5 Examples of Multi Disciplinary Mission Analysis

In this chapter we will present some examples of usage of multi disciplinary design analysis of three different types of LTA HAP missions:

- a **short duration mission** with batteries as energy source,
- a **mid-duration mission** with solar arrays as energy source and,
- a **long duration mission** with solar fuelcell system as a regenerative energy source.

Since the design of LTA HAP for a specific mission incorporating several design disciplines simultaneously is a well comprehensive task, we will use the object oriented graph grammar based design model in order to achieve optimized design configuration of LTA HAP for each mission. The object oriented graph grammar based design model facilitate a domain independent representation of the design object by maintaining all dependencies between the involved disciplines. It allows manipulation of the graph for optimization purpose by applying the rule based approach in order to achieve optimized design configurations for LTA HAP for mission analysis.
Particularly, it is taken into account that not only each design discipline is for it self optimized but also the overall network of several design domains is multi disciplinary optimized in order to meet specific mission goals.
The type of energy system plays a crucial role for design of a LTA HAP, since the success of a mission is highly dependent upon it. Because only with a sufficient energy supply of propulsion system a specific mission duration can be fulfilled.
The duration of a mission is influenced by the type of installed energy system. Therefore we will analyze three different types of missions of a LTA HAP dependent on their energy system.
The values of the variables and parameters necessary for such an analysis are listed in table 5.1.

Variable	remark	**Parameter**	value	Remark
Mission Requirements				
L	size/length of LTA HAP	E	bat; sol; hydro	type of energy system
		v_{wind}	5-30 $\frac{m}{s}$	velocity of wind
		H	2.5; 20 km	altitude
		m_{PL}	3 - 2000 kg	payload mass
		t	1 - 24 h	mission duration
		m_{sys}	2 - 100 kg	mass systems
		θ	sum./ wint.	time of year
Structure				
V_{total}	HAP volume	m_{sp_env}	36 $\frac{g}{m^2}$	material envelope
V_i	volume of segment i	m_{sp_GC}	26 $\frac{g}{m^2}$	material gas cell
A_{env}	area envelope			
A_{env_i}	area envelope segment i			
m_{env}	mass envelope			
m_{env_i}	mass envelope segment i			
m_{gc}	mass gas cell			
m_{gc_i}	mass gas cell segment i			
Propulsion System				
m_{engine}	mass of propulsion system	η_{prop}	0.5 -	efficiency of propeller
d_{blade}	propeller diameter	η_{motor}	0.8 -	efficiency of motor
P_{engine}	power of engine			
R_{prop}	propeller radius			
Energy System				
m_{bat}	mass batteries	η_{SA}	0.17 - 0.41 -	efficiency of solar array
C_{bat}	capacity of batteries	m_{sp_bat}	156 $\frac{Wh}{kg}$	specific mass battery
m_{SA}	mass solar arrays	m_{sp_SA}	0.25 $\frac{kg}{m^2}$	specific mass solar array
A_{SA}	area of solar arrays	m_{sp_EL}	2.81 $\frac{kg}{kW}$	specific mass electrolyzer
m_{El}	mass of electrolyzer	m_{sp_Fz}	3.62 $\frac{kg}{kW}$	specific mass fuel cell
m_{Fz}	mass of fuel cell			
BC	on board computer system			
Aerostatics				
F_B	buoyancy lift	Δp	50 Pa	over pressure in segment
Aerodynamics				
F_D	axial drag	C_w	0.1 - 0.05 -	axial drag coefficient
Re	Re number	ν		kinematic viscosity
C_{w_F}	friction drag coefficient			
C_{w_P}	pressure drag coefficient			
Environment				
T_{air}	temperature of air	SI	1352 $\frac{W}{m^2}$	solar radiation
p_{air}	pressure of air			
p_{He}	density of air			
ρ_{air}	density of air			
ρ_{He}	density of helium gas			
Power Network				
P_{disp_i}	power dissipation in cable i	C_i	AWG type	cable type i
U_i	voltage in cable i	U	3.6 V	battery voltage per cell
I_i	current in cable i	E	2.1 Ah	capacity of battery
d_i	diameter of cable i	m	46.5 g	mass of each battery cell
m_i	mass of cable i			

Table 5.1: Main parameters and variables of each discipline for rule based design

As mentioned before the main limitation factor for the duration of a mission are the available on board power resources. Therefore the three missions we will assay are characterized by their energy system. The main power consumption component on board is the propulsion system with more than 80% of energy usage. For station keeping task in a region with higher wind speeds the power consumption of the electrical motors is also higher which decreases the mission duration of a LTA HAP with a non regenerative energy system or requires a huge size of regenerative energy system for fulfilling the mission duration.

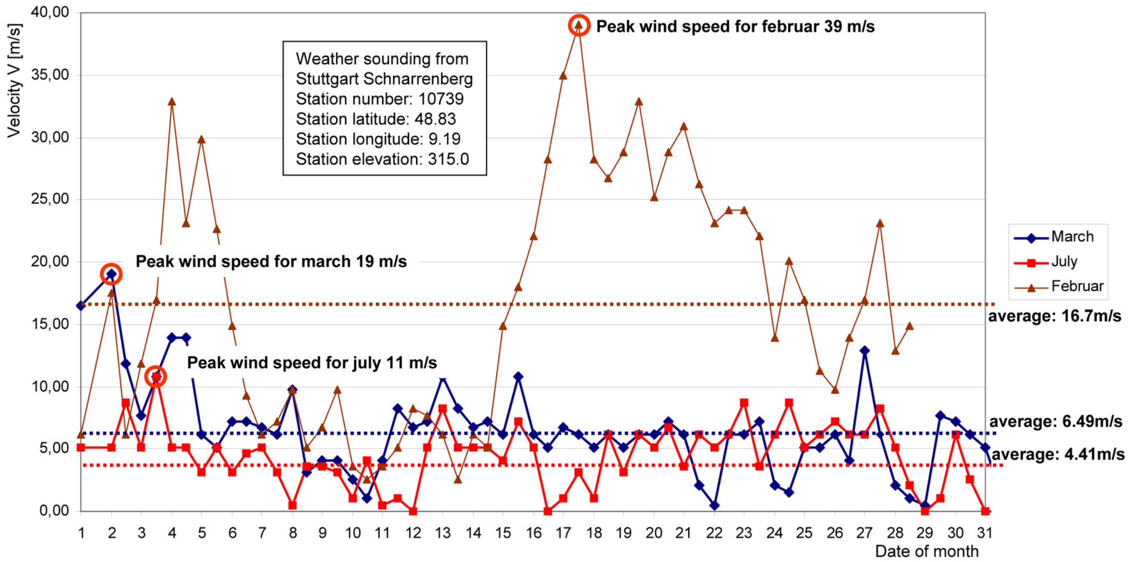


Figure 5.1: Wind speed values for three different months for altitude of 20 km

For layout of the propulsion and energy system wind charts of desired regions are analyzed. Figure 5.1 presents such a chart for 20 km altitude and 48.83° whether station latitude. There we have wind speeds for the whole month of February, March and July and the mean values. For winter months the wind speeds are much higher than in summer, but there are also days in winter with lower values than in summer. However the mean values of winter months are much higher than that of summer months. Therefore the propulsion system should be able to overcome the peak speeds for station keeping tasks. In turn the mean values are considered for calculation of the capacity of energy system and mission duration.

5.1 Short Duration Mission; Energy Source: Battery

In this section we will present some configurations of LTA HAP design for analyzing a short duration mission. The characteristic of such a mission is the type of on board used energy system. Since the main limitation factor of a HAP mission is the amount of on board energy available for the propulsion system we will use LiIon-battery blocks as an energy source for a short duration mission. Because of their higher specific mass and less capacity the duration of such a mission will be limited for only some hours.
The mission analysis is done for different configurations of LTA HAPs by varying the main mission parameters (table 5.2).

Therefore two different approaches are applied for designing such a system. The first one is to ascertain the flight duration by a given size and configuration of a LTA HAP. The second approach is to ascertain the optimized size of LTA HAP for given set of mission parameters.

Mission description: The mission is to carry a telecommunication or video payload for a specific duration at desired altitude. The LTA HAP has to fulfill station keeping task by holding the altitude. The aim is to launch from a base with a latitude of about $\phi = 48°$ and to carry back the payload to the base station. Table 5.2 presents the main mission parameters used for design and analysis of LTA HAP variants within a mission scenario of short duration mission.

	Main Mission Parameters					
No.	Energy system	Altitude	Length	Duration	wind velocity	Payload
Scenario 1	Battery	20 km	L(PL)	par	var	var

Table 5.2: Main mission parameters of a short duration mission with battery as energy source, the mission duration is a parameter (par) and the velocity and payload are design variables (var). The length of HAP L(PL) is dependent from payload mass PL.

Energy system concept: The energy system is based on accumulator batteries which are combined to battery blocks and are placed under the segments. They build two units (figure 5.2). One unit provides system components with constant electrical power over the whole mission. The other unit is switched on during maneuver tasks such as station keeping. They are separated because of electrical fluctuations caused by power cycles of propulsion unit which could disturb the functionality of system components.

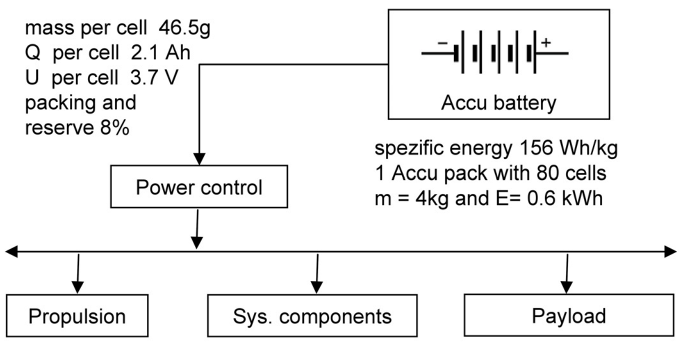
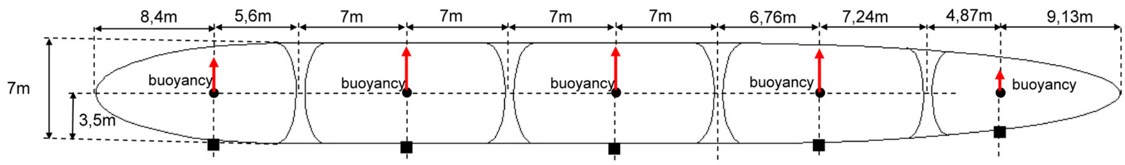


Figure 5.2: Energy system concept based on accumulator batteries for a short duration mission with batteries as energy source for electrical devices. The mission duration is limited by the amount of electrical energy of the batteries.

5.1.1 Mission Scenario 1

Energy source: Battery, H = 20km, wind speed 12m/s varying payload non regenerative mission

As presented in figure 5.3 the first mission scenario is to analyze the flight performance



material: Envelope=34 g/m^2 ; Gascell=26g/m^2

	Segment 1	Segment 2	Segment 3	Segment 4	Segment 5	Total
Gas volume (20km)	359 cbm	502 cbm	502 cbm	470 cbm	201 cbm	2034 cbm
Envelope & Gas cell						97 kg
Buoyancy lift (20km)	Total buoyancy lift=152kg;			Net buoyancy lift: 55kg		55 kg
Propulsion	8 kg	Payload=3kg		Systems=2kg (100W)		
Power (Accu: 156 Wh/kg)	4 kg	10 kg	15 kg	11 kg	2 kg	42 kg (6.5kWh)
Propulsion: 3,2kW max Cw=0,08	2,4 kW for 50 km/h 314 W for 25 km/h		**Flight duration** **2.5 h** for 50 km/h (13,9m/s) **15 h** for 25 km/h(7m/s)		**50%: 2,4kW (50kmh)** **50% 314W (25kmh)** **→ ~1,4kW+100W** **4.3h flight → 3.5h**	15 % reserve on time

Figure 5.3: Design of LTA HAP with 7m diameter in operational altitude of 20km and a maximum flight duration of 4.3 h

of a LTA HAP with a length of 70m and a diameter of 7m in an operational altitude of 20 km. This is our start configuration for this altitude and we will carry a payload of 3kg and will analyze possible mission duration. The HAP has a volume of 2034cbm and therefore produces a net buoyancy of about 48kg. Subtracting propulsion, payload and system components mass we achieve 42kg for batteries with 6.5kWh energy on board. With this amount of energy we can persevere for 2.5h with 13.9m/s and 15h with 7m/s.

For further analysis we will vary the payload from 50kg to 1000kg and calculate the HAP length for a mean velocity of 12m/s in an altitude of 20km. Results are presented in figure 5.4. The diagram represents length over payload. For each calculated configuration in figure 5.4 the mass of integrated batteries is presented in table 5.3. For instance we have a LTA HAP carrying 1 ton payload in 20km altitude and have a length of 230m by consuming power of about 20kW and battery mass of about 3t. With increasing mass of payload and mission duration a larger HAP length is necessary which implicates a growing mass of accu batteries of the energy system. The lowest value is of about 0.1t for 50kg payload and 5h duration. For same duration and a payload of 1t the battery mass grows to 0.5t. The HAP length is here around 150m. Below this value the mass of battery is below 1t and increases to some ton for bigger sizes.

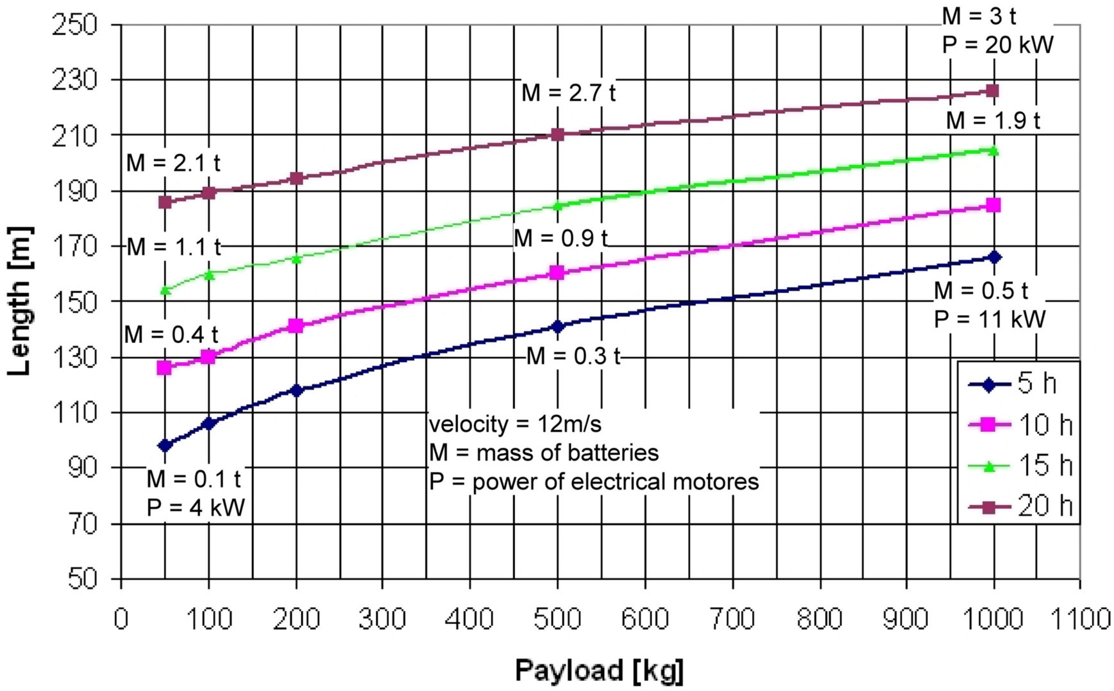


Figure 5.4: Results of HAP configurations with batteries as energy source and varying payload and duration in 20 km altitude for mean wind velocity of 12m/s

		Mission duration [h]			
		5	10	15	20
Payload		Mass of accu batteries [to]			
50	[kg]	0.14	0.45	1.1	2.1
100	[kg]	0.17	0.5	1.2	2.2
200	[kg]	0.22	0.6	1.3	2.35
500	[kg]	0.3	0.89	1.6	2.7
1000	[kg]	0.44	1.264	1.9	3

Table 5.3: Mass of batteries for varying endurance and payload with a mean velocity of wind about 12m/s (see also diagram in figure 5.4)

5.2 Mid Duration Mission; Energy Source: Photo Voltaic + Batteries

In this section we will present some configurations of LTA HAP design for analyzing a mid duration mission. The characteristic of such a mission is the type of on board used energy system. Since the main limitation factor of a HAP mission is the amount of on board energy available for the propulsion system we will use photo voltaic arrays as an energy source for a mid duration mission. The production of electrical energy by photo voltaic arrays depends in fact on the sun light, therefore the mid duration mission will be limited to day time period and can be extented by adding batteries for the night time.
The photo voltaic arrays are installed on the upper surface of the three mid segments and facilitates generating electrical power during day time. The electrical energy is fed directly into the electrical network which contains accumulator batteries for buffering purposes. Dependent on spare buoyancy additional accumulators can be integrated into the power system for storing electrical energy for shade phases or night time and therefore extending mission duration.
The mission analysis is done for different configurations of LTA HAPs by varying the main mission parameters (table 5.4).

Mission description: The mission is to carry a telecommunication or video payload for a specific duration at an altitude of 20 km. The LTA HAP has to fulfill station keeping task by holding the altitude. The aim is to launch from a base with a latitude of about $\phi = 48°$ and to carry back the payload to the base station.
Table 5.4 presents the main mission parameters used for analysis of the next two mission scenarios of a mid duration mission.

	Main Mission Parameters					
No.	Energy system	Altitude	Length	Duration	wind velocity	Payload
Scenario 2	photo voltaic	2,5 km	L(PL)	par	var	par
Scenario 3	photo voltaic	20 km	L(PL)	par	var	par

Table 5.4: Main mission parameters of a mid duration mission with photo voltaic as energy source; the HAP length is calculated dependent on payload L(PL) for varying (var) wind velocity and mission duration as mission parameter (par)

Energy system concept: The energy system is based on solar arrays and rechargeable batteries (figure 5.5). As mentioned before the flight is done during day time and therefore the solar arrays are the main energy system component to convert solar radiation into electrical energy and provide this power to the consumers.

The main energy consumers are the electrical motors of the propulsion system to generate

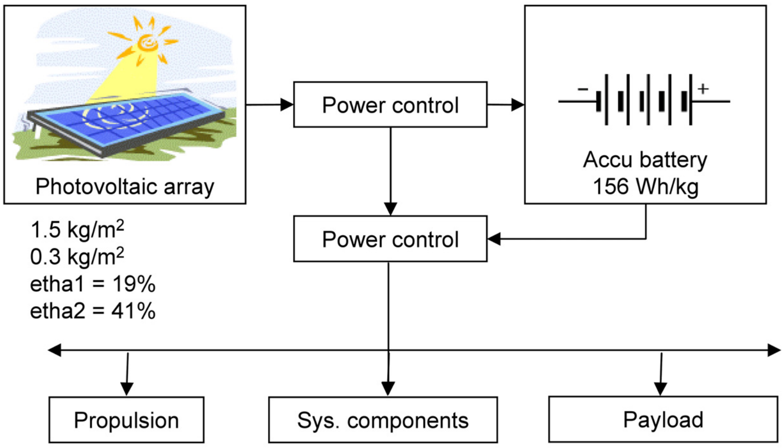


Figure 5.5: Energy system concept for a mid duration mission based on photo voltaic

enough thrust to overcome wind speeds in target altitude during mission duration. We will use two different type of solar arrays. One is a conventional solar cell with a specific mass of $1.5kg/m^2$ and the other one is a thin film solar cell with $0.25kg/m^2$. Both have an efficiency of about 19%.

Dependent on the energy consumption of the propulsion and system components, the total necessary area for the solar arrays is determined, which is the visible projection surface. Since the upper surface of the segments have the form of a cylinder, the installable solar array area is $\frac{\pi}{2} = 1.57$ time greater than that of the calculated projection area. This has an adverse effect on the mass development, because it is also factor $\frac{\pi}{2} = 1.57$ greater than the mass of solar arrays of projection area. Thus it means that because of higher mass, the center of gravity also climbs upwards and occur instable roll moments so that it causes risk of rolling the HAP up side down. In order to prevent these additional weights in form of batteries, payloads or system components have to be integrated, so that the center of gravity is below the point of $D/4$ (see also figure 3.17). Only the position of CG below the $D/4$ is a stable position which allows a flight free of disturbing roll movements. It has to be mentioned here that only designs with CG below this point are considered as valid designs. All other designs are not permitted.

A further design aspect which has to be considered is that the solar arrays are installed on the upper surface of the mid three segments. Thus the necessary area of solar array and the available surface area of the segments is balanced against each other in order to check whether the segments provide enough area to carry the solar arrays.

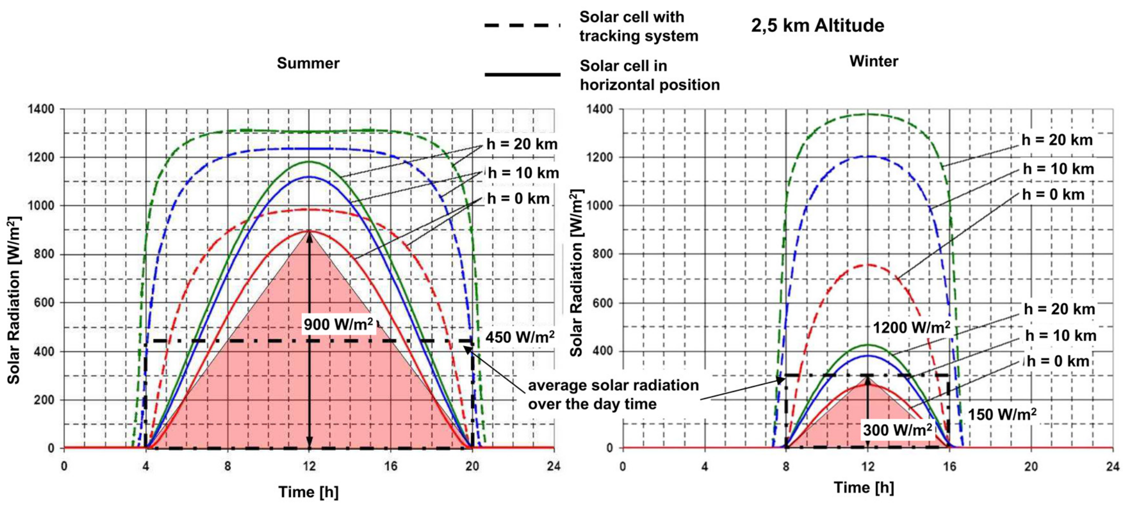


Figure 5.6: Solar Radiation in 2500m altitude for summer and winter [59]

For the flight during night phases we add batteries to compensate demand of electrical power.
We desire a flight in low altitude of about 2500m and in high altitudes of 20km and in both summer and winter seasons. For all cases the solar radiation varies significantly and has to be considered separately within the design task. Figure 5.6 presents the solar radiation in 2500m altitude [59]. The peak for summer time is $900 W/m^2$ and a day light duration of 16h, thus a mean solar radiation during the 16h is $450 W/m^2$.
For winter we have only one third of the peak radiation and only half of the day light

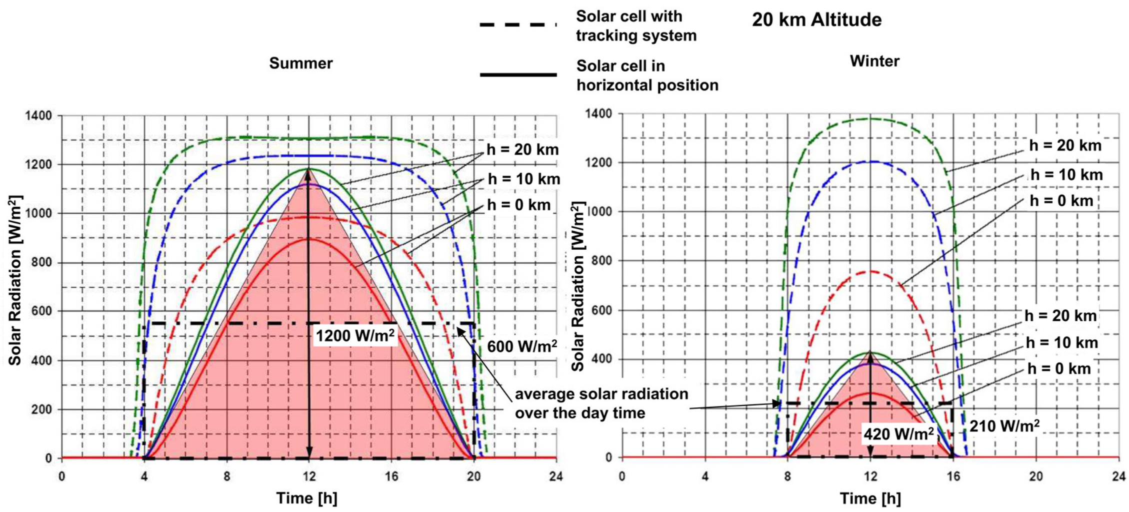


Figure 5.7: Solar Radiation in 20000m altitude for summer and winter [59]

duration, thus a mean radiation of $150 W/m^2$ is determined during the 8h of winter time.

With an efficiency factor of 19% we achieve a power for summer $85.5W/m^2$ and for winter $28.5W/m^2$.
Same calculations are done for the flight in 20km for summer time as well as for winter time [59] (figure 5.7). The flight in 20km altitude has an advantage over the flight in 2500m that there is a dryer air which means that there are no weather activities such as cloud formation which can cause shadows and inhibits electrical power production. We achieve $120W/m^2$ in summer months and $39.9W/m^2$ in winter.
Other factors which influence the power generation with solar arrays are the latitude ϕ of flight which will be between $\phi = 30°$ and $\phi = 50°$ for flight over Northern Europe and America. Time of year is the declination angle δ of the earth. The time of day is measured by the solar elevation angle θ relative to the surface. The atmosphere attenuation τ is assumed to be very low.

5.2.1 Mission Scenario 2

Energy source: Solar array + Batteries; H = 2.5km varying wind speed, PL and duration

In the mission scenario 2 we analyze the performance of a LTA HAP with 5 segments in an altitude of 2,5km. As mentioned before the mission is characterized by the type of on board energy system, namely photo voltaic arrays. Together with some buffer batteries they produce electrical energy for the propulsion system. The flight takes place during day time to utilize sun light for the production of electrical energy. For this purpose we will vary wind speed, flight duration and payload and determine for each design point the minimized size of LTA HAP for a flight in an altitude of 2500m.
As mentioned before we have a mean wind speed and a mean solar radiation over a period of 12h during day time. This means that the power consumption (constant mean wind speed) and power production (constant mean solar radiation) have a constant mean value over 12h during day time. Therefore the size of energy and propulsion system have a size dependent on these parameters which is constant over 12h independent from duration.
The results are presented in figure 5.8 containing three diagrams. The first diagram presents a design area for wind velocities of $5\frac{m}{s}$ restricted by several constraints.

- duration: $12h \leq t \leq 24h$
- center of gravity: $CG \leq \frac{D}{4}$
- payload: $PL \leq 3000kg$

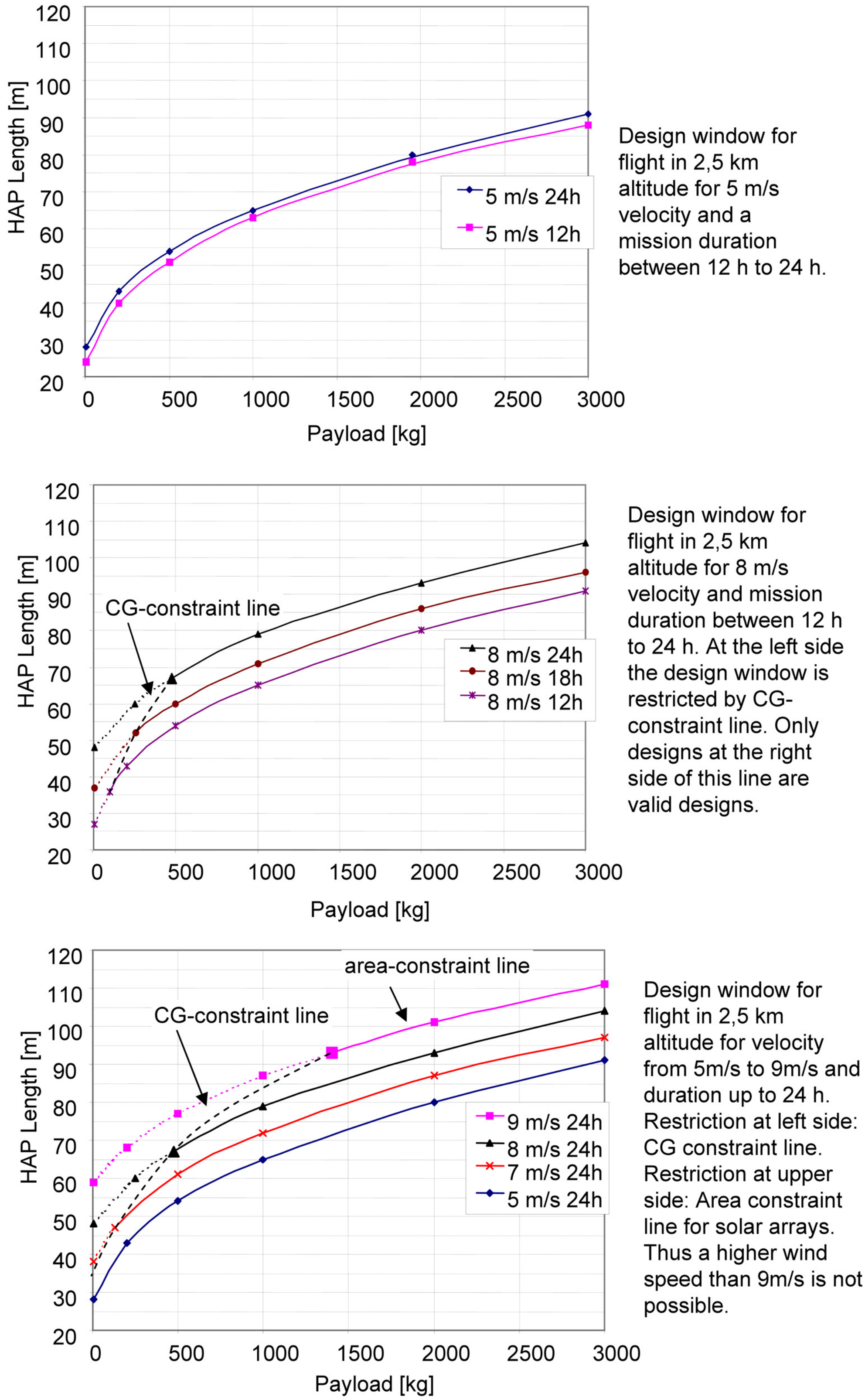


Figure 5.8: HAP-Mission in 2500m altitude with solar cells and accumulators for different payloads PL, wind speeds v and durations t

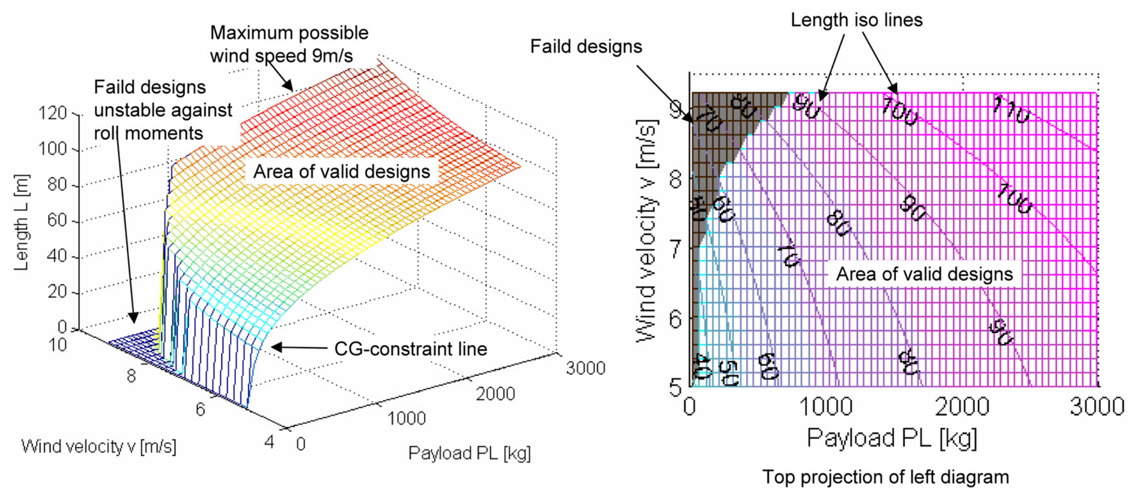


Figure 5.9: HAP-Mission in 2500m altitude with solar cells and accumulators for varying payloads PL, wind speeds v and a duration $t \geq 24h$

By this way we obtain a design window containing all valid designs. The designs for 12 h duration have mainly solar arrays as electrical energy provider. Above this line batteries are added to enlarge the mission duration up to 24h. The second diagram presents a design window for wind speed of $8\frac{m}{s}$. As it is recognizable the area is restricted by a CG-constraint line at the left side. All designs at the left side of this line are invalid designs because they are instable against roll moments.

The third diagram presents a design area valid for different wind speeds but for durations up to 24h thus a regenerative energy system. The minimum wind speed is 5 m/s according to the mean wind speed for summer months. A further restriction is the wind speed of $9m/s$, since beyond this wind speed the available surface area is not enough to carry the necessary solar arrays, since the available surface area is smaller than the required surface area for installation of the solar arrays.

Figure 5.9 presents the design surface in a three dimensional diagram. All designs lying on this surface are valid designs. All invalid designs which are instable against roll moments are presented in the gray area.

Figure 5.10 presents diagrams corresponding to the design surface. There we have the area of solar arrays and their mass as well as the mass of batteries. E.g. we pick out a design point for a payload of about 700kg, for which a HAP length of L=90m is required with a maximum velocity of 9m/s. For this design point solar area with $300m^2$ and a mass of 750 kg as well as batteries with a mass of 1000kg are required.

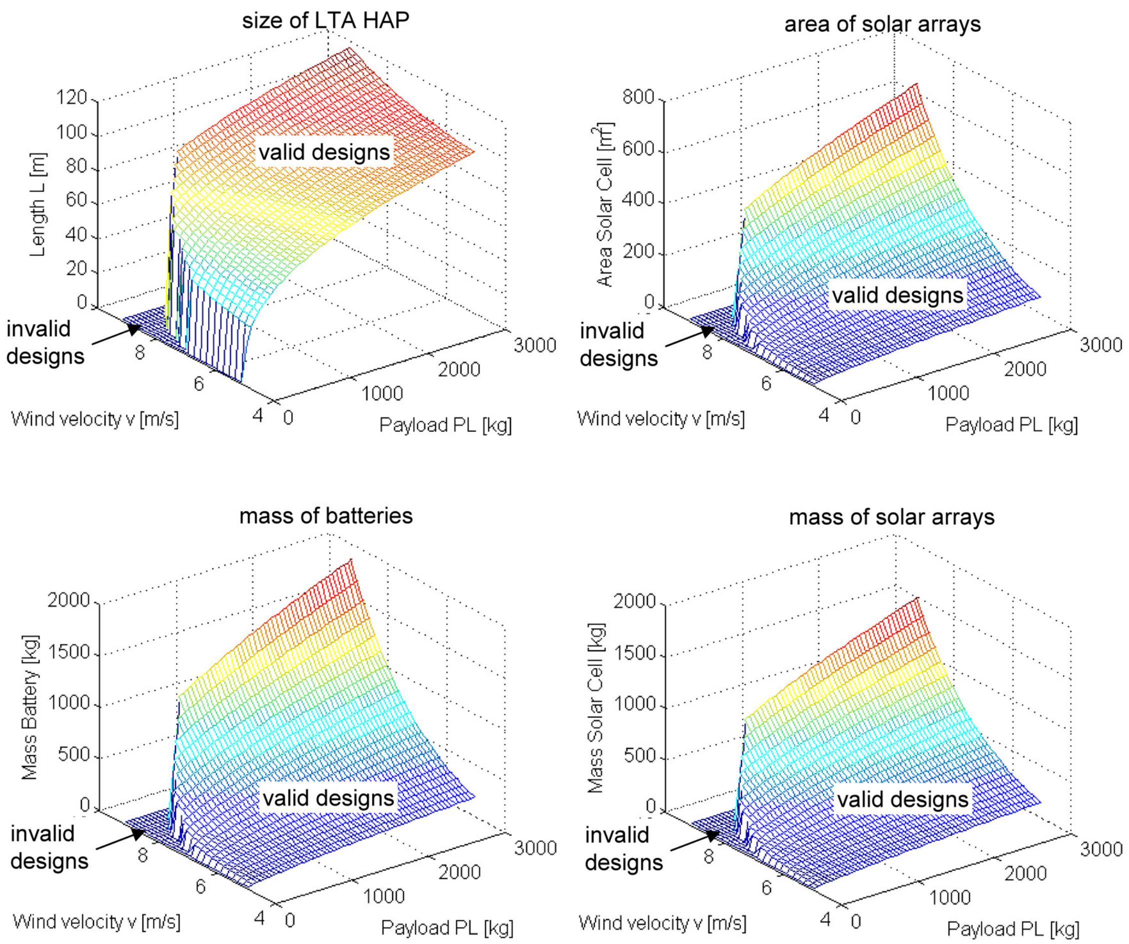


Figure 5.10: HAP-Mission in 2500m altitude with solar cells and batteries as energy source for varying payloads PL, wind speeds v and a duration $t \geq 24h$; diagrams displaying area and mass of solar arrays as well as mass of batteries for same mission

5.2.2 Mission Scenario 3

Energy source: Solar array and batteries; H = 20km varying wind speed and payload; $T \geq 24h$

In mission scenario 3 a design analysis is performed for altitude of 20km by varying payloads, wind velocities, durations and following restrictions:

- duration: $t \geq 24h$
- center of gravity: $CG \leq \frac{D}{4}$
- payload: $PL \leq 2000kg$

As mentioned before the power generation during daylight is constant because of mean solar radiation and the power consumption is also constant because of mean wind speed over 12h, so therefore the size of LTA HAP during day light of 12h is independent from the duration and is hence constant.

The results of the analysis are presented in figure 5.11. There we have the design surface

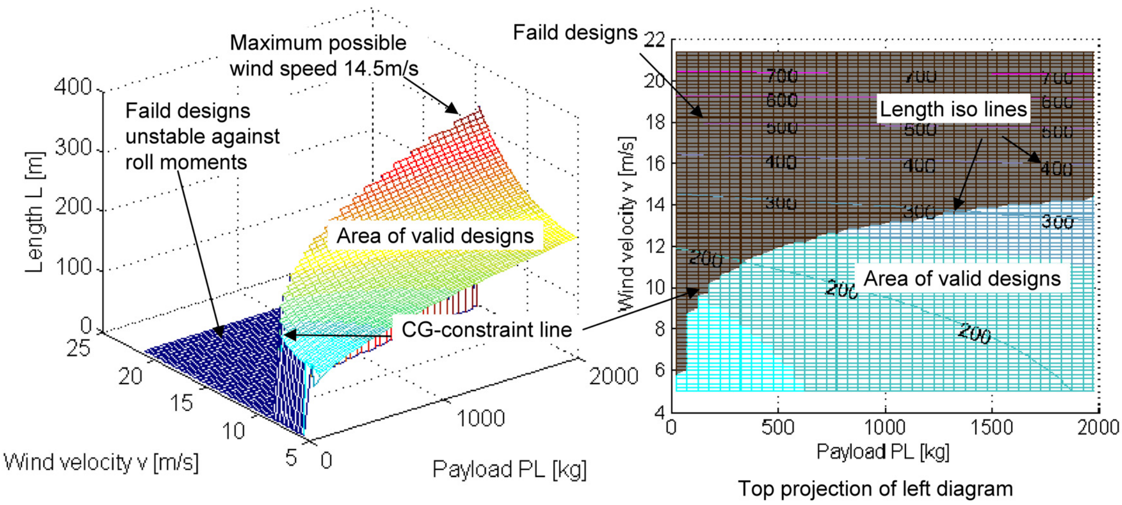


Figure 5.11: HAP-Mission in 20000m altitude with solar cells and batteries as energy source; solar array: η=19% and 1.5 kg/m^2; battery: 156 Wh/kg

with all valid designs. The design window is restricted at the left side from the CG-constraint line. Only designs on the right side of this line are valid all other design points at the left side are invalid designs. At the upper side the restriction is determined by the wind speed of $14.5\frac{m}{s}$. Above this velocity of wind the area of solar array is greater than the available area on the upper surface of the segments.

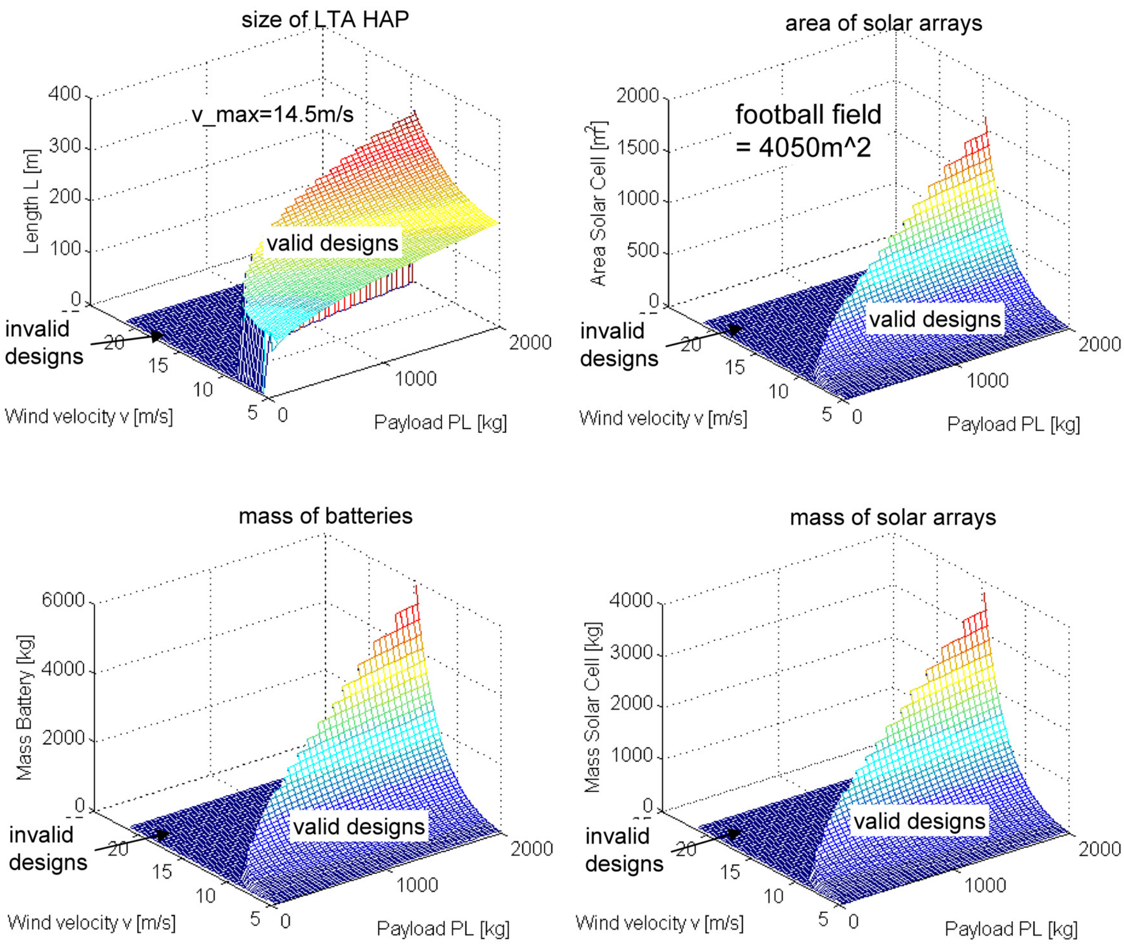


Figure 5.12: Diagrams of mass and area of solar array and battery mass for HAP-Mission in 20000m altitude with solar cells and battery as energy source

In figure 5.12 corresponding diagrams of mass and area of solar arrays as well as mass of batteries are presented. For a maximum wind velocity of 14.5 m/s a solar area of $1500m^2$ is required which has a mass of 4000kg. The corresponding mass of batteries is 6000kg.

5.3 Long Endurance Mission; Energy Source: Solar-Fuelcell System

In this section we will present the next two design scenarios of LTA HAP for analyzing a long duration mission. As mentioned before the characteristic of such a mission is the type of on board used energy system. Since the main limitation factor of a HAP mission is the amount of on board energy available for the propulsion system we will use a solar fuelcell as an energy source for a long duration mission. The solar-fuelcell system has the ability to collect electrical energy by photo voltaic arrays during day time and store one part of this energy with help of an electrolyzer-fuelcell system for usage during night time. Thus such an energy system concept gains the ability of self regeneration and imparts the mission a capability characteristic of longer than 24 h, even up to unlimited time.
The mission analysis is done for different configurations of LTA HAPs by varying the main mission parameters (table 5.5). The objective is to ascertain the optimized size of LTA HAP by given flight duration in compliance with restriction parameters.

Mission description: The mission is to carry a telecommunication or video payload for a long endurance (many days to weeks) at an altitude of 20km. The LTA HAP has to be able to overcome mean wind speeds for purpose of station keeping task or loitering with a velocity between 5m/s and 30m/s. The design is to be done with a regenerative energy system thus the size of LTA HAP operating one day or many weeks is almost equal.
Table 5.5 presents the main mission parameters used for analysis of the next two mission

	Main Mission Parameters					
No.	Energy system	Altitude	Length	Duration	wind velocity	Payload
Scenario 4	solar hydro	2,5 km	L(PL)	> 24h	par (5 - 30m/s)	var
Scenario 5	solar hydro	20 km	L(PL)	> 24h	par (5 - 30m/s)	var

Table 5.5: Main mission parameters of a long duration mission with solar-fuelcell as energy source, the wind velocity and payload are mission parameters (par), the length L(PL) is dependent on payload mass PL, which is variable (var)

scenarios of the long duration mission.

Energy system concept: The energy system is a regenerative energy system concept with solar cells, electrolyzer, fuel cells and a small pack of batteries (figure 5.13). The photo voltaic arrays collect solar energy during day time and provides the electrical consumers with electrical energy. One part of the electrical energy is stored with help of the electrolyzer-fuelcell system. Therefore the electrolyzer is fed with electrical energy

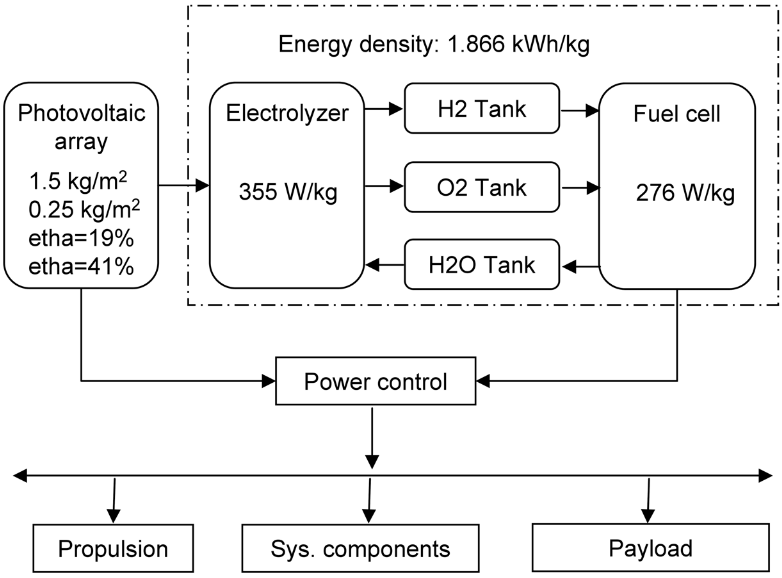


Figure 5.13: Energy system concept with photovoltaic arrays to produce electrical energy and electrolyzer fuel cell combination for storing electrical energy for usage during the night phases

and decomposes water into its elementary particles such as hydrogen and oxygen gasses. These gasses are then stored into tanks for usage in fuelcell reactors to produce electrical energy for night phases. Within the fuel cell hydrogen and oxygen gasses react to water by producing electrical energy.

The hydro fuelcell system has an energy density of $1.866\frac{kWh}{kg}$. In comparison to the battery as energy storage system with $156\frac{Wh}{kg}$ it is about 11 times lighter.

5.3.1 Mission Scenario 4

Energy source: Solar-fuelcell system,
altitude: H=2.5km, duration $t \geq 24h$

In mission scenario 4 a long endurance mission is calculated for flight in 2,5km altitude and the results are presented in figure 5.14. The calculations were done for varying wind speeds and payloads. Starting from a minimum wind speed of $5\frac{m}{s}$ we arrive at a maximum wind of speed of $9\frac{m}{s}$. Above this wind speed the segment surface area is not big enough to integrate the required solar array area. At the left side we have the restriction of CG-constraint line, only designs at the right side of this line have a center of gravity below the stable point $\frac{D}{4}$ (see also figure 3.17. Thus all valid designs lying at the right side of the CG-constraint line are stable against roll moments.
For 3kg payload and velocity of 5m/s we have a HAP length of about 30m. As it is observable that because of the CG constraint line missions with higher wind speeds are only possible by integrating larger payload. E.g. for 9m/s only missions above 88m HAP length and 1600kg payload are possible.

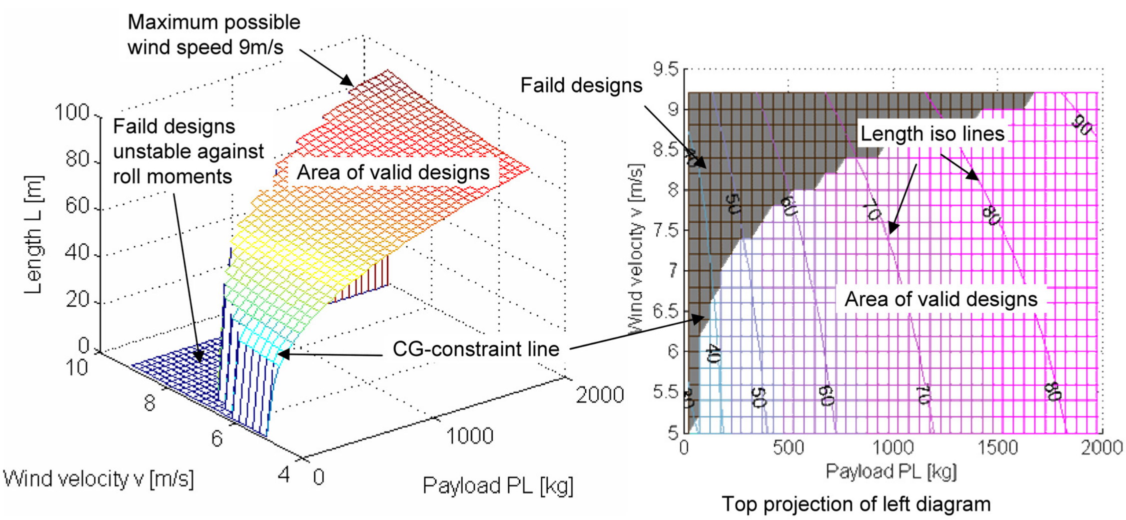


Figure 5.14: HAP-Mission in 2500m altitude with a regenerative solar fuelcell system; solar arrays: $1.5kg/m^2$, fuelcell: 1866 Wh/kg and duration $t \geq 24h$

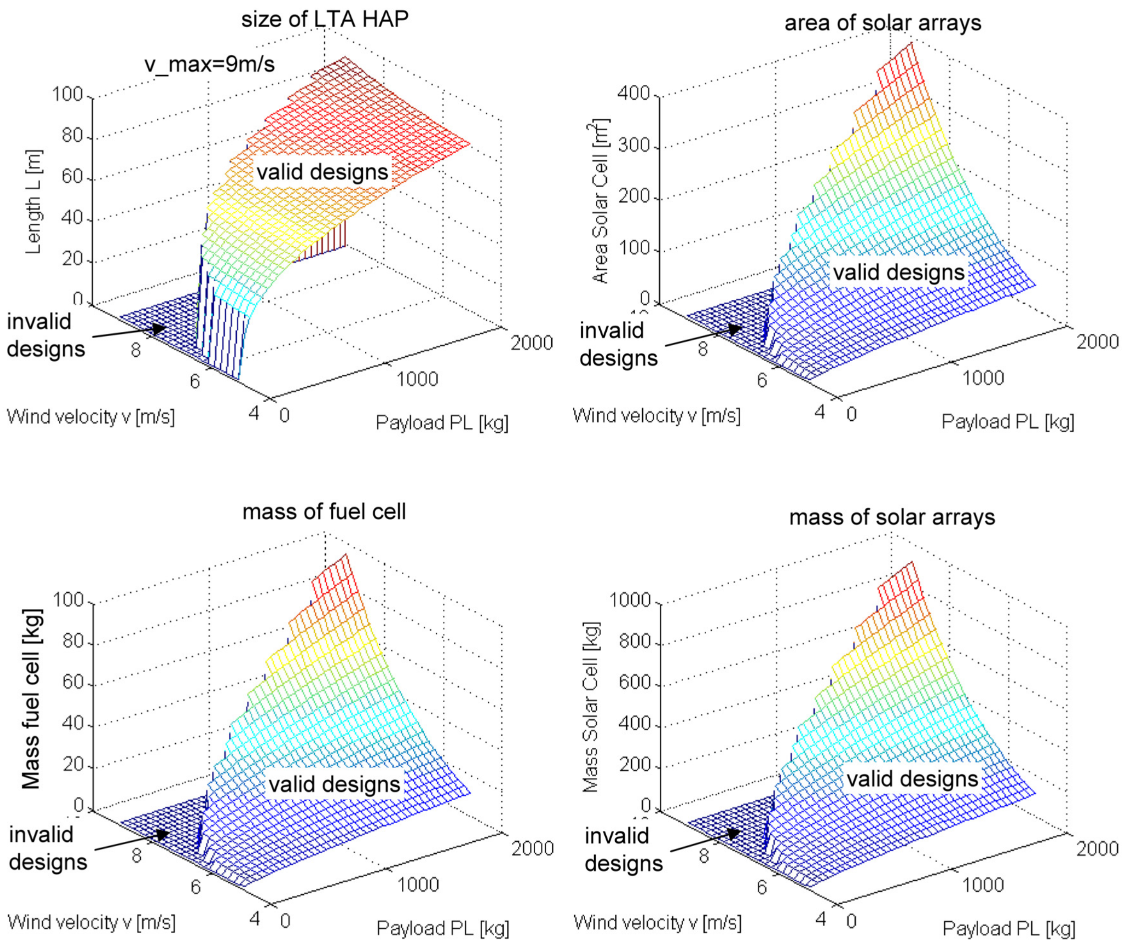


Figure 5.15: Diagrams of area and mass of solar arrays and fuelcell mass for a HAP-mission in 2500m altitude with a regenerative solar fuelcell system and duration $T \geq 24h$

In figure 5.15 the corresponding diagrams of area and mass of solar cells as well as the mass of batteries are presented. The one example design point is valid for 1600kg payload and v_max of $9\frac{m}{s}$. There is a solar area surface of about $300m^2$ with 900kg mass and the fuel cells have a mass of about 90kg. These values can be handled well but the design allows only a v_max of $9\frac{m}{s}$.

5.3.2 Mission Scenario 5

Energy source: Solar-Fuelcell system, H=20km and duration $t \geq 24h$

In mission scenario 5 a long endurance mission is calculated for flight in 20km altitude and the results are presented in figure 5.16.
Following restrictions are considered:

- duration: $t \geq 24h$
- center of gravity: $CG \leq \frac{D}{4}$
- payload: $PL \leq 2000kg$
- area balances: $A_{SegSA} \geq A_{SA}$

There we have the design surface with all valid designs and the invalid designs are restricted by the CG-constraint line. With the used technology a v_max of up to 12m/s is possible.

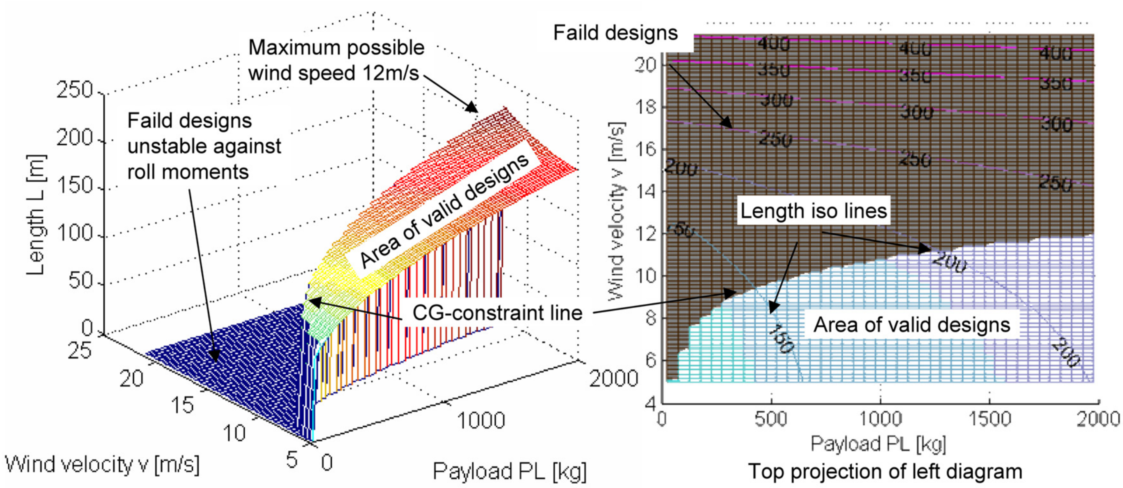


Figure 5.16: HAP-Mission in 20000m altitude with a regenerative solar-fuelcell system; solar arrays: $1.5kg/m^2$ and fuelcell: 1866 Wh/kg

As it is visible, in regard to integration of solar cell on the top of the LTA HAP surface there is enough potential so that velocities of up to 22m/s are achievable. But because of the heavy mass of solar cells only velocities of up to 12m/s for a payload mass of 2000kg are achievable. For a payload mass of 500kg only a velocity of 9m/s is obtained. Above the CG-constraint line all designs lying in the dark area are invalid designs because they are instable against roll moments.

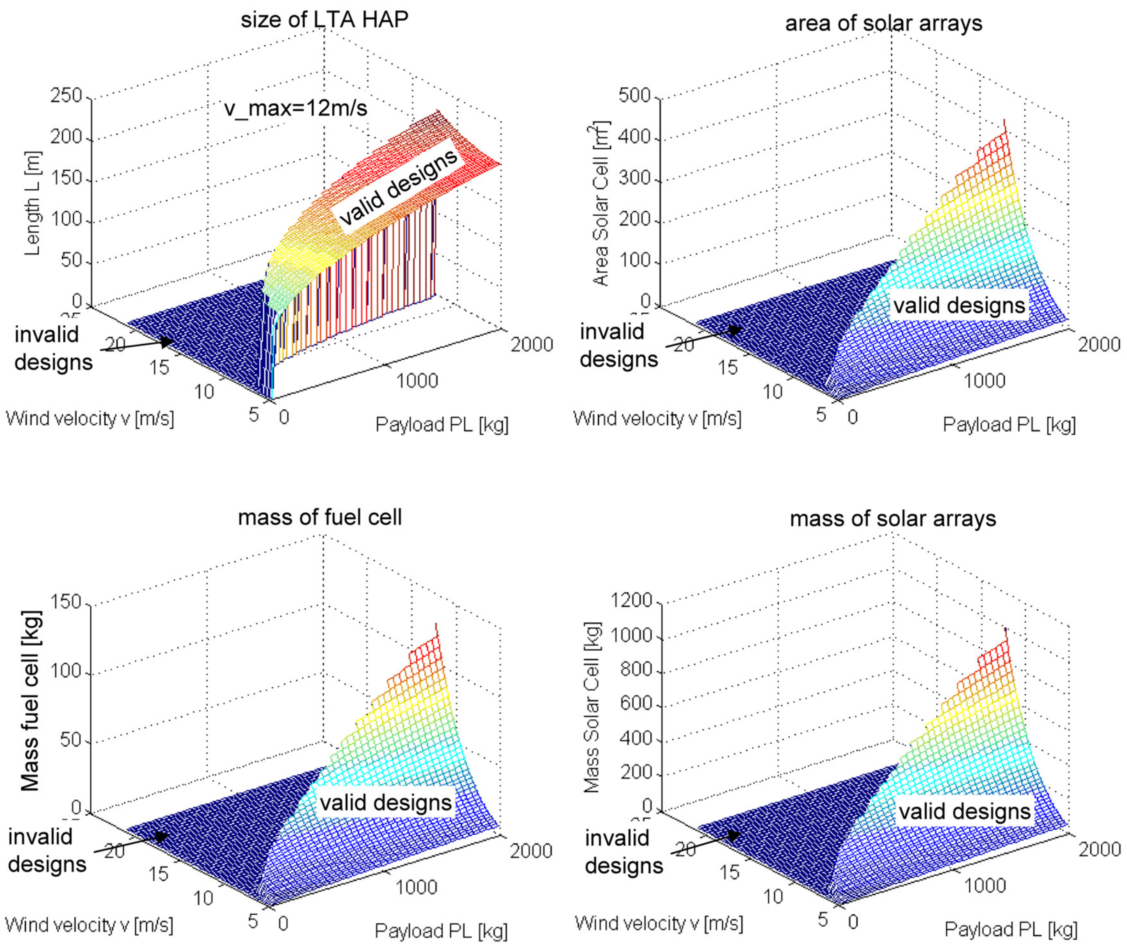


Figure 5.17: Diagrams of area and mass of solar arrays and fuelcell mass for a HAP-mission in 20,000m altitude with a regenerative solar fuelcell system with $T \geq 24h$

In figure 5.17 the corresponding diagrams of mass and surface of solar arrays as well as the mass of fuel cell are presented.

5.4 Comparison and Discussion of the Results

In this section all results of designs are compared and discussed with each other. These are the

- results of designs for flight in altitude of 2.5km and
- results of designs for flight in altitude of 20km.

Our object of investigation the chain-body LTA HAP was modelled within the method of graph grammars (see chapter 3). Altogether many hundred optimal variants were generated for 5 different type of mission scenarios and three different concepts of energy systems:

1. accumulator batteries
2. solar array and batteries
3. solar-fuel-cell system

Thus the aim of comparison of the obtained variants is to investigate the design space for feasible designs.

The calculated mission scenarios are described and discussed by comparing the result diagrams with each other. The missions described here are long endurance missions within the summer months which can persist over many days or weeks. Therefore solar cells are used as energy source in combination with electrical storage such as batteries or fuel cells for shadow and night phases, as well. The solar arrays and energy storage system are designed in a variable manner so that their impact on the formation of the design space is investigated to that fact. A closer look at the design space diagram reveals that the design space is delimited by four different types of constraint lines which induce to a restricted design window within the design space. Only design points lying within this design window are valid designs according to mission requirements.