Company is planning that the cargos of its customers will be distributed (maximum distance is 10 NM and in 60 minutes) by the new drones in 2015 [8]. There are many usage areas of UAS in the U.S., however UAS are especially began to be used as active in the border patrol task.

On June 23 (2010), The Federal Aviation Administration (FAA) granted a certificate of authorization requested by CBP (U.S. Customs and Border Protection), clearing the UAV flights along the Texas border and Gulf region [9]. CBP, Office of Air and Marine (OAM) operates the highly capable and proven Predator B unmanned aircraft system (UAS) in support of law enforcement and homeland security missions at

the nation's borders [10]. In partnership with the U.S. Coast Guard, OAM developed a maritime variant of its Predator B UAS, called the Guardian [11], to increase reconnaissance, surveillance, targeting, and acquisition capabilities in maritime operating environments.

If a manned aircraft has clean (without extra payloads) configuration, it can endure more than twice times. For UAS, this ratio varies between 5-10 times. UAS with additional payloads is able to perform their tasks more effectively. To extend the endurance time in the air, payloads are minimized. As a result, the task efficiency of UAS decreases and UAS are unusable for some tasks. Some UAS (Global Hawk, Predator etc.) is designed to carry a lot of useful load, but more powerful and heavier engine is needed to carry more payloads. Consequently larger UAS were produced.

### C. UAS, Manned Aircrafts and Airways Usage

There are VFR (Visual Flight Rules) and IFR (Instrument Flight Rules). IFR, which are strict rules, and requires close contact with the ground control unit. For VFR, the pilot must "see and avoid" from other aircraft. "IFR flight depends upon flying by reference to instruments in the flight deck, and navigation is accomplished by reference to electronic signals. For VFR, Separation responsibility rests with the pilots of all aircraft. Pilots separating themselves often use electronic aids and ATC (Air Traffic Control) advisory services to assist in this task, but it ultimately relies on the concept of "see and avoid" [12].

For UAS, only "sense and avoid" principle can be applied. Unfortunately, an acceptable sense and avoid system, (one that has been approved and licensed) does not yet exist, nor has what such a system might consist of been formally agreed [13]. A combination of manned and unmanned aircrafts flies together, but there are only military rules for UAS flight, because there aren't international rules for the flight of UAS. "In 2000, unmanned aircrafts' percentage of IFR traffic was 0.05%. The percentage is estimated to be % 3.9 in 2025. It is 38% for 2050" [14]. In the future, some regulations for manned / unmanned traffic flight must be made to avoid the need for distinction.

Unmanned aircraft operations must be at least as safe as manned aircraft operations; and the operation of an unmanned platform must not create any extra workload for air traffic agencies [13]. One in the United States, one in Europe and one in UK are three major initiatives. These initiatives are Federal Aviation Administration (FAA) in USA, "Autonomous Systems Technology Related Airborne Evaluation and Assessment (ASTRAEA) Programme" and "AIR4ALL (AeroSpace and Defence Industries Association of Europe)" in Europe.

FAA roadmap related to UAS was published in November 2013. According to FAA, "ultimately, UAS must be integrated into the NAS (National Airspace System) without reducing existing capacity, decreasing safety, negatively impacting current operators, or increasing the risk to airspace users or persons and property on the ground any more than the integration of comparable new and novel technologies." [15]

ASTRAEA is a two-phase program. Phase 1 of the programme finished successfully in 2008 with a demonstration of a simulated unmanned aircraft flight through UK airspace. Second phase will investigate 2 specific problems: separation assurance and control; and autonomy and decision-making. The main aim of the programme is to enable the routine use of uninhabited air vehicles in all classes of UK airspace without the need for restrictive, specialized or non-routine conditions of operation. [16]

AIR4ALL is a program of Europe. AIR4ALL consists of 12 leading members, which are interested in UAS, in the field of space industry. The group's vision is 'to open European Air Space and have the required technology demonstrations in order to produce UAS that can routinely fly across national borders'. The group has identified 4 separate groupings of challenges to be overcome; technical, rules and regulations, procedures and training and transversal issues. Topics under investigation range from separation, collision avoidance, weather detection/protection on board and autonomous behaviour/decision making through to pilot/operator training, public acceptance and impact on the environment. [13]

The AIR4ALL roadmap describes a 6 step process (although steps 5 and 6 each have 2 parts) that provide incremental increases in capability from the simplest Step 1: 'fly experimental UAS within national borders in segregated airspace (regular, at short timescale) -unpopulated range', through to the most complex Step 6a, 'fly a civil UAS as Instrument Flight Rules (IFR) and visual flight rules traffic across national borders, routinely in non-controlled airspace (airspace classes A, B, C, D, E, F, G). The step that is probably of most use to medium/large military UAS is Step 5: 'fly a civil or state UAS as IFR traffic across national borders, routinely in controlled airspace (airspace classes A, B, C). Informed commentators indicate that Step 5 will be achievable, at least technologically, by around 2015. [13]

ICAO, a special agency of the United Nations, promotes "the safe and orderly development of international civil aviation throughout the world. It sets standards and regulations necessary for aviation safety, security, efficiency, and regularity, as well as aviation environmental protection". The goal of ICAO, in addressing unmanned aviation is to provide the fundamental international regulatory framework to support routine operation of UAS throughout the world in a safe, harmonized, and seamless manner comparable to that of manned operations. [17]

## IV. UAS IN THERMALS AND AIRWAYS

UAS has a structure similar to birds and gliders and can benefit from thermals due to this structure. There are many researches relevant to the glider but there are few published documents about usage of thermal for UAS.

### A. UAS Thermal Utilization

Uncrewed aerial vehicles may soon borrow the same technique to save precious fuel, using software that identifies regions of rising air. To seek out nearby thermal currents, the software first analyses video of the sky taken by an on-board

camera. It searches for the telltale grey, dome-shaped clouds that are formed by rapidly rising hot air. The system combines this with real-time weather forecasts and computer simulations of air flow across the local terrain to predict the locations of further thermal currents. The team also fed the software information from anecdotal reports by expert gliders. During a mission, in order to determine the best route and find most powerful thermal, the software is using all this data together with the aircraft's GPS coordinates [18]. When UAS finds a thermal location, it can transmit the location of thermal for other UAS. This is one of the best ways of finding a thermal.

An autonomous soaring research Project was conducted at the NASA Dryden Flight Research Center to evaluate the concept through flight test of an electric-powered motor-glider with a wingspan of 4.27 m (14 ft), 6.8kg motor-glider called

Cloud Swift. The UAV's commercial autopilot software was modified to include outer-loop soaring guidance and control. The aircraft total energy state was used to detect and soar within thermals. Estimated thermal size and position were used to calculate guidance commands for soaring flight. Results from a total of 23 thermal encounters show good performance of the guidance and control algorithms to autonomously detect and exploit thermals. The UAV had an average climb of 172 m (567 ft) and ascended 844m in one strong thermal during these encounters. UAV simulation with thermals calculated from meteorological data from Desert Rock, Nevada, found that a UAV with a nominal endurance of 2 hours can gain up to 12 hours of flight time by using thermals. [2]

TABLE I  
THE RELATIONSHIP BETWEEN THE POWER OF THERMAL, TIME, AND CLIMB RATE

UAS	Climb Rate (feet/min)	Climbing to 12000 feet (min)	According to Power of Thermals, Gaining Altitude in The Thermal (feet/min)				According to Power of Thermals, Time of Climbing to 12000 Feet in The Thermal (min)				According to Power of Thermals, The Difference of Gained Time (min)				According to Power of Thermals, Percentage of Earnings (-%)			
			1 m/s	2 m/s	5 m/s	10 m/s	1 m/s	2 m/s	5 m/s	10 m/s	1 m/s	2 m/s	5 m/s	10 m/s	1 m/s	2 m/s	5 m/s	10 m/s
Predator	550 [19]	21,8	747	944	1534	2519	16,1	12,7	7,82	4,76	5,75	9,1	14	17,1	26,4	41,7	64,2	78,2
Global Hawk	1036 [19]	11,5	1233	1430	2020	3005	9,73	8,39	5,94	3,99	1,85	3,19	5,64	7,59	16	27,5	48,7	65,5
Heron Elbit	492 [20]	24,3	689	886	1476	2461	17,4	13,5	8,13	4,88	6,97	10,8	16,3	19,5	28,6	44,5	66,7	80
Hermes 450	900 [20]	13,3	1097	1294	1884	2869	10,9	9,28	6,37	4,18	2,39	4,06	6,96	9,15	17,9	30,4	52,2	68,6
PLT06	985 [21]	12,1	1182	1379	1969	2954	10,2	8,7	6,09	4,06	2,03	3,48	6,09	8,12	16,7	28,6	50	66,6

We can explain UAS-thermals relationship with this table. For example, Predator's climb rate is 550 ft/min. If a Predator climbs in thermal with 1 m/s vertical thermal power, UAS climb rate becomes 747 ft/min. Predator needs 21,8 min to climb to 12,000 feet. If thermal power is 10m/s, the total climb rate becomes 2,519 ft/min. The time required for climbing reduces to 4,76 min from 21,8 min. To sum up, a very important time and fuel savings are provided.

When Table I is examined, it can be seen that climbing time of UAS is long. If UAS climb in a thermal, climbing period is shorter. Considering climbing in thermal, the average time gain of the UAS (Table I) is 21.1% for 1 m/s, 34.5% for 2 m/s, 56.3% for 5 m/s, 71.7% for 10 m/s. In the future, the number of UAS in the airways will increase. UAS ratio compared to manned aircraft ratio in the airways will also increase. Through thermals in addition to time and fuel earnings, some toxic gases spreading resulting from fuel combustion can be prevented.

"As markets are defined and refined, it is expected that beginning in the 2022 to 2023 period commercial sales of UAS vehicles, including products and services, will experience accelerated growth with total UAS vehicles approaching 250,000 by 2035, of which 175,000 will be in the commercial marketplace." [22]

Usage of UAS in the Operations field with the effects of the payload loaded in UAS greatly reduces the endurance.

Because of this decline, UAS and manned fighter aircraft have similar maximum endurance values. The locations of the thermal can be detected some ways. If UAS stay in thermal

region throughout all tasks or some part of it, they may execute the tasks longer time.

Thermal and power management will become increasingly important for UAS, particularly when Stealth and Directed Energy Weapons (DEW) technology is employed [23]. If a UAS use the thermals, the infrared image (thermal cross section) of the UAS can be reduced with the use of low engine power (or not using an engine power like birds), because infrared image is associated with the degree of temperature. As a result, Enemy infrared camera and sensors can detect more difficult the existence of UAS. One important element, which reduces the effect of stealth, of today's stealth technologies is harder the reduction of infrared image. For example, the location of CAP (Combat Air Patrol) UAS is confidential and should remain confidential. RF (Radio Frequency) emission can be prevented. However, reducing the degree of heat is related to the aircraft's structure and it is difficult to reduce. In thermals, the heat dissipation of UAS decreases and the detection of the UAS's temperature with infrared sensors are more difficult.

The garbage in a city is dumped in a garbage dump. The garbage dump produces some hot gases. Gas formation in the body of garbage in landfills lasts 25-30 years [24]. The gases rise and some birds can use that hot gases for ascend without flapping. The concrete is poured over the garbage. There is a special pipe system laid in the concrete. When desired, the pipes are used for release of the hot gases into the air. UAS can benefit from hot gases emerging from the dump. However,

a study on this topic has not been found and needs to be done on this subject.

### B. Thermals, Airways Checkpoints and Airfields on South of Berlin

Airway checkpoints, good degree thermals and air fields in the south area of Berlin were processed on the map.

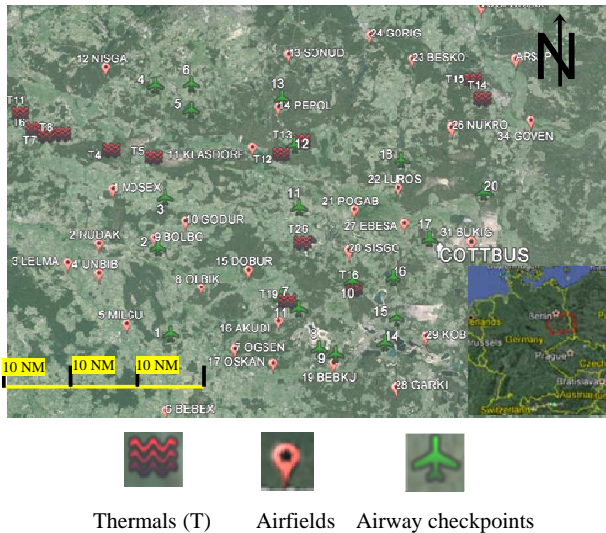


Fig. 1 Good thermals to fly and gain altitude between the airway checkpoints and airfields on South of Berlin [25]

When over Fig. 1, the number of airfields around the world can be seen that it has increased considerably. In Future, UAS can be used in these airfields on the map. Due to the increasing number of UAS, the UAS integration into the airways is important issue. There are gaps between airways. There are good degree of thermal currents in some gaps and pretty much control points on airways. If UAS want to enter into the airways from different regions and they want to go in different directions, this may lead to a complex traffic density.

When an aircraft takes off from an airfield, some applications must be applied to enter an airway. To do this, patterns of departure from the airfields are used. UAS can be used departure patterns but UAS is generally low rate of climb. Due to low rate climb, UAS remain longer in the intersection. Ultimately, this case raises safety issues. Increase of the number of UAS may make the problem cannot be solved.

If UAS go to thermal regions from low-altitude for airway checkpoints and UAS increase altitude in the region, it is possible to solve the traffic jams. UAS can climb to the desired altitude in the thermal region. During climb at checkpoints, entering the airways at this altitude will prevent many intersections. UAS in thermal regions climb faster. As a result, UAS during climb spend more less time and fuel. To control air traffic of thermal regions with using sensors will not be difficult. If thermal regions are used during climbing, UAS distinctions with other aircrafts can be made in a safe

manner. In a similar way the cold air flow regions can be identified and used during descent of UAS.

### V. CONCLUSION

For a cleaner environment, we need to find more sources of clean energy. Thermals are a natural energy source that we can use. In the future, thermals will likely to be used by UAS as actively and intensely. The main problem in the future is the integration of UAS into civilian controlled non-segregated airspace without compromising safety.

If UAS use thermals, time and fuel savings between 28% and 80% (for UAS in Table I) can be achieved, and by spending less fuel can contribute to a cleaner environment. Number of UAS vehicles in lonely USA is estimated to be 250,000 at 2035. Thermals provide important fuel and time savings for every UAS.

There are many gaps among airways which are used. If gaps where are located in the intensely thermals can be determined, this gaps can be selected as UAS climbing regions. In these regions, so as to form a cone within a radius of 2-3 NM to ensure separation from each other of UAS can be set up. The first aircraft entered into the thermals should be on the top of a ranking. UAS entries to the airways can be done safely with a ground control unit. If the rule which is the climb in thermals is applied, manned aircrafts and UAS separation can be done easily. While UAS integration into civil airspace hasn't been ensured by air traffic control authorities, suitable thermals should be registered as UAS climbing point and an air navigation rule. Also, a detailed investigation is required for detection of thermal Regions in the world.

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