4 Building Design Variants and Alternatives

In this chapter the graph grammar based object oriented design model developed in the chapter before is used to generate design variants and alternatives of the individual disciplines. The aim is in fact to demonstrate the performance of the model within each discipline by varying the main design parameters. Following disciplines are considered for building variants and alternatives:

- envelope configuration,
- power and energy system,
- propulsion system,
- system integration and multi criteria optimization of power network.

Each design was generated by executing a set of rules from the grammar illustrated in chapter 3. By this way the design engineer gains freedom of analysing not only one design point of LTA HAP design but a bigger design space spanned by the specific design language.
For this purpose a set of rules is put together to a production system which generates a graph of each variant. Thus each modification of production system generates an alternative graph.
Figure 4.1 presents schematically a set of rules (production system) of the graph grammar based design model. By executing these groups of rules a graph is maintained which is a formal representation of each variant. The initial rules are called axiom of the production system followed by 5 groups of rules the so called programs (P1 - P5). In this case the axiom specified the basic topology of the desired LTA HAP containing some initial parameters, such as number of segments, mission altitude, average wind speed and several other mission requirement parameters. The subsequent programs are then responsible for detailed design of individual domains.

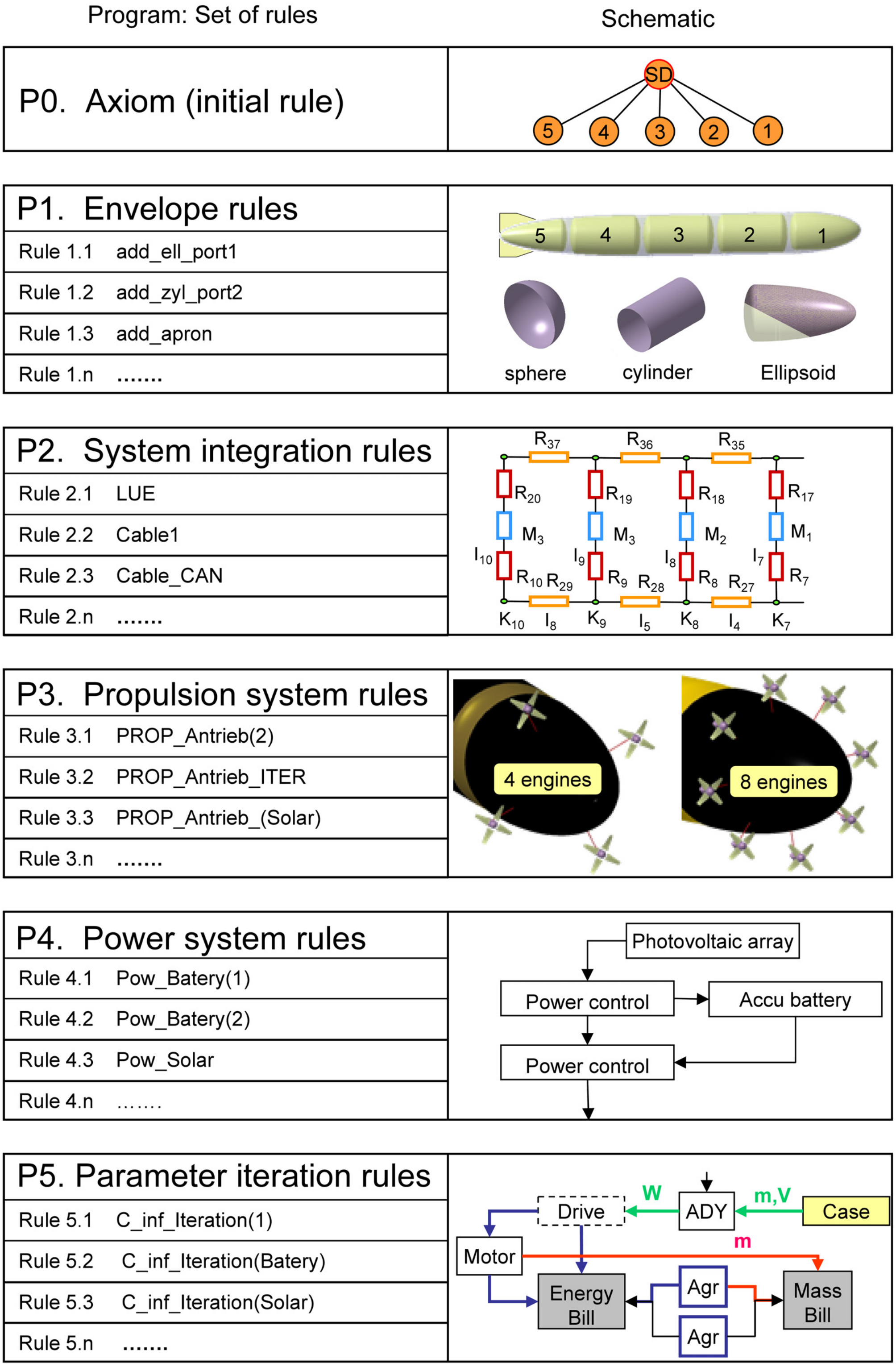

Figure 4.1: Programs (groups of rules) within production system of a graph grammar based design model

Program 1 facilitates layout of the envelope structure. The necessary design knowledge is encoded within the rules of this program. As afore mentioned it can be of any kind such as mathematical equations, physical formulas or in form of geometrical information. Some of the rules must have a specific order, others can be executed arbitrarily. The modification of parameters and exchanging the rules within the programs leads to generation of design variants such as parametrical and topological nature. Number of rules within a program is not fixed but varies for each HAP configuration. There are basically five domains essential for design of the overall HAP as presented in the production system of figure 4.1.

There are several other domains which are not explicitly separately presented but integrated within these programs. For instance the aerostatic and aerodynamic calculations are integrated in program P1 but the results are used in almost every calculation of other domains. Thus these programs are not isolated cells but forms a network of complex connections within a compound of graph nodes.

Program P2 is executed for system integration and calculation of the wiring harness. Design rules within P3 are explicitly used for layout of the propulsion system whereas the power system is designed within P4. Program P5 includes rules for the overall design of LTA HAP by multi disciplinary parameter variation.

In the following sections we will discuss the programs of the production system individually and will emphasize the possibilities the design model provides for building design variants and alternatives.

4.1 Envelope Configurations

Layout of envelope is one of the initial and major tasks within LAT HAP design. Basic configuration we choose for our LTA HAP is a multi segment body where segments are building a row of chain (figure 4.2). This is the significant difference to a conventional airship with only one segment. Here the envelope is devided into many chambers which are connected to each other within a row. The advantage of this concept over conventional airship concept is the reduction of

- buckling,
- differential load,
- munk load and
- static load.

Thus structural mass can be reduced by dividing the gas chamber into smaller independently suspended gas compartments. To compensate the destabilizing moments (munk

load) of a conventional airship large empennages are necessary which create there self bending moments. Also the static mass of the loads and the empennage generates a static bending moment. These loads are almost zero for chain body LTA HAP. The chain body LTA HAP do not need large empannages but only small stabilizers for flights in high altitude.
The number of segments is usually five but varies depending on the task. Buoyancy is generated by helium gas thus it is distributed over the number of segments. The main

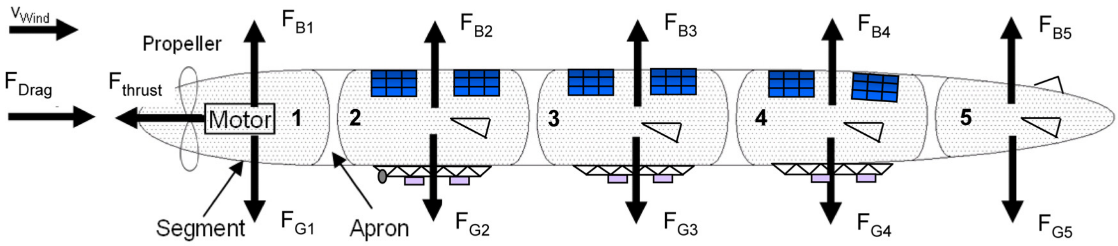

Figure 4.2: Structural configuration of LTA HAP: distribution of buoyancy forces and aerodynamical drag

task of structural configuration is to find a layout which fulfills the mission requirements. Thus it should carry the payload, system components, power and propulsion system to the desired altitude. The configuration should also have favourable less aerodynamic drag in order to reduce the mass of propulsion system and to enhance mission duration.
As presented in figure 4.2 buoyancy force of each segment is equal to total mass of each segment whereas the thrust force is equal to the total aerodynamical drag of the LTA HAP (equation 4.1, 4.2).

$$\sum_i Fx_i = 0 \rightarrow F_D = F_T \tag{4.1}$$

$$\sum_i Fz_i = 0 \rightarrow F_{B1} = F_{G1} \quad \cdots \quad F_{Bi} = F_{Gi} \tag{4.2}$$

Thus by a given mass of payload and of system components and the average wind speed the size of segment and propulsion motors can be calculated. By increasing the wind speed the drag rises and higher motor power is required for station keeping tasks. A larger motor means higher total mass and consequently a bigger segment size and therefore a bigger envelope mass and because of a bigger segment volume a bigger aerodynamic drag. However the size of the envelope has to be optimized incorporating all other domains of the HAP.
The parametrical and topological configuration of the envelope structure of the LTA HAP is done in P1 of the production system. Figure 4.3 presents the configuration process of the LTA HAP with program P0 and P1. The basic topology and the initial main parameters are defined within the axiom. Also the atmospheric model and the requirement list is defined

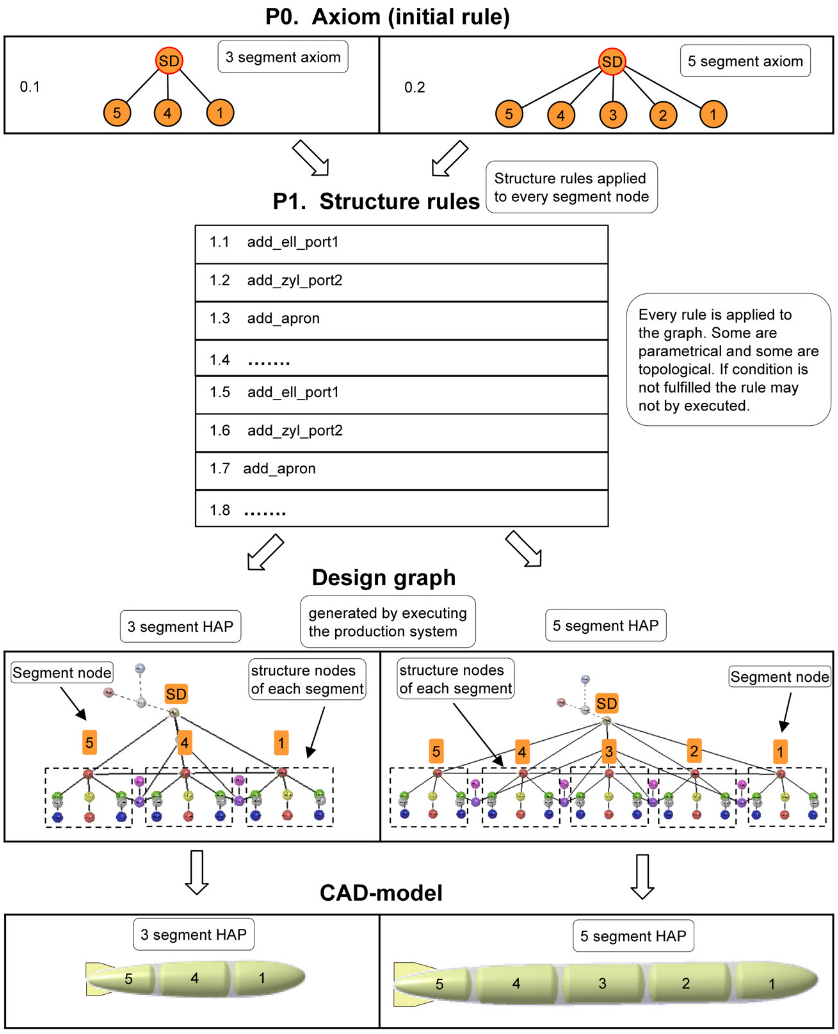

Figure 4.3: Programs P1 for structural layout of a LTA HAP

within the axiom. All the parameters are fed by initial values independent from intention of establishing a model for analysing only one design point or for purpose of sensitive analysis. Here program P0 contains two different axioms for two different topologies of 3 segment and a 5 segment axiom. P1 contains a set of rules compiled from the predefined rule library. Dependent from the chosen axiom two different design graphs are generated. Each one is a formal domain independent representational form of the specific LTA HAP. On this stage it contains all information concerning structural configuration of the HAP envelope. As shown in the figure the graph allows even the derivation of the CAD-model for visualization purposes.

By this way the mightiness of the graph grammar is made much clearer: A program needs an axiom as a starting condition followed by a set of rules. This program can be executed to achieve a specific topological configuration. For purpose of variation of the envelope we use a set of rule which we combined it with two different axioms. Thus within two programs the same set of rules is used but with two different starting conditions. As expected the two results are also different. Since we achieve two topological different configurations of LTA HAP with same set of rules but two different axioms. Thus by this way a large number of variants can be generated by only modifying either the axiom or any rule within the set.

4.1.1 Design Variants by Topological Modifications

In this section we will demonstrate potentials of the developed design model concerning generation of variants by applying topological modifications to the envelope structure. Possible topological modifications are encoded within the predefined rules. By executing these rules an existing graph can be manipulated, which is a formal representational form of an envelope structure. By this way the topology of an existing envelope structure can be manipulated by exchanging, deleting or adding new geometrical components.

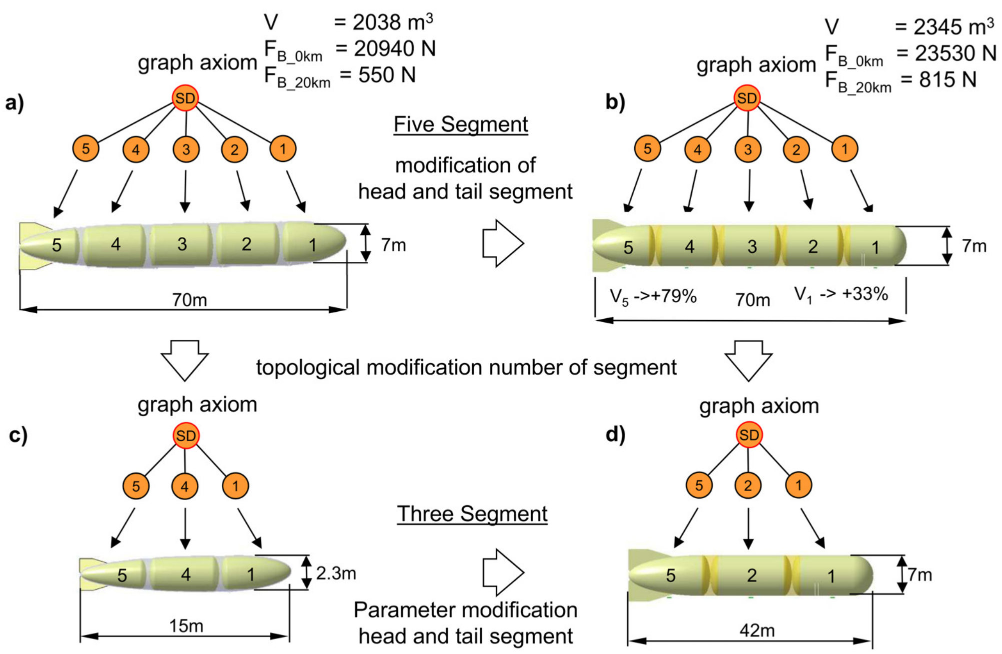

Figure 4.4: Topological variation of envelope of a LTA HAP

Figure 4.4 presents some possibilities of generating design variants of envelope structure. Variant a) is a 70 m HAP with five segments. The head and tail segment are of ellipsoid form. The corresponding graph of the axiom is presented above. It consists of five segment nodes connected with a central HAP node. Comparing the modifications in figure 4.4 means that transition from variant a) to b) means modification of node 1 and 5 which belongs to the tail and head segment. These two segments in b) are more cylindrical than in a) so that they have more volume and therefore a higher buoyancy lift. Further modifications are done to the axiom from a) to c) by subtracting node 2 and 3. Transition c) $\rightarrow$ d) is of parametrical nature whereas transition b) $\rightarrow$ d) is a similar transformation as a) $\rightarrow$ c). Quite as simple we applied parametrical and topological modifications to our HAP model in almost the simple manner we can now analyse the buoyancy behaviour of our LTA HAP. Net lift is dependent from mission altitude as well as from the envelope material. Because the gas containing in the gas cells of segments generates a total buoyancy lift.

Thus the net lift ($Lift_{net}$) is therefore defined as the difference of total buoyancy lift ($Lift_{total}$) and the total envelope and gas cell mass ($M_{env+cell}$) of the HAP:
$Lift_{net} = Lift_{total} - M_{env+cell}$.
There are much more possibilities of varying the envelope structure. By varying the length or number of segments the volume of the LTA HAP is modified which have an effect on buoyancy lift generation. For instance two configurations which generate equal net lift of about 25 kg in 20000m altitude are a 3 segment HAP with a diameter of 6 m and a length of 36m and second a HAP with 8 segments with 5m diameter and a length of 80 m. Furthermore the ratio $\frac{O}{V}$ is $0.8\frac{1}{m}$ for the 3 segment HAP and $1.0\frac{1}{m}$ for the 8 segment HAP. Thus the HAP with lower ratio is preferable. Which means that the HAP reacts very sensitive to ratio $\frac{O}{V}$ in 20 km altitude, whereas in 18km altitude it is not so sensitive.

4.1.2 Design Variants by Parameter Modifications

In this section we will present an analysis concerning parameter modifications of a five segment LTA HAP. The basic analysis tool is still a graph grammar.
Parameters which will remain constant during the analysis are:

- the number of segments: 5,
- envelope material $36g/m^2$,
- gas cell material $26g/m^2$ and
- the ratio of length to diameter $L/D = 10$.

Variable parameters are the altitude, payload and entire length of LTA HAP. For each altitude and HAP length the buoyancy lift is calculated. With this the total mass of the airship is determined. The total mass is equal to the total buoyancy lift generated by the helium gas containing therein.

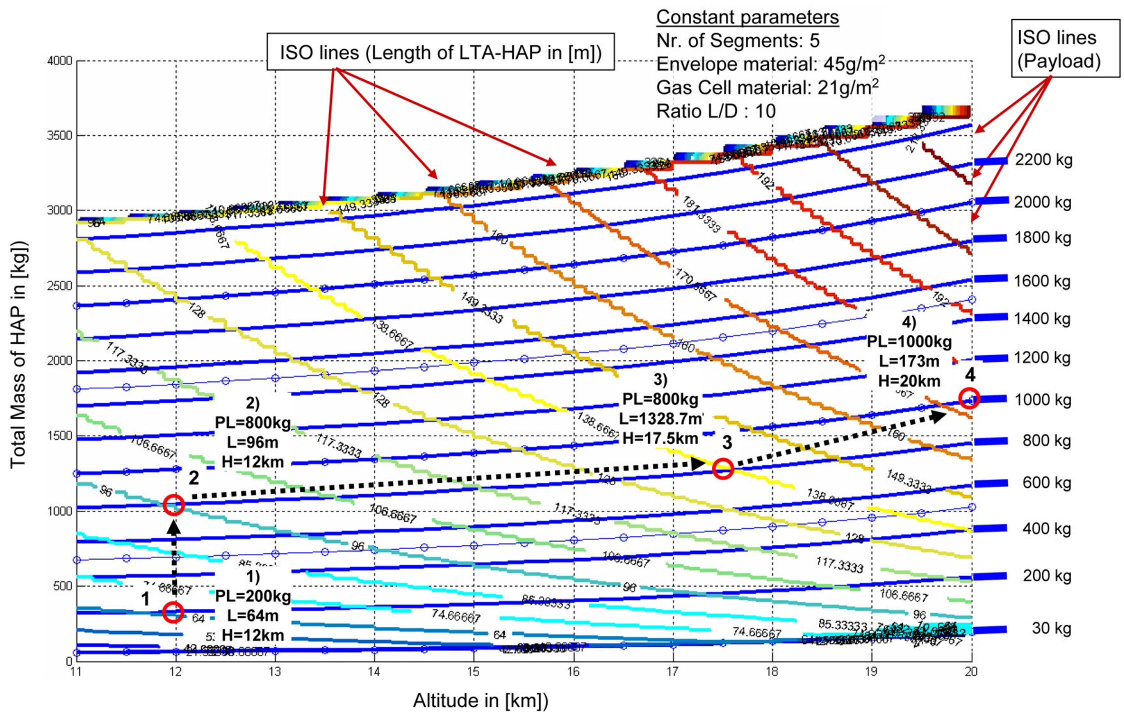

Figure 4.5: Result of sizing the envelope structure by varying parameters of altitude and payload

The results achieved from the calculation are presented in figure 4.5. For a better explanation of the diagram we emphasize four points on the surface. There is the axis of altitude and total mass the enclosed buoyancy gas can carry in the specific altitude. There we have the iso lines of HAP length and the iso lines of payload. Along these lines the HAP length and the payload are constant. Point P1 means a HAP carrying 200kg payload in an altitude of 12km and therefore the required size is of a length of 64m with a diameter of 6.4m. For the same altitude of 12 km we increase the payload to 800kg. Thus the size of HAP increases also to a length of 96m. The third point refers to same payload but for a flight in an altitude of 17.5km. For this altitude the size is of about 138m. For point 4 the altitude is of 20km and the payload is 1000kg, thus the size is of about 173m.

4.2 Layout of Energy System

The design of energy system is one of the complex design problems within the LTA high altitude platform design. As mentioned in chapter before there are much more possibilities for the selection of a feasible configuration of power generation and power storage system.

The main effort by designing such a system with complex dependencies is the basic and constant supply of electrical power to the propulsion and system components to fulfill mission requirements throughout the mission duration.

The design of power system is an iterative process and depends on the operational environment, the day night periods, weather conditions, mission requirements such as duration, altitude, overall electrical power consumption, HAP size etc. Incorporating all these aspects during the design process is well comprehensive.

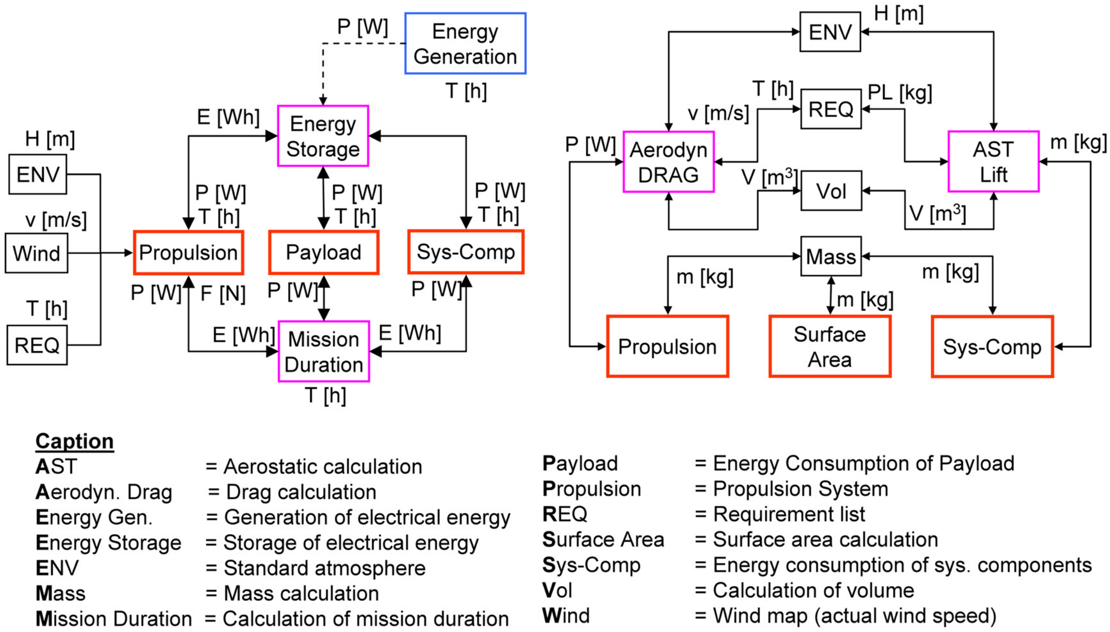

Figure 4.6: Graph of dependency for design of power system

The dependency graph of power system design is presented in figure 4.6. The design depends mainly on the size of the propulsion system which on his part depends on the HAP size, operational altitude and wind speed. The LTA HAP size depends on its part from the total mass of power and propulsion system, as well as from the mass of system components, payload and envelope structure. This problem is solved with the graph grammar based design model by initially estimating the total masses and then iteratively optimizing the three systems to another. We will now present some configurations of power supply system.

4.2.1 Energy system based on accumulator

The basic concept of a battery based power supply is presented in figure 4.7 where power is provided by Li-Ion batteries. A battery cluster consists of a compound of Li-Io-cells which are gathered in such a series and parallel circuit so that a required amount of power voltage and current is achieved. The electrical energy is then supplied by the controller to the consumers. The system components and payload have almost a constant usage over the mission duration whereas the usage of propulsion system is dependent on the velocity of wind at the target altitude.

As mentioned before the design depends on mission altitude, average wind speed and

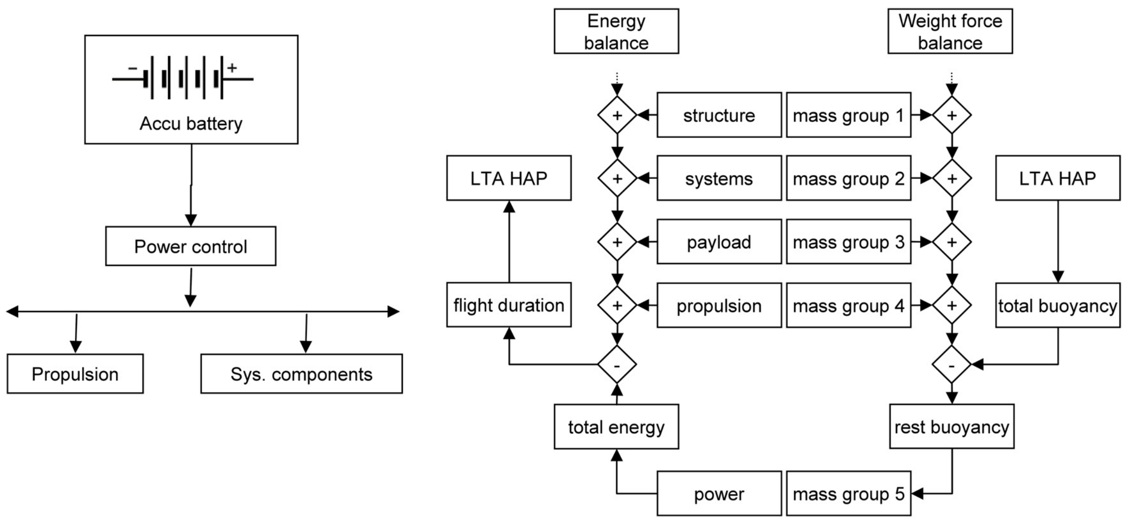

Figure 4.7: Concept of energy system based on accumulator batteries

mass of payload for fulfilling the mission requirements. A higher altitude means a less buoyancy lift. Higher average wind speed means a higher aerodynamic drag and therefore a high powered propulsion system which consumes a lot of limited on board energy. Also a high weight payload means a less buoyancy capacity left for the integration of the battery packs. Non of the three factors is clearly preferable because each of them is rather dictated by the customer or for instance the wind speed depends on local weather conditions.

Figure 4.7 presents schematically steps of designing a battery based power system by the design model. There are four groups of energy consumer and mass units. The structure unit did not consume any energy but presents a significant factor of mass. The propulsion system is one of the main energy consumer and has comparatively a higher mass than the payload and system components. By a given size of HAP the helium gas containing therein generates the total available buoyancy lift. Mass balances delivers a rest buoyancy lift by which the amount of accumulator batteries is determined that could be carried by the rest buoyancy lift of the HAP. Thus the amount of battery cells dictates the total energy

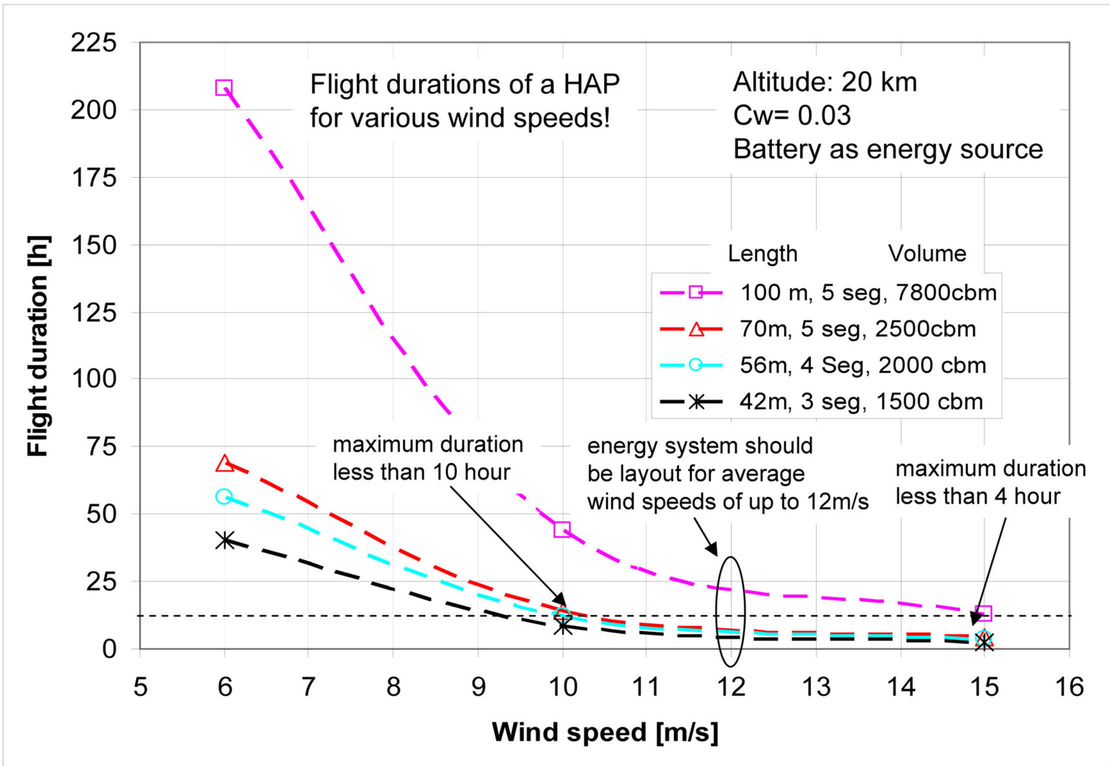

Figure 4.8: Schematic of designing energy system based on accumulator batteries

available on board. And by this dependent on the mean wind speed the maximum mission duration is determined.

As an example a diagram of mission duration over wind speed for 4 different configurations is presented in figure 4.8. The digressive course of the curves is distinctly visible. The mission duration of all configurations decreases exponentially with increasing wind speeds. For a mean wind speed of 10m/s the mission duration is less than 10h. For a wind speed of about 15m/s the mission duration is less than 4h. Which means that for a long duration mission with higher wind speeds such an energy storage system is not sufficient. But for short durations and lower wind speeds it presents an adequate approach.

4.2.2 Power system based on photovoltaic

The basic concept of photovoltaic based power system is presented in figure 4.9. Photovoltaic solar cells have the ability to convert solar energy into electrical energy during the day light hours. It is then supplied by the controller to the on board consumers of a LTA HAP. The system components and payload have an almost constant power consumption over the mission duration whereas the power usage of propulsion system is dependent on the velocity of wind at the target altitude. Thus the size of solar array system depends on the average power demands of the electrical consumers and on the average solar radiation over the day time. To compensate the deviations and power shortages battery cluster are required which can also be expanded to cover the energy demands of the night phases.

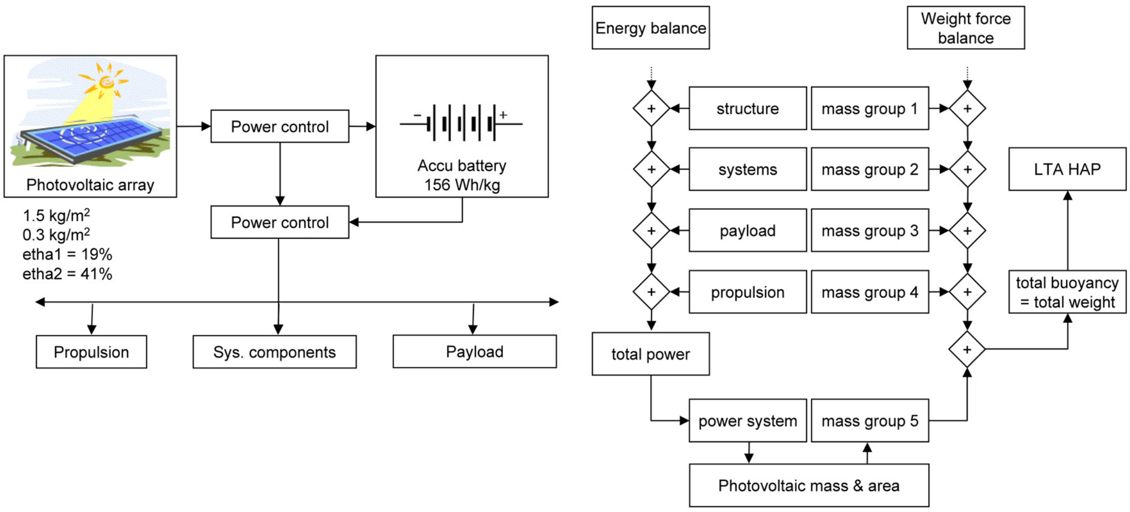

Figure 4.9: Energy system based on photovoltaic arrays and accumulator batteries

A schematic graph for an optimum designing of a photovoltaic based energy system is presented on right part of figure 4.9. There are 4 groups of energy consumers and mass groups. The structure group is the only one with out consuming any energy and presents only a mass unit (mass group 1). The designing process starts with the mass balances of all groups including the mass of energy system with an initial value and determine the necessary buoyancy lift for carrying these loads into the target altitude. If the size is given, than with the rest amount of buyancy the size of power system is calculated with which the mission duration is determined. In case of that the mission parameters including the mission duration are given and the size of HAP is sought, the solution is approximated by itteration steps. For each iteration step energy balances are performed to size the photovoltaic system including area of solar cells and their mass. Since the size of propulsion system is determined to overcome the wind speeds at target altitude and both balances of mass and energy are positive the entire design of photovoltaic based power system is completed.

4.2.3 Energy system based on hydro-solar fuel cell system

An alternative energy storage concept is the usage of an electrolyzer-fuel cell combination system (figure 4.10). The electrolyzer separates water molecules into their constituent components H_2 and O_2 gas which are stored in separate gas tanks. The H_2 and O_2 gas is then used in a fuel cell to generate electricity for power supply during the night hours. The electrolyzer-fuel cell storage system combined with solar arrays presents a regenerative energy system. The solar cells convert during the day light solar power into electrical power and provide over a controller the consumers with energy and at the same time it drives an electrolyzer for separating water into hydrogen and oxygen for energy storage for night time.

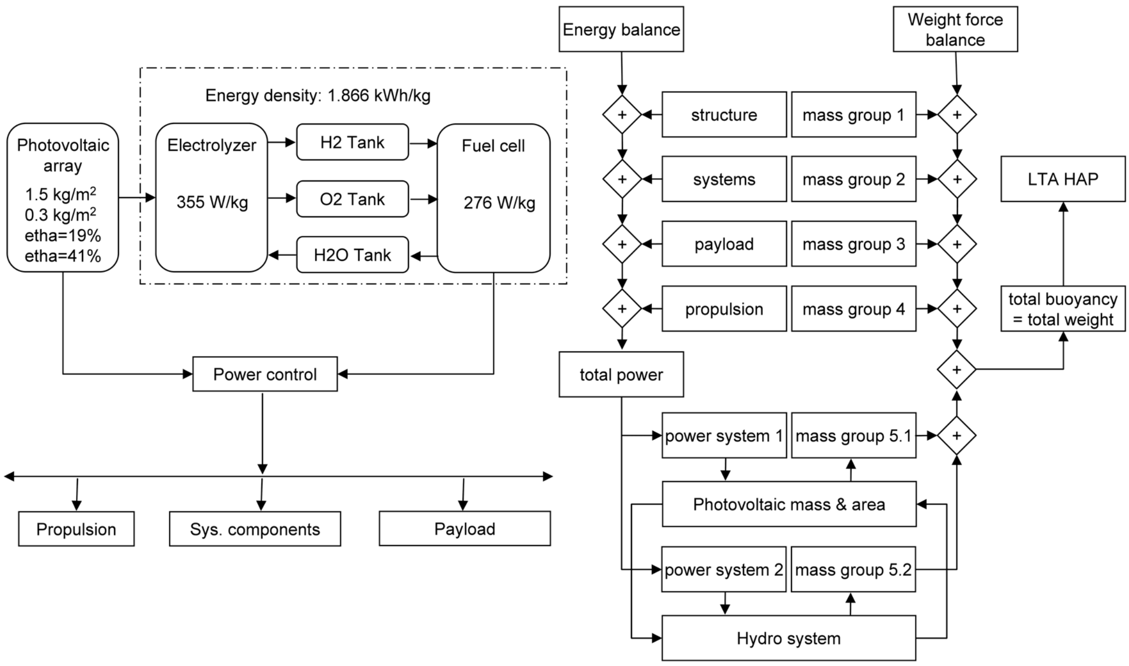

Figure 4.10: Energy system based on photovoltaic hydrogen energy system

A schematic graph for an optimum designing of a solar-hydro based energy system is presented in right part of figure 4.10. There are 4 groups of energy consumers and mass groups. The structure group is the only one with out consuming any energy and presents only a mass unit (mass group 1). The designing process starts with the mass balances of all groups including the mass of power energy system (power system 1 and 2) with an initial value and determines the necessary buoyancy lift for carrying these loads into the target altitude. If the size of HAP is given, than with the rest amount of buyancy the size of power system is calculated. Usually such an energy storage concept of electrolyzer fuelcell is used as a regenerative energy system for long endurance missions. Thus in case that the mission parameters including the mission duration are given and the size of HAP is sought, the solution is approximated by itteration steps. For each iteration step energy balances are performed to size the power system including area of solar cells, their mass and the size of fuel cell. Since the size of propulsion system is determined to overcome the wind speeds at target altitude and both balances of mass and energy are positive the entire design of power system is completed.

4.3 Layout of Propulsion System

Since the design analysis of propulsion system for LTA HAP missions is a well comprehensive task, the model developed on basis of object oriented graph grammar based design language is applied to generate design variants and alternatives of the components of propulsion system. It consists of electrical motors and propellers to produce enough thrust to overcome the velocity of winds in target altitude in order to fulfill mission requirements.

In order to search the design space for feasible designs of a specific mission it is necessary to modify not only the parameters but also the topology of the propulsion. Therefore dependent from the axial drag the necessary power is achieved to select an adequate electrical engine, and with a given specific mass the actual mass of the motor can be obtained. There are many possibilities of designing a propulsion system. Dependent on the power and specific mass the actual size of the engine can be achieved. Furthermore the number of engines can be specified and thus allow to distribute the power over the number of motors.

However a set of specific motors can also be defined for the analysis, so that the determination of engine is not continuously but discrete. Furthermore the propellers can be determined which depends on several factors, such as velocity, efficiency, density of operational altitude etc. Dependent on depth of propeller model, the layout can be atomized within the language, so that by means of decision criterias the number of propeller blades can be determined. Although the form, pitch angle and several other factors of propeller design plays a major roll.

There are a number of parametrical and topological modifications possible by the design model:

- set with different type of motors,
- number of motors,
- position of motors,
- type of propeller blades and size,
- number of propeller blades etc.

Thrust is dependent on the aerodynamic drag produced by moving the whole volume of LTA HAP against the winds. The calculation of aerodynamic drag is made for the speed of worst case. Also the form of LTA HAP and the C_w coefficient plays a major roll for determining the aerodynamic drag. It can be divided into the pressure drag and friction drag coefficient.

$$C_w = C_{w,F} + C_{w,P} \tag{4.3}$$

As described in Hoerner [52] friction drag coefficient $C_{w,F}$ of elongate bodies is about 80% and pressure drag $C_{w,P}$ is about 20% of the total drag coefficient C_w. The friction drag is a function of the Re-Number and is given by the equation:

$$C_{w,F} = \frac{0,455}{lgRe^{2.58}} \tag{4.4}$$

The equation is valid for higher Re-numbers of the turbulence area valid up to $Re > 1 \cdot 10^6$ according to the wett surface area. The Re-number is calculated by the following equation:

$$Re = \frac{v \cdot d}{\nu} \tag{4.5}$$

In equation 4.5 v is the air speed, d the length of the HAP and and ν is the kinematic viscosity.

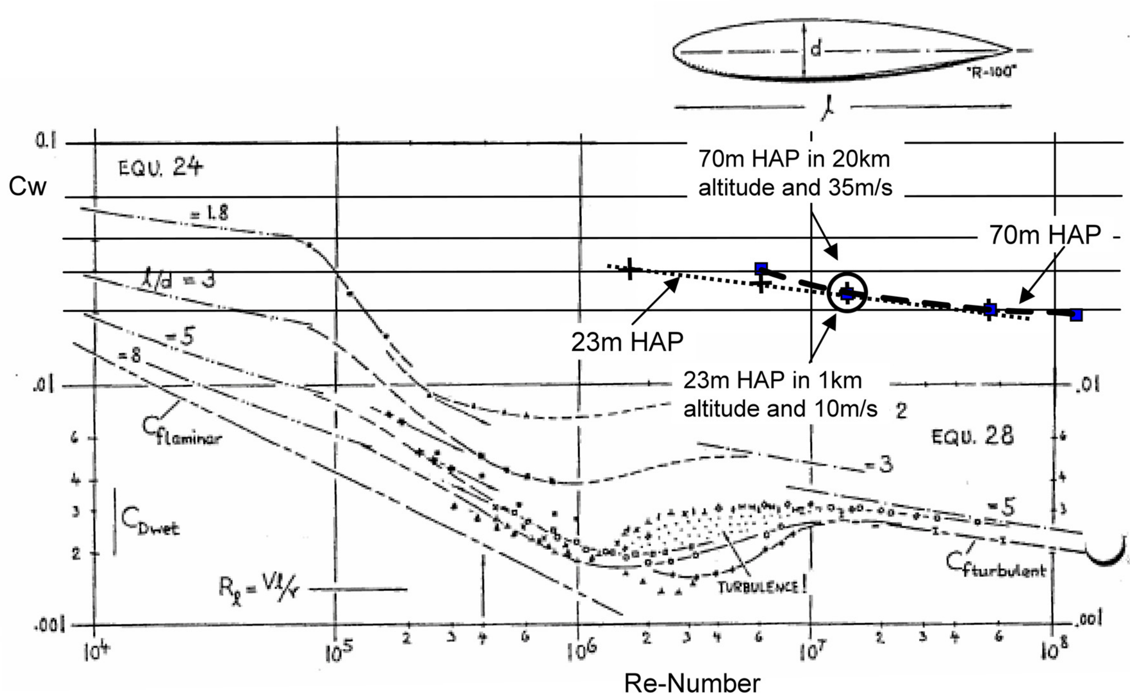

Figure 4.11: Comparison of Re-Number of 70m and 23m LTA HAP, figure from [52]

Figure 4.11 presents the Re-numbers of a 23 m and a 70 m HAP system for altitudes between ground surface and 20 km and wind speeds between 10 and 35 $\frac{m}{s}$. The Re-number for the 23 m HAP lies between 1.4E+6 and 5.5E+7 and for the 70m HAP it lies between 4.4E+6 and 1.7E+8. The X-axis is the Re-number and the y-axis is Cw-coefficient. As it is recognizable the 23 m HAP at ground surface has similar Re-number (1.5E+7) by a wind speed of 10 $\frac{m}{s}$ as the 70 m HAP at 20km altitude by a wind speed of 35 $\frac{m}{s}$. Thus it means that a 23 m HAP is well suited for analysis purposes of the 70 m HAP at target altitude. By this way the Cw-Coefficient can easily be estimated. It lies at about 0.03 according to $V^{\frac{2}{3}}$ (Table 4.1).

Re-Number	Cw			
	friction wetted	total wetted	$V^{\frac{2}{3}}$ 23m	$V^{\frac{2}{3}}$ 70m
1.4E+6	0.0042	0.0053	0.04	-
4.4E+6	0.0034	0.0043	0.03	0.04
1.5E+7	0.0028	0.0035	0.03	0.03
5.5E+7	0.0023	0.0029	0.02	0.02
1.7E+8	0.0020	0.0025	-	0.02

Table 4.1: Cw coefficient dependent from Re-numbers

By this way the aerodynamic drag can be sufficiently calculated by equation:

$$F_D = \frac{1}{2} \cdot \rho \cdot v^2 \cdot Cw \cdot V^{\frac{2}{3}} \tag{4.6}$$

$F_D = F_T$ means that the power of the electrical motors can be calculated by:

$$P = \frac{F_T \cdot v}{\eta} \tag{4.7}$$

In this equation v is the wind speed, η is the efficiency factor. With equation 3.38 the radius of the propeller can be achieved.

The object oriented graph grammar based design language allows both parametric and topological design of LTA HAP propulsion system, respectively. Figure 4.12 shows parametrical and topological variations of propulsion system for different size of HAP. For generating same propulsion power bigger and less number of motors can be used or smaller and more number of motors can be used. On one hand less number of motors may be advantageous because of the reduced number of systems to handle. On the other hand higher number of motors may be more advantageous because of redundancy and reduced size of individual motors. The decision is one of the difficult tasks of the design process.

Following modifications are performed:

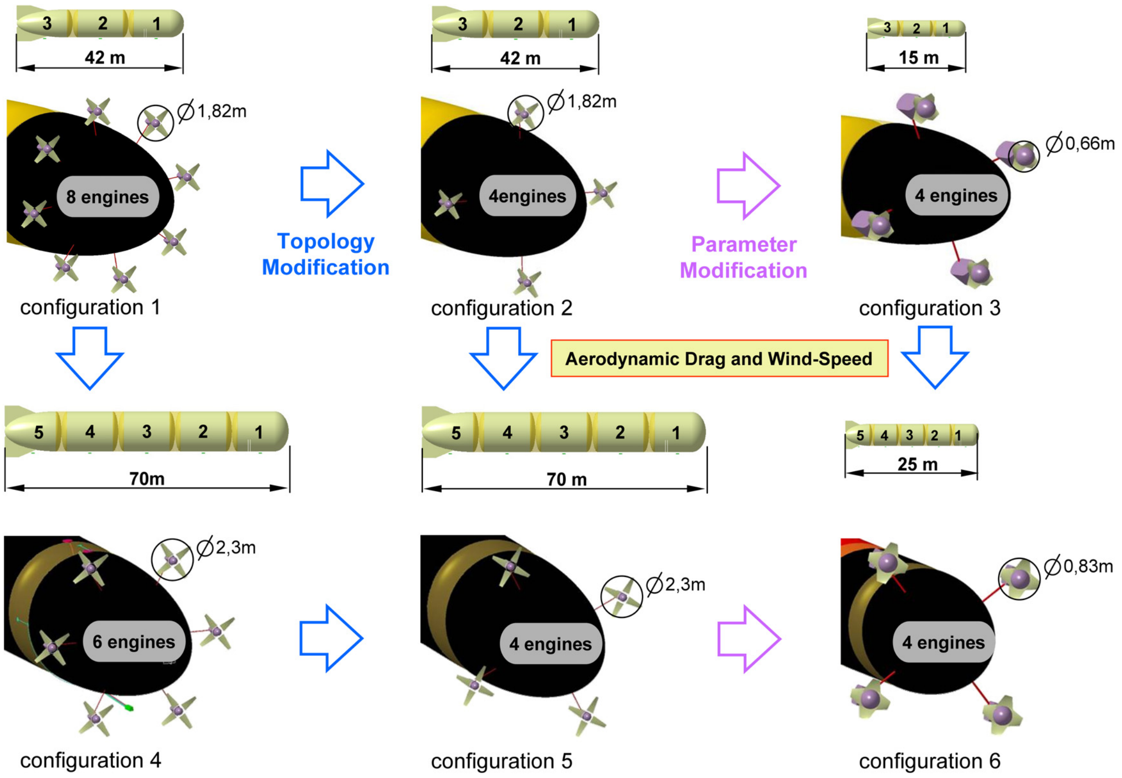

Figure 4.12: Topological variants of propulsion system of various LTA HAPs

- configuration 1 → 2: topological modification: 8 to 4 engines
- configuration 1 → 4: topological modification: 8 to 6 engines
- configuration 2 → 5: parameter modification: 4 engines
- configuration 4 → 5: topological modification: 6 to 4 engines
- configuration 3 → 6: parameter modification: 4 engines
- configuration 2 → 3: parameter modification: 4 engines
- configuration 5 → 6: parameter modification: 4 engines

As soon as the necessary power for the propulsion system is obtained, the size of the electrical motors can determined. Therefore the factor of specific motor mass can be used to calculate the motor mass dependent from the power usage. In addition the desired number of motors can be specified which allows to distribute the power over the number of the motors.
It can, how ever, also define a set of motors which are allowed to use within the design, so that the selection of the size of motors is not continuously but a set of points.

4.4 Systems Integration and Multi Criteria Optimization of Power Network

This section presents the system integration process of a LTA HAP done by graph grammars. At least the circuit plan and wiring harness of the system is optimized by applying rule based multi criteria optimization incorporating Evolutionary Algorithm [25].

Figure 4.13 presents a CAD-model of a LTA HAP demonstrating one possible configu-

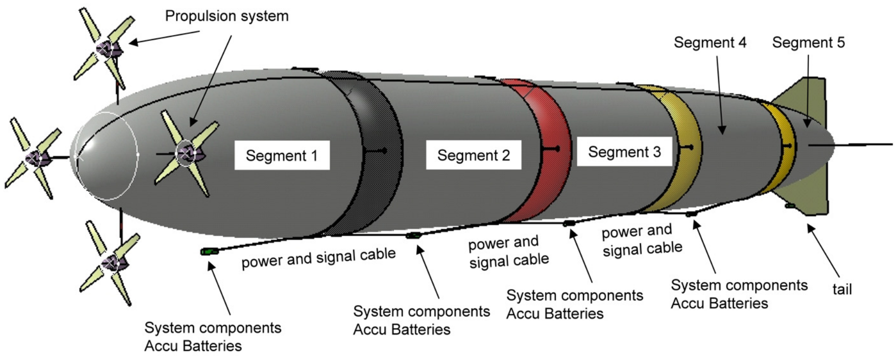

Figure 4.13: CAD model of a HAP system demonstrating configuration of power, propulsion and system components

ration of power, propulsion, system components and wiring harness, respectively. Particular characteristic of this system integration design is that the propulsion unit consisting of electrical motors is integrated in the head segment and the rest of the segments behind the first segment are pulled and hence non driven segments. Thus the electrical motors which are the main energy consuming system components have there fixed position in front of the LTA HAP. According to the number of electrical motors they are radially distributed around the segment. Some of further system components are integrated within the head segment such as power control unit as well as a helium valve for purpose of discharging helium during descent phase of HAP mission. Rest of the system components are distributed throughout the rest of the segments. Further power providing components such as the integration of solar arrays or fuel cell electrolyzer system will not be considered within the system integration task. Instead of this accumulator batteries are used as source of electrical energy. They are also distributed equally throughout the segments and are connected with each other with electrical power cables and power control units. The geometrical arrangement of each system component will also not be discussed in this section.

Considering the multi segment airship concept one way of system integration is of an independent system integration of each segment which is then able to function autarkic from other segments. This means that each segment has its own propulsion, power supply, GPS-, and control system, as well as communication system. Depending on mission targets there may be also multiple redundancy of all system components. Equipping each segment with separate propulsion means on the one hand a high flexibility of manoeuvring the airship, causing on the other hand huge masses, increasing size and costs of the airship. An other configuration is to have only a single propulsion on the head segment of the HAP and to reduce also the amount of other system components to a minimum.

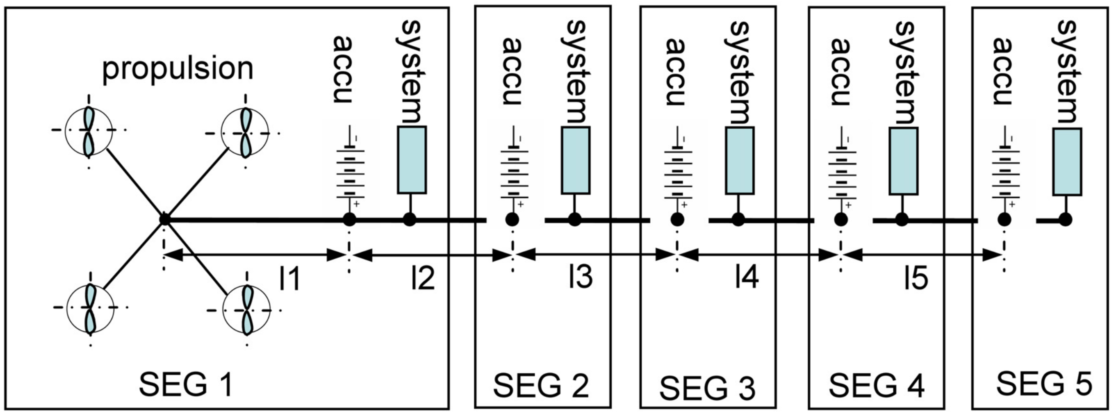

Figure 4.14: Systems integration strategy 1: one power network for overall supply of electrical energy

Other strategies are reusable or disposable system. A reusable system may produce a huge amount of maintenance and storage costs, whereas a disposable system would be a suboptimal solution for use of only one time and less costs. The main point which arises designing such system is to decide designing a suboptimal cheap system or a super optimum high cost system. Thus the main point is to optimize both the costs and the physical integration of the HAP-mission. A tailored solution for each mission is necessary to sufficiently fulfill the targets by remaining cost optimized at the same time.

An other aspect of system integration is the power supply and wiring problem. This is presented in figure 4.14 schematically. Each box represents a HAP segment. Segment one includes propulsion motors, some batteries and system components. The line between propulsion unit and the battery is a power cable with a length $l1$, where by the system components are placed direct to the battery. Segment 2, 3 and 4 contains also system components and accumulator batteries and they are all connected to the main power supply. The cable connecting two battery units has a specific length of l_i. Both the system components and the propulsion unit are connected to the same electrical power unit.

An other strategy of power network design is presented in figure 4.15 where the power supply network for propulsion system is separated from that of system component. The system components usually operate with an almost constant power consumption by contrast the propulsion unit have a very undefinable power consumption. It depend on the mission task and especially on the wind speed in the operational altitude. In case of station keeping task power consumption may be very low for less wind speeds and rise cubically dependent on increasing wind speed. Thus fluctuating peaks of electrical current may cause disturbances in the power supply of system components, thus this configuration my be beneficial. Here the electrical propulsion motors are integrated in front of the

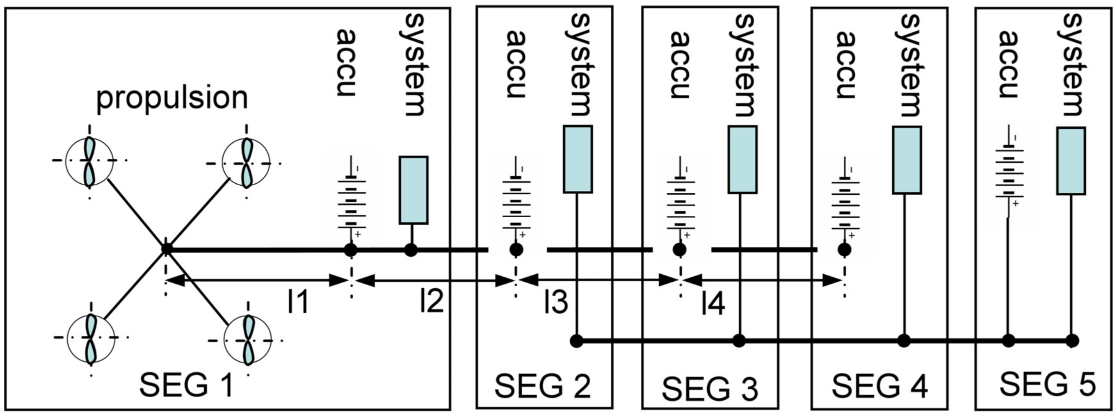

Figure 4.15: Systems integration strategy 2: two different power networks for system components and propulsion unit

head segment and are connected with power cables to the batteries. These are placed in segment 1, 2, 3 and 4. Some of the system components concerning power management unit are also placed in segment one. The batteries of the propulsion power unit are connected with each other. The power dissipation P_{disp} within the power cables is calculated with the ohmic law $P_{disp} = R \cdot I^2$ and $R = \frac{\rho \cdot l}{A}$:

$$P_{disp} = \frac{\rho \cdot l \cdot I^2}{A} \tag{4.8}$$

The bigger the length of the cables the larger is the resistance of the cable. During high load phases power dissipation is also larger because of bigger currents thus cables with bigger diameter are necessary to reduce the resistance and therefore power dissipation in the cables. Length of cable is dependent on the HAP length and can therefore not be reduced. Thus the cable diameter has to be modified to reduce power dissipations within the power cables. Increasing the cable diameter means also increasing the mass of cables, and big mass means that less rest mass remains for batteries and therefore less total energy and a reduced mission duration. On the other hand less diameter means less cable mass but higher power dissipations. Which means an overall higher power consumption and also a reduction of mission duration. In both cases a wrong selection of cable diameter could reduce the mission duration significantly. Thus a multi criteria optimization has to

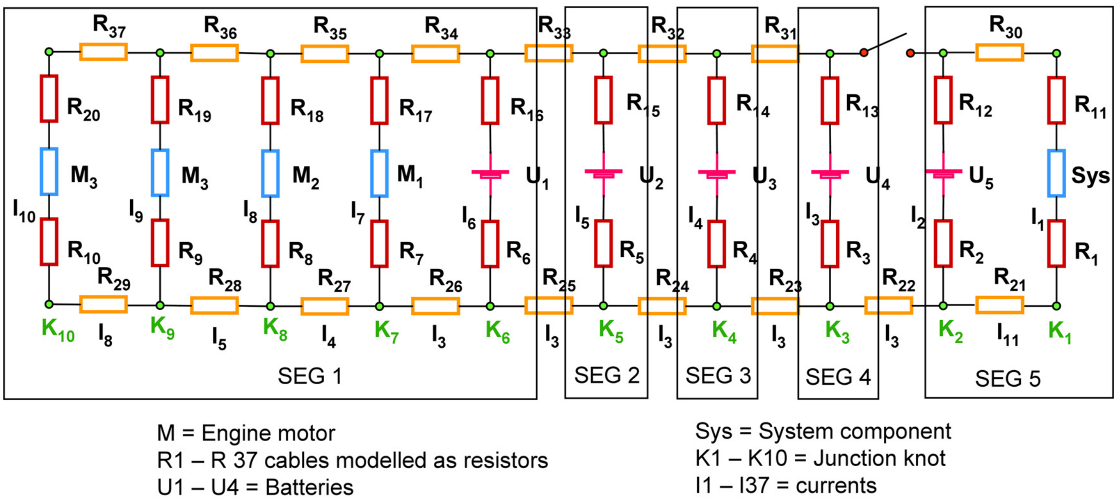

Figure 4.16: Abstraction electrical model of circuit plan of HAP configuration

be performed, in order to achieve cable diameter which has a right balance of entire mass and resistance reduction.

Figure 4.16 presents an abstraction of electrical model of circuit plan which we will optimize within the graph grammar based design model. All cables and electrical consumers are represented as ohmic resistance.

The four motors are the main consumer of electrical energy and each segment carries batteries. Segment five should contain system components with its separate batteries.

Two criteria have to be optimized for this model, one is the mass of the cables which is directed by the cable diameter and the other criteria is the power dissipation. Therefore the problem of multi objective optimization is formulated as following:

$$min_x[\mu_1(x), \mu_2(x)] \tag{4.9}$$

Where $\mu_i(x)$ is the objective function with the constraints $g(x) \leq 0$ and $h(x) = 0$ and $\vec{x}$ is the vector of optimization. The solution of the above problem is a set of Pareto Points.

first objective: $\mu_1(x)$ = mass of cable
second objective: $\mu_2(x)$ = power dissipation

the vector to optimize:

	cable diameter	current	power
x_1	d_1	I_1	P_1
x_2	d_2	I_2	P_2
x_3	d_3	I_3	P_3
x_4	d_4	I_4	P_4
x_5	d_5	I_5	P_5

An evolutionary algorithm developed by DEB [25] is used as an approach to solve the multi objective optimization problem.
The setting parameter for the Evolutionary algorithm are described as following:

General Parameters		value	Mutation probability		value
Populations	:	2	Repetition	:	0.01
Individuals per population	:	56	Application	:	0.01
Generations	:	100	Parameter	:	0.15
Cross over probability	:	0.5	Add rule	:	0.1
Parents selection	:	yes	Remove rule	:	0.1
Mutation parameters			**Migration**		
Max. repetition	:	1	Migration intervals	:	40
Max. Application	:	500	Migrants	:	5
Parameter variation	:	0.3			
Add rule at end of program	:	no			

The main characteristic of the multi objective optimization of our case is that the optimization approach of the evolutionary algorithm is performed in combination with optimization rules. Such a rule based multi criteria optimization allows not only optimization of continuously defined functions but also discontinuous functions. For example the diameter of the cable can be continuous within an optimization interval, but a set of cable diameters existing in the market with for e.g. five type of diameters is very discontinuous. Thus a rule based multi-criteria optimization is well suited for such an optimization task. The optimization is done with an evolutionary multi criteria optimization algorithm integrated within the design compiler [5]. For the simulation of the electrical circuit plan a software tool LT-spice [79] is used. The corresponding graph is presented in figure 4.17

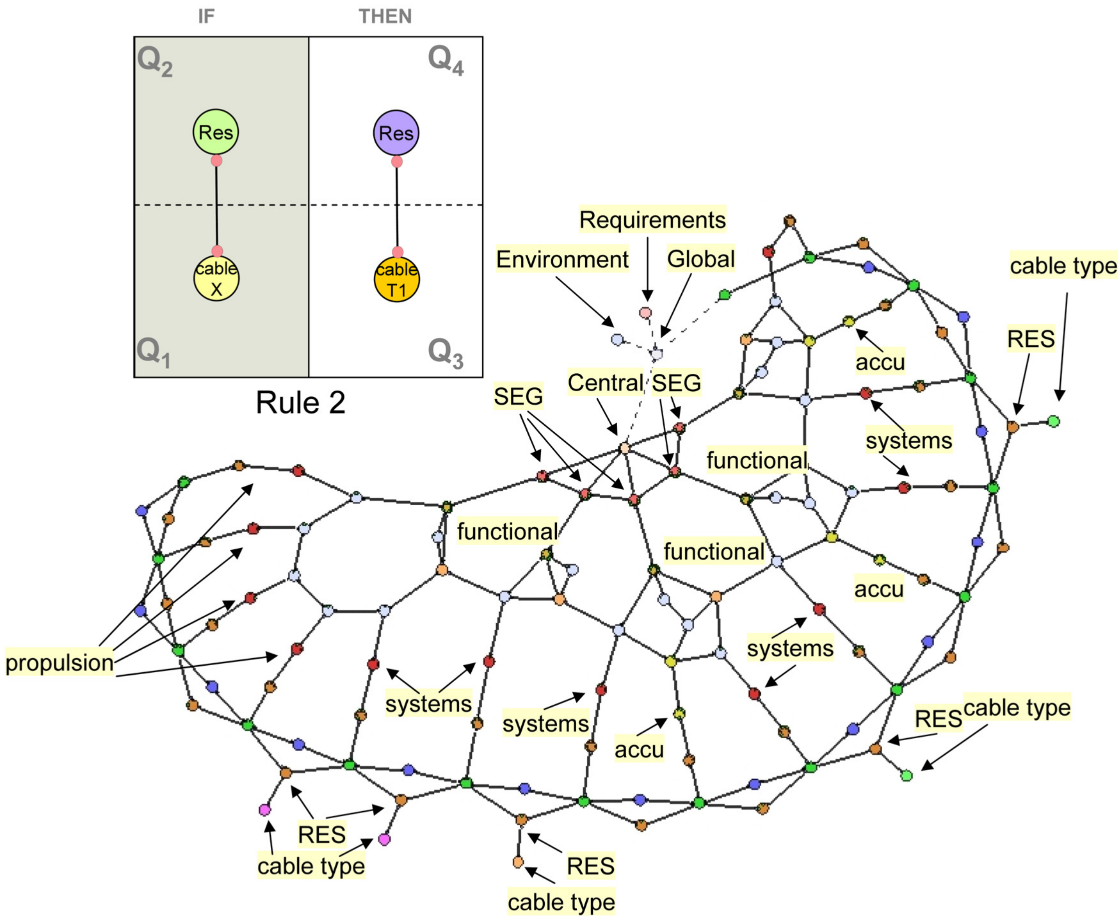

Figure 4.17: Graph based representation of electrical circuit plan for multi criteria optimization of wiring harness

which is a formal domain independent representation of our design object incorporating a number of disciplines. These are for e.g. the discipline of structure, envelope, systems and the cables which are connected with each other within a network. For instance modification of the length of LTA HAP propagates through the whole graph of LTA HAP and modify those part of the graph which concerns the circuitplan. Which means that the distance between the system components changes and the length of the cable is either enlarged or reduced. Thus modification of the diameter of cable length requires a re optimization of the cable diameter. Which means that for each design point of a mission a Pareto optimized solution of the circuitplan can be generated. The software tool LT-spice delivers the electrical analysis result for each configuration and iteration step of the optimization process until a pareto optimization result is achieved. Figure 4.18 presents a diagram including such a Pareto optimization solutions of about 400 configurations. They were calculated for velocities of wind of 25% and 75% during the entire mission

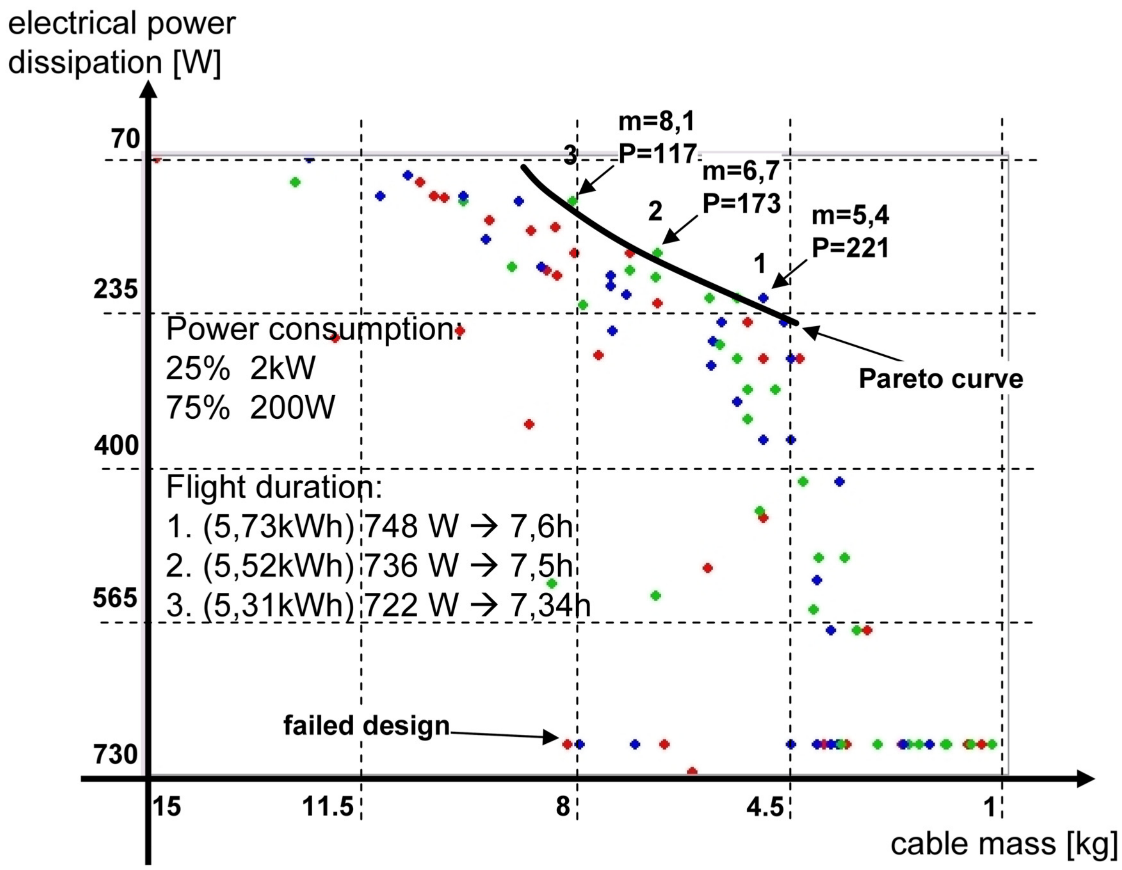

Figure 4.18: Optimization result of wiring harness of power cables

duration. Since the power consumption of the propulsion system depends on the velocity of wind for a station keeping task we achieve values of 25% 2kW and 75% 200W. By devoting particular attention to the solutions in the diagram the interesting region is the Pareto boundary with three solutions lying direct on it. In order to choose that solution which meets the mission requirement best they are compared with each other by calculating the capacity of the batteries, dissipation power and the flight duration. Since the three configurations are lying next to each other we achieve values between 7.3h to 7.6h for the flight duration. Thus there is hardly a difference between the three solutions and therefore either of the solutions can be picked out for design purposes or the three solutions are further evaluated by other criterias to find out the best one.