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ONTOLOGY-ASSISTED AIRCRAFT CONCEPT GENERATION

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Abstract

This paper presents a method for generating a geometrical representation of a concept aircraft from an ontology description. An ontology is used as an overarching knowledge base where entities, such as required functions, their design alternatives, and requirements can be represented. Description logic reasoning is then used to process the available design space and generate suitable concepts to fulfil desired functions, as well as indicate suitable approaches for a subsequent sizing procedure. As ontology representations are limited in terms of numerical calculation capabilities, the obtained concept information must be extracted for additional processing. Further investigations, such as statistical analyses, are consequently performed in order to expand the available information of the concept generated from the ontology. This expansion is performed to obtain estimates of required inputs for a continued geometrical sizing procedure. The outcome of the method is an estimation of the concept's geometry and its characteristics. This information can from here be reintroduced into the ontology representation for further processing and to expand the original knowledge base. A case study is introduced to test the proposed method and to show how it can be used to estimate the characteristics of an already existing aircraft from basic requirements and configuration details. The results from the method and sizing are also compared with publicly available data for the reference aircraft to see how accurate the estimates were.

Keywords: Ontology, Aircraft Conceptual Design, Singular Value Decomposition, Geometry

1. Introduction

The use of ontologies in systems engineering applications, such as aircraft design, is becoming increasingly common. One of the reasons for this is that more and more systems today are regarded as being part of a larger overarching system; a so-called *System-of-Systems* (SoS). From an SoS perspective, ontologies can contribute by providing an overarching knowledge base where entities and their relationships can be modelled in order to increase the understanding of them. Consequently, ontologies can be seen as a complementary approach to common *Model Based Systems Engineering* (MBSE) languages such as the *Unified Modelling Language* (UML) or *Systems Modelling Language* (SysML). However, ontologies feature description logic reasoning capabilities which can be used to automatically classify and infer new relationships between modelled entities. This is a powerful feature that, among other things, give ontologies increased expressiveness and interoperability compared with other MBSE approaches.

Previously performed research has shown how ontologies with description logic reasoning can be used to represent and process a design space for *Search and Rescue* (SAR) air vehicles from an SoS perspective [1]. The design space has here consisted of different functions, that must be performed to meet the overarching SoS needs, and the alternatives that can fulfil the functions. Consequently, this design space has solely described different configuration possibilities for airborne systems and not any specific concept and corresponding performance metrics. A drawback with an ontology representation is that it is not suitable for more advanced numerical operations and optimizations. A temporary transition outside the ontology representation is needed to perform the initial sizing and numerical evaluations of possible concepts.

The main purpose of this paper is therefore to propose a method for transitioning from an ontology represented SoS design space of functions and their alternatives to an evaluation of different concepts and their subsequent initial sizing, geometrical representations, and performance evaluations. More information is thereby added about the available design space, and this can consequently be reintroduced into the ontology for further processing capabilities and explorations later. A case study for the design of a conventional passenger aircraft is used to show how the method can be utilized to arrive at suitable concepts with an initial sizing performed. Discussions about the proposed method are presented at the end of the paper together with brief thoughts about possible next steps for this work.

1.1 Related Work

Related work has suggested that a holistic engineering approach for SoSs can be divided into five successive and interrelated levels of interest [2]. Together, these five levels make up a process that connects SoS needs, capabilities and system requirements in the early stages of product development. This process is illustrated in Fig. 1.

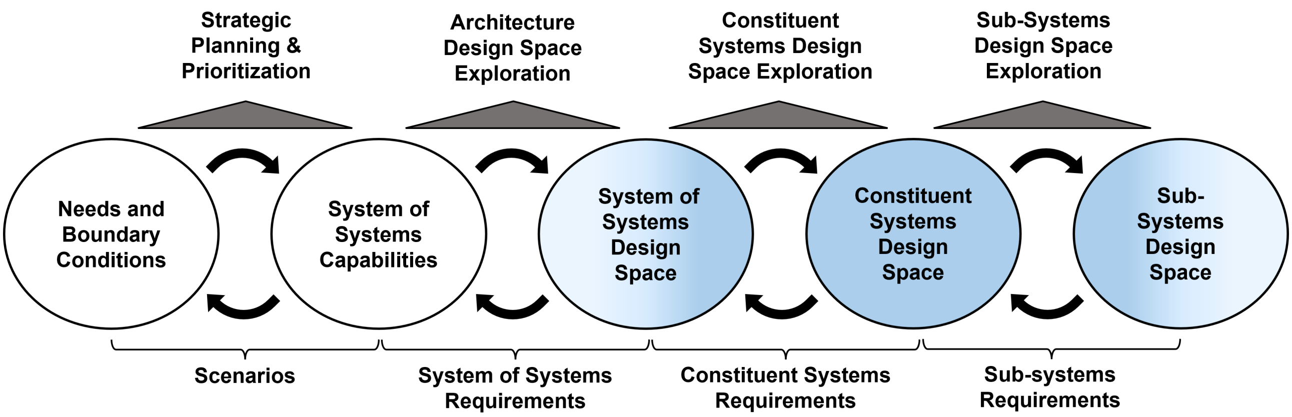

Figure 1 – An outline of the holistic *System-of-Systems* (SoS) design process, which has been adapted from [2]. The highlighted circles show the area that this work is addressing.

The intention with the process from Fig. 1 is to enable design and trade space explorations on all five levels of interest. It thereby enables "what-if" investigations that can be used to gain more knowledge about different solutions early on in a design process. Previous work has shown how SoS needs can be broken down into capabilities and required functions to be performed using an architecture framework [3]. A subsequent study showed how the outcome from this breakdown could be represented in an ontology model [1]. This ontology was here also merged with other relevant ontologies to ultimately span an available design space of functions and their alternatives for an SoS. Therefore, the work presented in this paper also aims to illustrate how aircraft concepts can be generated from the outcome of these previous papers. This work thereby covers the highlighted levels in Fig. 1 by illustrating how the design for constituent systems, in this case aircraft, can be generated and used to fulfil the functions obtained from an SoS needs breakdown.

2. Frame of Reference

This section is intended to highlight and explain various fields and methods related to the presented work and problem outlined in the introduction.

2.1 System of Systems and Ontologies in Engineering

System-of-Systems (SoS) have been mentioned several times in this paper so far, but what does really an SoS imply? A definition from the *International Council On Systems Engineering* (INCOSE) states that it is *"a collection of independent systems, integrated into a larger system that delivers unique capabilities"* [4]. Consequently, collaboration between constituent systems of an SoS can lead to emergent behaviours that individual systems cannot produce on their own. An SoS can be distinguished from a “single” system if it fulfils five characteristic properties introduced by Mark W. Maier [5]. In his article, Maier also explains that it can be valuable to distinguish the two from each other to avoid problems from misclassification during development.

There are various ways to model and represent SoSs. One way of doing this is, as previously mentioned, to use ontologies. In short, ontologies are used to represent entities and their relationships in a formal and explicit way [6]. It can consequently be applied on SoSs to model involved entities, such as constituent systems and requirements and how these relate to each other. Ontologies implemented in the *Web Ontology Language* (OWL) feature description logic reasoning capabilities. A description logic reasoner, or simply reasoner, can check an implemented ontology for inconsistencies but can also be used to derive additional knowledge based on implicit relationships in the modelled domain [7]. OWL ontologies work under the “open world assumption” which essentially implies that additional information about a domain can appear at any time [8]. Consequently, non-existing data is simply assumed to be unknown under an open world assumption. In contrast, a “closed world assumption” regards non-existing data as false. The open world assumption is one of the reasons why ontologies are both flexible and scalable to the introduction of new information.

Ontologies implemented in OWL typically consist of classes, object properties, data properties and instances that together are used to model entities and their relationships. Classes can be seen as general descriptions of entities, such as airborne vehicles. Instances, also called individuals, can describe specific entities such as a specific aircraft model. Classes are consequently collections of instances. Object properties are used to describe the relationships that exist between classes and instances. This can, for example, be the relationship that describe how an aircraft wing is related to a fuselage, or how the constituent systems are connected to each other in an SoS. Data properties are used to describe relationships between entities and data values, for example, the weight of a particular aircraft instance.

Besides the related work mentioned in the introductory chapter, ontologies have been used in a variety of studies, for example in the design of aerospace systems as shown in [9, 10]. While numbers can be represented in an ontology as well, ontology languages are quite limited in terms of numerical calculation capabilities. A transition to a closed world must be made to, for example, perform mathematical operations. A temporary transition outside the ontology representation can therefore be made to e.g., evaluate performance metrics or perform optimizations on the underlying knowledge represented in the ontology. Previous work has shown how a transition from an ontology representation of SoS alternatives can be made in order to evaluate their performances using *Agent Based Simulations* (ABS) [11]. Another option could be to transition into matrix-based approaches from an ontology representation.

2.2 Matrix-Based Approaches and Design Space Representations

Matrix-based approaches and information introduced in a matrix-based format are, like ontologies, a convenient way of representing existing relationships between entities. There are several matrix-based approaches that can be used in the context of aircraft design and product development. Some of these are, for example, the *Design Structure Matrix* (DSM), the *Quality Function Deployment* (QFD) and the morphological matrix, or matrix of alternatives. A matrix of alternatives can be used to represent a design space by presenting required functions as the rows and the corresponding design alternatives as the matrix’s columns. A concept can consequently be generated by picking an alternative to each function represented in the matrix. A compatibility matrix can be used as a complement to a matrix of alternatives to illustrate any existing incompatibilities between design alternatives. An *Interactive Reconfigurable Matrix of Alternatives* (IRMA) can be seen as a combination of a matrix of alternatives and a compatibility matrix. As the name implies, an IRMA is also interactive and thereby highlights any incompatibility between alternatives as concepts are being generated [12]. This allows users to interactively visualize the available design space and to perform “what-if” analyses to explore it.

2.3 Statistical Methods and Regression Analyses

Statistical analyses of existing design solutions can be performed to identify trends that later can be used to make predictions about new concepts’ performances. This has especially played an important role in aircraft design where many well-established methods usually are based on statistical data, such as weight estimations. The reasoning for this is that existing solutions can be seen as a collection of knowledge that in some degree also is applicable on new designs as well. Estimations of a new design's characteristics can thereby be made with some degree of accuracy which usually is enough at an early conceptual design stage [13].

Methods such as trend line fitting and multiple regression analyses are fairly simple ways of determining relationships between data and to make predictive models. However, these are typically prone to biases and thereby uncertainty. As with any statistics, more data is always preferable to reduce uncertainty and to make more accurate estimations. Some more advanced methods for making prediction models include approaches such as symbolic regressions with genetic algorithms, neural networks, and *Singular Value Decomposition* (SVD).

2.3.1 Singular Value Decomposition

SVD is a form of statistical analysis that can be used to create, for example, estimation models based on statistical data [13]. A powerful feature of SVD is that only a few numbers of input parameters are needed to make an estimate of the remaining parameters in a data set [14]. SVD builds upon a *Principal Component Analysis* (PCA). The driving parameters in a data set can thereby be determined and the number of SVD variables can be matched against known or desired properties about a system under development. From an aircraft design perspective, SVD can be used to give quick estimates of a design based on given requirements [13]. SVD and other statistical analyses can also be used to create surrogate or meta-models from simulation results to reduce the computational cost for analysing and optimizing concepts among other things. New designs suggested from an SVD model can thereafter be further evaluated in detail, and eventually be added to the data set that the SVD originally was based on. An example of a continued evaluation is different aircraft sizing procedures.

2.4 Aircraft Sizing and Conceptual Design

Aircraft design is a highly iterative procedure that typically starts with the definition of a concept in a conceptual design phase. Concepts subsequently undergo an aircraft sizing procedure where basic analyses are performed to get initial estimates of characteristics such as dimensions, weights, and performance measures [15]. Evaluations can then be made in order to determine whether a concept fulfil stated requirements or not.

There are different existing aircraft sizing procedures and methodologies that have been suggested over the years. Some well-known sizing methods are, for example, the ones presented by Daniel P. Raymer [15], Egbert Torenbeek [16] and Snorri Gudmundsson [17]. These methods typically consist of different formulas and suggestions for sizing an aircraft. Calculations for disciplines such as weight estimations are typically derived from statistics of other aircraft, while relationships, such as sum of moments around the centre of gravity, can be used for stability and control calculations. An essential outcome of the conceptual design phase and the aircraft sizing step is a first geometrical representation of the intended aircraft.

2.5 Effective Parameterization for Geometry Build-up

There are many ways of obtaining a geometrical representation for a new concept under development. One way is to use parametric aircraft geometry tools, for example NASA's *Open Vehicle Sketch Pad* (OpenVSP) [18], to obtain a geometry from the previously performed sizing calculations. However, these tools are typically not as expressive and of as high fidelity as a typical *Computer-Aided Design* (CAD) software.

With the help of a parametric model, many designs can be explored. Here the association between the geometrical parameters helps propagate modifications to all the design features and to obtain a good working system. Bodein et al., Abt et al., La Rocca and Tooren [19, 20, 21] have implemented parametric modelling techniques and shown the advantages of the same. The parametrization that is implemented in the 2D/3D geometric modelling is termed as effective parameterization. With the use of effective parameterization, as shown in Fig. 2 [22, 23], there are several layers that are interconnected and always propagated from top-to-bottom as explained below. This interconnection between the parameters is also known as relational design.

- **Global references**: These are the parameters that affect objects and entities of the overall design. For an aircraft, the parameters could be the number of passengers, range, positions of all entities such as fuselage, wing, *Horizontal Tail* (HT) and *Vertical Tail* (VT), etc.
- **Interrelated references**: The parameters that are needed apart from the Global references to obtain a desired parameter value. For example, VT Volumetric coefficient is needed to compute VT area and it also depends on the position of the VT. A two-dimensional geometrical layout of the aircraft is obtained at this stage.
- **Relational references**: Based on the previously obtained two-dimensional layout, these references give a three-dimensional form to the obtained aircraft layout. For example, instantiation of wing partitions.
- **Sub-relational references**: These are the parameters available after the instantiation of the three-dimensional geometry. For example, options to change the wing airfoil in the wing partition.

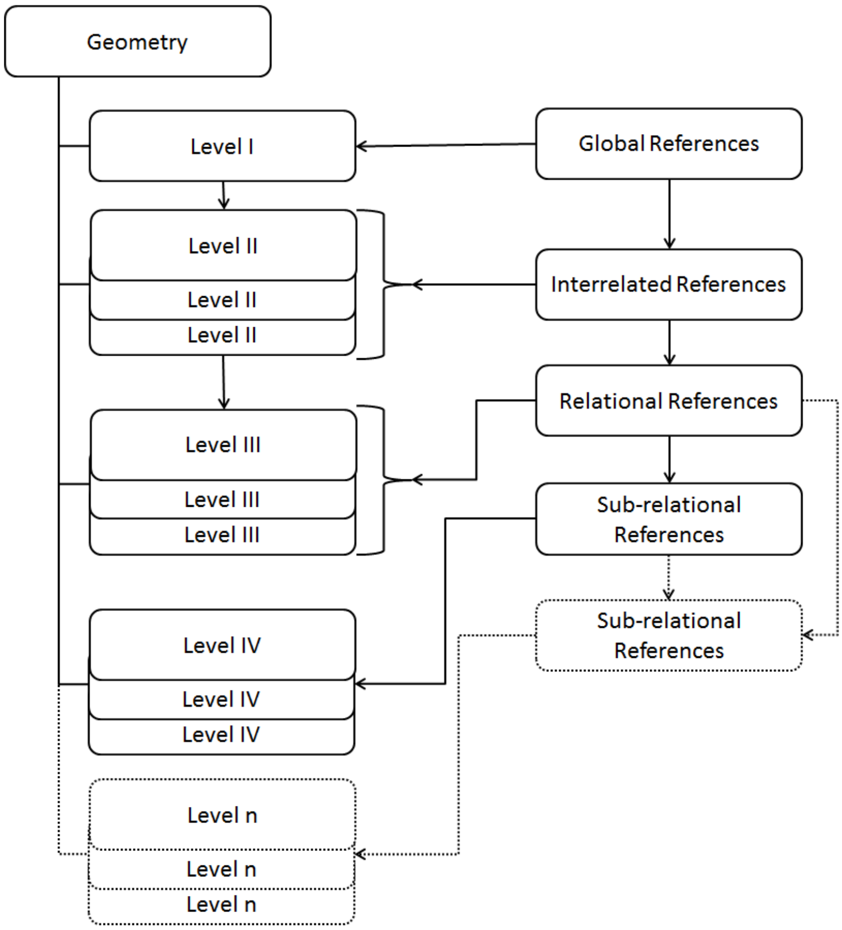

Figure 2 – An Effective Parameterization design flow. [22, 23].

The levels presented here are used in the *Robust Aircraft Parametric Interactive Design* (RAPID) [22, 23] which is a knowledge-based aircraft conceptual design tool built in the *Computer Aided Three-Dimensional Interactive Application* (CATIA) software to obtain a 3D geometry. In the present case of this paper, only a two-dimensional layout is obtained from the SVD results, thus using only *Global* and *Interrelated References* as shown in Fig. 2. An *Initial Geometry Layout Excel* implementation is built by including the sizing formulas and methods mentioned in Sec. 2.4, which also are further described in Sec. 4.4.

3. Method

This section introduces and illustrates the proposed method for utilizing ontology represented knowledge to generate and perform an initial sizing and geometry estimation of generated concepts. The method builds upon a combination of topics highlighted in the previous chapter. A summary of the method and its workflow is presented in Fig. 3.

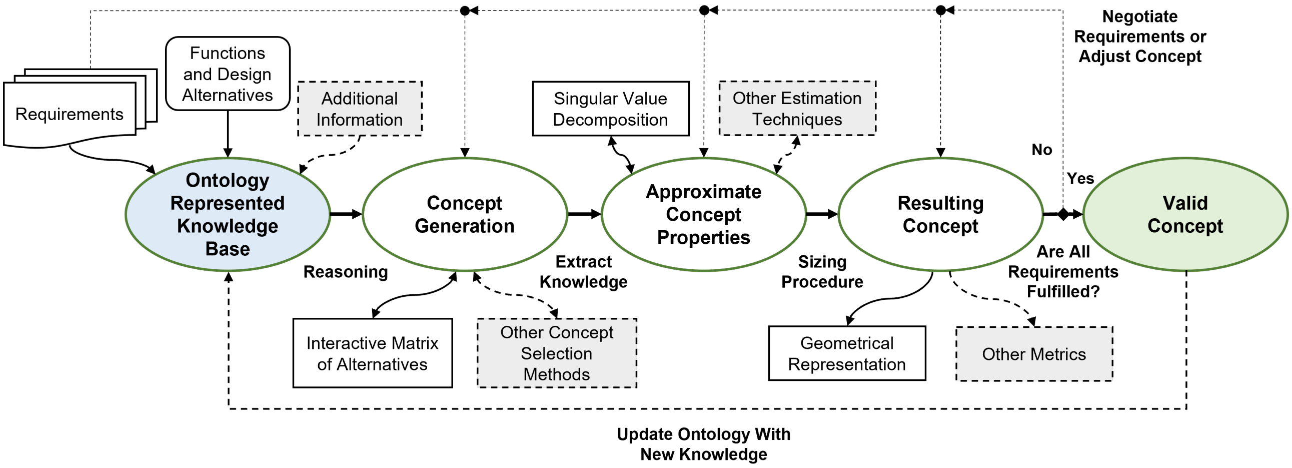

Figure 3 – An illustration of the proposed method and the overall workflow to generate valid concepts from an ontology description.

As illustrated in Fig. 3 the process starts with an ontology representation of underlying knowledge, such as stakeholder needs of an SoS. The ontology representation should in this case include information about requirements, functions that must be fulfilled and the corresponding design alternatives to do so. However, the ontology representation can also include additional information if desired, such as details about different sizing procedures or information about already existing aircraft. This is shown in a grey box with a dashed outline in Fig. 3. These boxes indicate additional options in the presented workflow.

Once an ontology representation is in place, description logic reasoning, can be used to infer relationships within the knowledge base and thereby both classify and check the ontology for inconsistencies. The description logic reasoner, or simply reasoner, can thereby indicate alternatives for different functions as well as the compatibility between them. Consequently, the reasoner is used to initially process the available design space and thereby also reduce it by, for example, only showing required functions that must be fulfilled according to the requirements [1]. There are many ways to generate a concept from this reduced design space of functions and their alternatives suggested by the reasoner. One way of doing this is to use an IRMA. Related work has proposed how an ontology represented design space can be converted into an IRMA for interactive concept selection and decision support [24]. Regardless of the method used for selecting alternatives for a concept, the underlying knowledge from the ontology representation should be extracted for further processing.

The "Approximate Concept Properties" step in Fig. 3 utilizes the extracted knowledge about a chosen concept together with relevant requirements in order to approximate properties for it. These approximated values should correspond to the ones needed to initialize an intended sizing procedure, such as an initial approximation of the *Maximum Take-off Weight* (MTOW). This can, for example, be done using statistical methods and analyses, such as an SVD, to get initial approximations about concept properties based on relevant requirements. Once initial estimates of a concept have been obtained, the sizing procedure can begin. This is typically an iterative process where more detailed approximations of a concept's characteristics are obtained. The outcome of this step is a resulting concept with its geometrical representation and specifications.

The resulting concept can thereafter be verified against the requirements to ensure that all still can be met. If the concept does not fulfil all requirements, the requirements will either need to be negotiated or adjustments must be made to the concept. Once all requirements are fulfilled, a valid concept has been generated. This concept can thereafter be reintroduced into the ontology representation

and knowledge base with the obtained information from the sizing procedure; and thus, also enabling further processing capabilities on the available design space. However, the concept can also be used for further analyses like, for example, *Computational Fluid Dynamics* (CFD) simulations or ABS.
The method in Fig. 3 has consequently described how a temporary transition from the ontology representation can be made to expand the information about a chosen concept generated from it.

4. Case study Implementation

In order to show how the method and workflow from Fig. 3 can be used, a case study is performed. This case study shows how the method can be used to generate a conventional passenger aircraft concept from basic requirements of range and number of passengers.
The case study starts from an ontology representations of basic aircraft functions and their alternatives, as well as relevant requirements and other information. As the method is intended to be used to generate more concepts than just conventional passenger aircraft, certain case study delimitations are needed to scope the work.

4.1 Case Study Delimitations

The case study is delimited to the design and initial geometrical sizing of a conventional passenger aircraft only for this paper. The Airbus A220 aircraft is chosen as a reference aircraft in order to see how well the proposed method can estimate the A220's characteristics from very basic information and requirements, such as its 120-passenger capacity and 6400 km range. Consequently, an SoS perspective of required functions to be performed to meet overarching needs is not considered at this stage. The purpose of the case study is rather to illustrate how the proposed method can be used to transition from an ontology representation in order to expand the knowledge and perform necessary numerical calculations that cannot be performed in the ontology representation directly. The case study then illustrates how this expanded knowledge can be reintroduced into the ontology representation afterwards.
Moreover, this case study only utilizes the particular approaches shown with white boxes in Fig. 3, such as *Singular Value Decomposition* (SVD). However, the method in Fig. 3 is intended to be general to facilitate the use of different approaches and in the evaluation of concepts for many other applications and concept types as well.
The aircraft sizing and geometrical representation is only performed in the *Initial Geometry Layout Excel* implementation in order to provide a basic first geometry. However, this implementation only contains basic geometrical sizing equations. For example, the sizing of the VT is only done with respect to the fuselage length and the position of the VT; the closer the VT is placed towards the nose of the fuselage, the bigger the VT will be. Consequently, only a geometrical iteration is performed, and other disciplines, such as structural analyses or weight estimations, are thus not considered.

4.2 Ontology Representation and Reasoning

The used ontology for this case study is partly based on an existing ontology for SoS introduced in [1]. The ontology has been implemented in the Protégé ontology editing software [25] and contain information about entities such as functions and their design alternatives. The represented functions are based on the core aircraft functions presented in [26]. It is here described that an overarching function of transporting airborne payload can be broken down into six sub functions that should be fulfilled. These are listed as functions to:

- *Accommodate payload and resources*
- *Control aircraft in flight*
- *Move aircraft on ground*
- *Provide flight information*
- *Provide lift*
- *Provide power*

Different suitable design alternatives were then represented in the ontology and mapped to the corresponding functions that they fulfilled. Ontology classes describing collections of entities, such as functions and alternatives, were added to the class hierarchy. This can be seen in Fig. 4 together with the class definition for the *Function* class and the corresponding instances for the specific functions listed above.

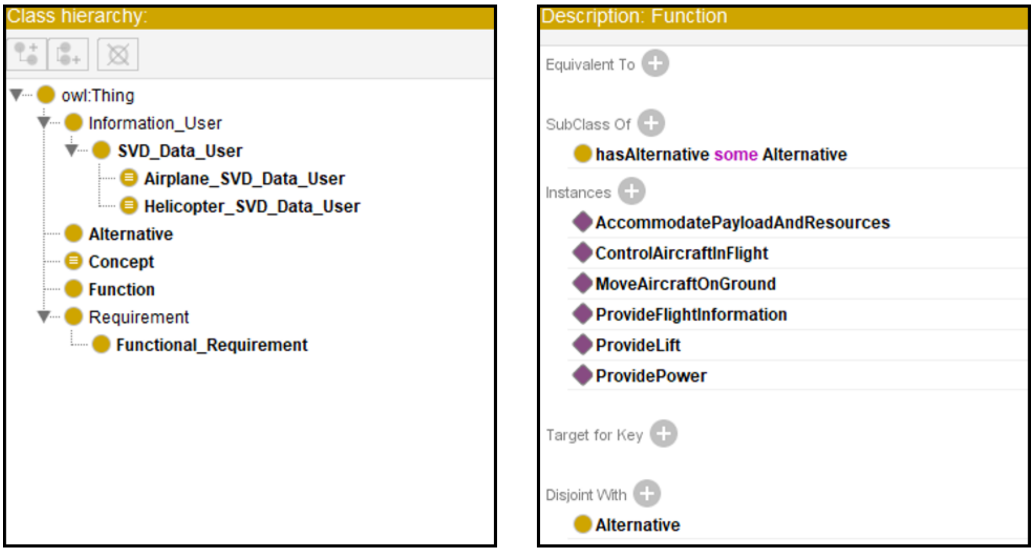

Figure 4 – The ontology class hierarchy (left) and the definition of the *Function* class (right).

As seen to the left in Fig. 4, the ontology includes classes for alternatives and functions. The specific functions can in turn be related to their corresponding design alternatives using object properties, or relationships. This can be seen in Fig. 5 for the *Provide Power* function. Any incompatibilities between the design alternatives can also be represented in a similar way.
Additionally, the class hierarchy include classes for requirements, concept selections and information. The concept class is used to describe a concept as an individual by selecting and relating different alternatives to the listed functions. The information class is used to describe relevant information, such as details for the subsequent sizing, which in this case includes information about different statistical SVD data sets to be used depending on the selected concept. The requirement class is here used to model relevant requirements as individuals. These individuals can thereby be used to describe, for example, range requirements with data property relationships to values. An example of this can be seen to the right in Fig. 5.

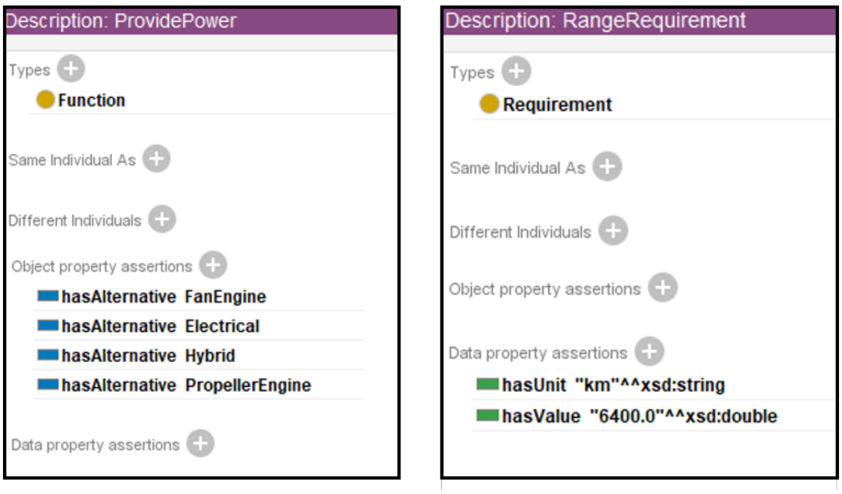

Figure 5 – The definition of the *Provide Power* function individual and its design alternatives (left), and the definition of the *Range Requirement* individual (Right).

The ontology representation can now be used for description logic reasoning and to create the initial estimation concept of the A220 aircraft as explained in the next section.

4.2.1 Reasoning and Concept Selection

In order to create a concept, alternatives to required functions must be chosen. This can be done in different ways, for example, with an IRMA as shown in [24] or simply by manually relating a concept individual with desired alternatives to functions that it must perform. An IRMA adapted from the work of [24] was created from the ontology representation and used for the concept definition in the case study of this paper. Here, the IRMA was mainly used for indicating incompatibilities between the available design alternatives, and the concept definition itself was thus performed directly in the ontology.

Figure 6 illustrates the IRMA that was used for the concept definition, while the resulting concept individual from the ontology can be seen in Fig. 7.

Function	Alternative 1	Alternative 2	Alternative 3	Alternative 4
AccommodatePayloadAndResources	Combination	ExternalAttachment	InternalNonPressurizedCompartment	InternalPressurizedCompartment
ControlAircraftInFlight	ControlSurfaces	SwashPlate	ThrustVectoring	
MoveAircraftOnGround	Rail	Skids	Wheels	
ProvideFlightInformation	Avionics			
ProvideLift	Rotor	Wing	WingRotor	
ProvidePower	Electrical	FanEngine	Hybrid	PropellerEngine

Figure 6 – The used *Interactive Reconfigurable Matrix of Alternatives* (IRMA) that has been adopted from the work of [24].

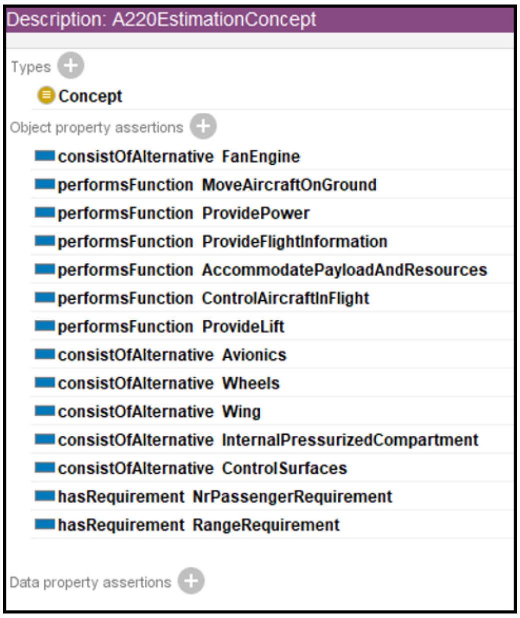

Figure 7 – The description of the *A220 Estimation Concept* individual.

As seen in Fig. 6, one alternative for each function has been chosen to generate a concept that corresponds to the A220 aircraft. These are marked in green while incompatibilities, based on the selections, are marked in red. Consequently, the *A220 Estimation Concept* individual in Fig. 7 consists of the design alternatives chosen previously in the IRMA. It also includes all the function that the concept must perform together with relationships to requirement individuals via the *hasRequirement* object property.

A description logic reasoner can now be used to automatically infer implicit information in the ontology representation and check it for inconsistencies. The reasoner can also be used to process the available design space and, for example, reduce it to only a few numbers of functions that must be performed, as shown in related work [27]. In this case study, the reasoner is mainly used to infer what information is needed for the upcoming sizing procedure, as all represented functions must be fulfilled. This is done by implicitly relating different possible concept selections to, for example, information about different suitable statistical data sets. It can be seen in Fig. 4 that the *Information_User* class has sub-classes for two different SVD data types; one for airplanes and one for helicopters. These classes do each have individuals that can describe specific statistical data sets. An example of this can be seen in Fig. 8, where the definition for the *Airplane_SVD_Data_User* class is shown. Consequently, any concept that consists of the alternatives listed in this class description will be inferred to be a member of the *Airplane_SVD_Data_User* class. The reasoner can thereby automatically infer that the *A220 Estimation Concept* individual must be a member of the *Airplane_SVD_Data_User* class, based on its selected design alternatives, and thereby also indicate that this dataset should be used in the continued sizing. This newly inferred information from the reasoner is consequently found in the description of the *A220 Estimation Concept* individual (as seen to the right in Fig. 8) and can from here be extracted and used for further processing outside the ontology representation and OWL-file.

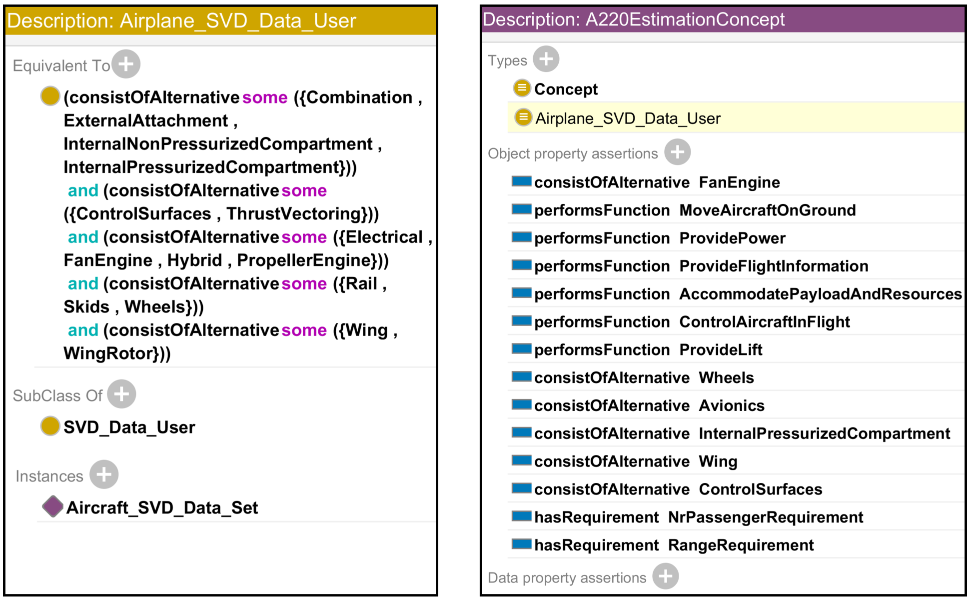

Figure 8 – The definition of the *Airplane_SVD_Data_User* class (left) and the *A220 Estimation Concept* individual with inferred information highlighted in yellow background (right).

4.3 Singular Value Decomposition

After extraction, the information from the ontology is expanded based on statistics of other aircraft using an SVD analysis. The statistical database that the SVD is based on consists of specifications for 72 different passenger aircraft, ranging from sizes of 50 to 660 passengers. The Airbus A220 aircraft specifications were not included in this data set, as the purpose of the case study was to estimate these with the configuration and requirement information from the ontology.
The SVD analysis was performed on the logarithmic values of the original data to gain a better model structure. An Excel-implemented macro was used to do the analysis and the required matrix operations to determine the SVD-variables and obtain the overall SVD model. The resulting model can be seen in Fig. 9.
As seen in the three leftmost columns in Fig. 9, the *Estimate* and the *Embraer EMB 145* reference aircraft columns have a relative error of zero percent against each other. This is expected since this aircraft is included in the original data set and all SVD variables are used. The number of SVD variables can from here be reduced in order to create an estimation model that requires just a few numbers of inputs, which in this case study is the number of passengers and the range requirements from the ontology. The number of SVD variables to use can be determined by looking at the *w-diagonal* column in Fig. 9. This column is also visualized as a bar chart in Fig. 10.
As Fig. 10 shows, the first SVD variable is most significant, while the degree of influence quickly tapers off after that. Consequently, just one SVD variable would give a reasonably good estimate in the case for this data set. The rightmost residual column in Fig. 9 shows how the maximum relative error for all characteristics are affected when the least significant SVD variables are set to

	Rel error	EMBRAER_-EMB-145	Estimate	Adjusted	Result	Average
Passenger Capacity	0,00	50,00	50,00	1,70	-0,64	2,34
Design range (km)	0,00	2574,28	2574,26	3,41	-0,37	3,79
Wing Area (m²)	0,00	51,18	51,18	1,71	-0,57	2,28
Wing Aspect Ratio	0,00	7,85	7,85	0,89	-0,03	0,92
VT Area (m²)	0,00	7,20	7,20	0,86	-0,62	1,48
VT Aspect Ratio	0,00	1,33	1,33	0,13	-0,04	0,16
HT Area (m²)	0,00	11,20	11,20	1,05	-0,62	1,67
HT Aspect Ratio	0,00	5,16	5,16	0,71	0,04	0,67
No. Seat abreast	0,00	3,00	3,00	0,48	-0,35	0,83
Take-off (m)	0,00	1500,00	1499,99	3,18	-0,19	3,36
Landing Distance (m)	0,00	1290,00	1289,99	3,11	-0,10	3,22
Speed (Mach)	0,00	0,62	0,62	-0,21	-0,08	-0,13
Max. wing load (kg/m2)	0,00	375,15	375,14	2,57	-0,20	2,78
Thrust/Weight Ratio	0,00	0,33	0,33	-0,48	0,07	-0,54
MTOW (kg)	0,00	19200,00	19199,79	4,28	-0,77	5,06
Thrust (N)	0,00	62640,00	62639,23	4,80	-0,71	5,51
	0,00					

	K-matrix																SVD variables	w-diagonal	residual
Passenger Capacity	0,270	-0,024	0,009	-0,011	0,050	-0,012	0,004	-0,001	0,007	-0,020	0,001	0,007	-0,004	0,005	0,000	0,000	-2,12	6,82	4,95
Design range (km)	0,246	-0,037	-0,068	0,006	-0,040	0,009	0,019	0,007	0,001	-0,007	0,001	0,004	-0,003	0,003	0,000	0,000	-0,19	1,11	0,29
Wing Area (m²)	0,296	0,026	-0,004	0,012	-0,014	-0,028	-0,026	0,010	0,001	-0,001	0,001	0,000	0,000	-0,004	0,000	0,000	-0,69	0,95	0,29
Wing Aspect Ratio	-0,014	-0,027	-0,009	-0,018	0,008	-0,008	0,010	-0,001	-0,010	-0,004	-0,003	-0,007	-0,009	-0,018	0,000	0,000	1,58	0,80	0,26
VT Area (m²)	0,256	0,014	0,027	-0,029	-0,011	0,047	-0,013	0,011	0,004	-0,010	-0,002	-0,004	0,005	-0,003	0,000	0,000	-2,01	0,71	0,24
VT Aspect Ratio	0,055	-0,093	0,046	0,042	-0,015	0,005	-0,013	-0,009	0,005	0,001	-0,001	-0,001	-0,001	-0,001	0,000	0,000	-0,75	0,59	0,11
HT Area (m²)	0,297	0,026	0,060	0,010	-0,016	-0,008	0,034	0,005	-0,016	0,002	0,000	0,002	-0,001	0,002	0,000	0,000	-0,06	0,52	0,10
HT Aspect Ratio	-0,038	-0,048	-0,004	-0,026	0,008	-0,001	-0,013	0,019	-0,028	0,004	0,004	0,006	0,008	0,001	0,000	0,000	-0,61	0,48	0,10
No. Seat abreast	0,116	-0,016	0,016	-0,039	-0,002	0,002	-0,003	0,011	0,013	0,020	0,003	0,005	-0,013	0,002	0,000	0,000	-0,44	0,37	0,09
Take-off (m)	0,079	0,015	-0,011	0,043	0,027	0,023	0,007	0,009	0,004	0,008	0,003	0,013	0,003	-0,010	0,000	0,000	-1,41	0,31	0,09
Landing Distance (m)	0,059	0,025	-0,013	0,028	0,011	0,023	-0,018	-0,006	-0,021	-0,001	0,000	-0,003	-0,015	0,006	0,000	0,000	-1,30	0,14	0,10
Speed (Mach)	0,015	0,003	0,004	0,002	0,003	0,003	0,005	-0,003	0,004	-0,003	0,014	-0,013	0,000	-0,001	0,000	0,000	1,39	0,24	0,10
Max. wing load (kg/m2)	0,061	-0,027	-0,014	-0,006	0,028	0,017	0,019	-0,007	-0,001	0,011	-0,003	-0,009	0,004	0,004	0,000	0,000	0,55	0,21	0,08
Thrust/Weight Ratio	-0,023	0,005	0,004	-0,021	-0,013	0,008	-0,001	-0,034	-0,004	-0,002	0,003	0,010	0,000	-0,002	0,000	0,000	1,60	0,20	0,07
MTOW (kg)	0,357	-0,002	-0,018	0,007	0,014	-0,011	-0,007	0,003	0,001	0,009	-0,002	-0,009	0,004	0,000	0,000	0,000	-0,79	0,00	0,00
Thrust (N)	0,334	0,003	-0,014	-0,014	0,000	-0,003	-0,007	-0,031	-0,004	0,008	0,000	0,001	0,004	-0,002	0,000	0,000	2,88	0,00	0,00

Figure 9 – The full *Singular Value Decomposition* (SVD) model, where the *Embraer EMB 145* aircraft from the data set is used as a reference against the estimated values.

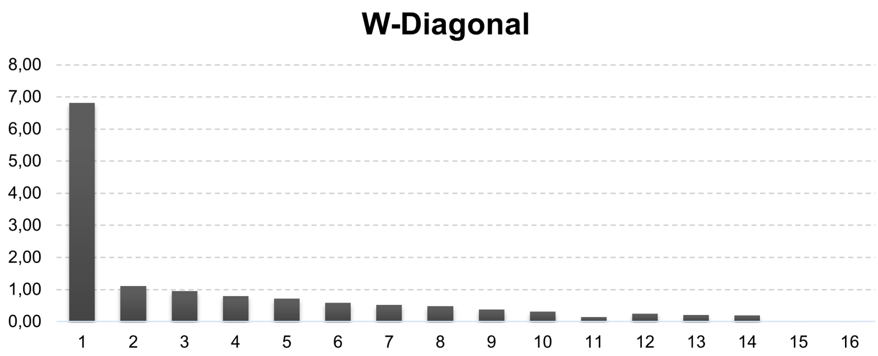

Figure 10 – The relative importance and influence of the SVD variables.

zero sequentially. Figure 11 shows the SVD model and the relative error against the reference aircraft where just three SVD variables are used.

	Rel error	EMBRAER_-EMB-145	Estimate	Adjusted	Result	Average
Passenger Capacity	0,17	50,00	58,52	1,77	-0,57	2,34
Design range (km)	0,19	2574,28	2075,10	3,32	-0,47	3,79
Wing Area (m²)	0,13	51,18	44,69	1,65	-0,63	2,28
Wing Aspect Ratio	0,17	7,85	9,16	0,96	0,04	0,92
VT Area (m²)	0,14	7,20	8,22	0,92	-0,56	1,48
VT Aspect Ratio	0,19	1,33	1,08	0,03	-0,13	0,16
HT Area (m²)	0,12	11,20	9,80	0,99	-0,68	1,67
HT Aspect Ratio	0,12	5,16	5,79	0,76	0,09	0,67
No. Seat abreast	0,26	3,00	3,77	0,58	-0,25	0,83
Take-off (m)	0,06	1500,00	1587,38	3,20	-0,16	3,36
Landing Distance (m)	0,04	1290,00	1242,56	3,09	-0,12	3,22
Speed (Mach)	0,09	0,62	0,67	-0,17	-0,04	-0,13
Max. wing load (kg/m2)	0,23	375,15	459,99	2,66	-0,11	2,78
Thrust/Weight Ratio	0,04	0,33	0,32	-0,50	0,05	-0,54
MTOW (kg)	0,07	19200,00	20557,66	4,31	-0,74	5,06
Thrust (N)	0,02	62640,00	63905,59	4,81	-0,70	5,51
	0,26					

	K-matrix																SVD variables	w-diagonal	residual
Passenger Capacity	0,270	-0,024	0,009	-0,011	0,050	-0,012	0,004	-0,001	0,007	-0,020	0,001	0,007	-0,004	0,005	0,000	0,000	-2,12	6,82	4,95
Design range (km)	0,246	-0,037	-0,068	0,006	-0,040	0,009	0,019	0,007	0,001	-0,007	0,001	0,004	-0,003	0,003	0,000	0,000	-0,19	1,11	0,29
Wing Area (m²)	0,296	0,026	-0,004	0,012	-0,014	-0,028	-0,026	0,010	0,001	-0,001	0,001	0,000	0,000	-0,004	0,000	0,000	-0,69	0,95	0,29
Wing Aspect Ratio	-0,014	-0,027	-0,009	-0,018	0,008	-0,008	0,010	-0,001	-0,010	-0,004	-0,003	-0,007	-0,009	-0,018	0,000	0,000	0,00	0,80	0,26
VT Area (m²)	0,256	0,014	0,027	-0,029	-0,011	0,047	-0,013	0,011	0,004	-0,010	-0,002	-0,004	0,005	-0,003	0,000	0,000	0,00	0,71	0,24
VT Aspect Ratio	0,055	-0,093	0,046	0,042	-0,015	0,005	-0,013	-0,009	0,005	0,001	-0,001	-0,001	-0,001	-0,001	0,000	0,000	0,00	0,59	0,11
HT Area (m²)	0,297	0,026	0,060	0,010	-0,016	-0,008	0,034	0,005	-0,016	0,002	0,000	0,002	-0,001	0,002	0,000	0,000	0,00	0,52	0,10
HT Aspect Ratio	-0,038	-0,048	-0,004	-0,026	0,008	-0,001	-0,013	0,019	-0,028	0,004	0,004	0,006	0,008	0,001	0,000	0,000	0,00	0,48	0,10
No. Seat abreast	0,116	-0,016	0,016	-0,039	-0,002	0,002	-0,003	0,011	0,013	0,020	0,003	0,005	-0,013	0,002	0,000	0,000	0,00	0,37	0,09
Take-off (m)	0,079	0,015	-0,011	0,043	0,027	0,023	0,007	0,009	0,004	0,008	0,003	0,013	0,003	-0,010	0,000	0,000	0,00	0,31	0,09
Landing Distance (m)	0,059	0,025	-0,013	0,028	0,011	0,023	-0,018	-0,006	-0,021	-0,001	0,000	-0,003	-0,015	0,006	0,000	0,000	0,00	0,14	0,10
Speed (Mach)	0,015	0,003	0,004	0,002	0,003	0,003	0,005	-0,003	0,004	-0,003	0,014	-0,013	0,000	-0,001	0,000	0,000	0,00	0,24	0,10
Max. wing load (kg/m2)	0,061	-0,027	-0,014	-0,006	0,028	0,017	0,019	-0,007	-0,001	0,011	-0,003	-0,009	0,004	0,004	0,000	0,000	0,00	0,21	0,08
Thrust/Weight Ratio	-0,023	0,005	0,004	-0,021	-0,013	0,008	-0,001	-0,034	-0,004	-0,002	0,003	0,010	0,000	-0,002	0,000	0,000	0,00	0,20	0,07
MTOW (kg)	0,357	-0,002	-0,018	0,007	0,014	-0,011	-0,007	0,003	0,001	0,009	-0,002	-0,009	0,004	0,000	0,000	0,000	0,00	0,00	0,00
Thrust (N)	0,334	0,003	-0,014	-0,014	0,000	-0,003	-0,007	-0,031	-0,004	0,008	0,000	0,001	0,004	-0,002	0,000	0,000	0,00	0,00	0,00

Figure 11 – The reduced SVD model where just three variables are used to make predictions.

The results in Fig. 11 shows that the *Embraer EMB 145* reference aircraft can be predicted within 26 % relative error using just three SVD variables. In this case, three SVD variables are used to make the predictions for the intended Airbus A220 aircraft from the ontology. The built-in solver in Excel is used to determine the values for the SVD variables that gives an aircraft with the same range and passenger requirements as those coming from the ontology. Consequently, the objectives in the solver for the three SVD variables are used to find a solution for the requirements corresponding to the Airbus A220; which in this case is a passenger capacity of 120, a range of 6400 km, and to a minimum MTOW. Figure 12 shows the resulting estimated Airbus A220 characteristics with three SVD variables compared with some publicly available data in the reference column with yellow background.

	Rel error	Airbus A220	Estimate	Adjusted	Result	Average	K-matrix																SVD variables	w-diagonal	residual
Passenger Capacity	0,00	120,00	120,00	2,08	-0,26	2,34	0,270	-0,024	0,009	-0,011	0,050	-0,012	0,004	-0,001	0,007	-0,020	0,001	0,007	-0,004	0,005	0,000	0,000	-1,04	6,82	4,95
Design range (km)	0,00	6400,00	6400,00	3,81	0,02	3,79	0,246	-0,037	-0,068	0,006	-0,040	0,009	0,019	0,007	0,001	-0,007	0,001	0,004	-0,003	0,003	0,000	0,000	-1,96	1,11	0,29
Wing Area (m²)	0,23	112,30	86,00	1,93	-0,35	2,28	0,296	0,026	-0,004	0,012	-0,014	-0,028	-0,026	0,010	0,001	-0,001	0,001	0,000	0,000	-0,004	0,000	0,000	-3,00	0,95	0,29
Wing Aspect Ratio	0,06	10,97	10,33	1,01	0,09	0,92	-0,014	-0,027	-0,009	-0,018	0,008	-0,008	0,010	-0,001	-0,010	-0,004	-0,003	-0,007	-0,009	-0,018	0,000	0,000	0,00	0,80	0,26
VT Area (m²)	-	-	12,71	1,10	-0,37	1,48	0,256	0,014	0,027	-0,029	-0,011	0,047	-0,013	0,011	0,004	-0,010	-0,002	-0,004	0,005	-0,003	0,000	0,000	0,00	0,71	0,24
VT Aspect Ratio	-	-	1,41	0,15	-0,01	0,16	0,055	-0,093	0,046	0,042	-0,015	0,005	-0,013	-0,009	0,005	0,001	-0,001	-0,001	-0,001	-0,001	0,000	0,000	0,00	0,59	0,11
HT Area (m²)	-	-	13,43	1,13	-0,54	1,67	0,297	0,026	0,060	0,010	-0,016	-0,008	0,034	0,005	-0,016	0,002	0,000	0,002	-0,001	0,002	0,000	0,000	0,00	0,52	0,10
HT Aspect Ratio	-	-	6,57	0,82	0,15	0,67	-0,038	-0,048	-0,004	-0,026	0,008	-0,001	-0,013	0,019	-0,028	0,004	0,004	0,006	0,008	0,001	0,000	0,000	0,00	0,48	0,10
No. Seat abreast	0,01	5,00	4,93	0,69	-0,14	0,83	0,116	-0,016	0,016	-0,039	-0,002	0,002	-0,003	0,011	0,013	0,020	0,003	0,005	-0,013	0,002	0,000	0,000	0,00	0,37	0,09
Take-off (m)	0,15	1676,50	1927,07	3,28	-0,08	3,36	0,079	0,015	-0,011	0,043	0,027	0,023	0,007	0,009	0,004	0,008	0,003	0,013	0,003	-0,010	0,000	0,000	0,00	0,31	0,09
Landing Distance (m)	0,04	1448,00	1396,28	3,14	-0,07	3,22	0,059	0,025	-0,013	0,028	0,011	0,023	-0,018	-0,006	-0,021	-0,001	0,000	-0,003	-0,015	0,006	0,000	0,000	0,00	0,14	0,10
Speed (Mach)	0,15	0,80	0,68	-0,17	-0,03	-0,13	0,015	0,003	0,004	0,002	0,003	0,003	0,005	-0,003	0,004	-0,003	0,014	-0,013	0,000	-0,001	0,000	0,000	0,00	0,24	0,10
Max. wing load (kg/m2)	0,15	561,89	644,74	2,81	0,03	2,78	0,061	-0,027	-0,014	-0,006	0,028	0,017	0,019	-0,007	-0,001	0,011	-0,003	-0,009	0,004	0,004	0,000	0,000	0,00	0,21	0,08
Thrust/Weight Ratio	0,06	0,30	0,29	-0,54	0,00	-0,54	-0,023	0,005	0,004	-0,021	-0,013	0,008	-0,001	-0,034	-0,004	-0,002	0,003	0,010	0,000	-0,002	0,000	0,000	0,00	0,20	0,07
MTOW (kg)	0,12	63100,00	55449,07	4,74	-0,31	5,06	0,357	-0,002	-0,018	0,007	0,014	-0,011	-0,007	0,003	0,001	0,009	-0,002	-0,009	0,004	0,000	0,000	0,000	0,00	0,00	0,00
Thrust (N)	0,17	187700,00	155744,24	5,19	-0,31	5,51	0,334	0,003	-0,014	-0,014	0,000	-0,003	-0,007	-0,031	-0,004	0,008	0,000	0,001	0,004	-0,002	0,000	0,000	0,00	0,00	0,00
	0,23																								

Figure 12 – The reduced SVD model where the solver has been used to estimate the Airbus A220 aircraft using only three SVD variables.

The estimation results presented in Fig. 12 show good agreement with the found Airbus A220 reference data. The highest difference comes from an under estimation of the wing area. However, the intention with the SVD analysis is to expand the configuration and requirement data coming from the ontology in order to give fairly accurate estimations for a continued geometrical sizing procedure. The obtained results are therefore deemed as reasonable "ballpark" estimates for this case study. These results have consequently shown how just two requirements, range and passengers, can be used with an SVD model to expand and estimate additional information about a concept for a continued sizing procedure.

4.4 Initial Geometry Layout and Performance Estimation

The sizing of the aircraft concept is also performed using Excel, mostly using the equations from [15, 16]. These equations are further simplified to reduce the number parameters needed as inputs for sizing as explained in Sec. 2.5, using relational design [22, 23]. The SVD values obtained in the previous section are used as the input parameters. The primary inputs are the number of passengers and the range of the aircraft. The former enables to obtain the cabin size, and further, the total length of the fuselage. Both the primary inputs help in designing the wing and are proportional to the size of the wing; if either of the parameters are increased, the size of the wing increases or vice versa.
For both the HT and VT, only two parameters are needed, namely, aspect ratio and volumetric coefficient for sizing. The positioning of both tail surfaces is relative to the length of the fuselage. The wing area obtained previously, and the volumetric coefficient, aid in obtaining the respective tail areas while the aspect ratio helps in giving a form to the tail surfaces. The volumetric coefficients for the HT and VT are computed from the respective areas provided by the SVD model. Furthermore, the cruise speed gives an updated performance value of the aircraft. The below mentioned parameters are obtained from the SVD analysis and inserted to the *Initial Geometry Layout Excel* implementation. These are presented in-respect to relational design as described earlier in Sec. 2.5 along with the performance parameters.

- **Global parameters**: Passenger Capacity, Design Range, Design Speed, No. Seat Abreast, Thrust
- **Interrelated parameters**: Wing Area, Wing Aspect Ratio, VT Area, VT Aspect Ratio, HT Area, HT Aspect Ratio
- **Performance parameters**: Take-off Distance, Landing Distance, Max. Wing Loading, Thrust to Weight Ratio, MTOW

A 2D geometry, updated with the values obtained from the SVD analysis, is shown in Fig. 13. The engines are not presented in Fig. 13 as their details were not part of the SVD analysis, nevertheless, they are used in the sizing.
The SVD parameters are further exported using RAPID [22, 23] to obtain a 3D geometry as shown in Fig. 14. The initial 3D geometry (Fig 14 (Left)), is obtained using the SVD results and additional parameters to get the form of the airfoil or fuselage as represented by the *Relational References* in

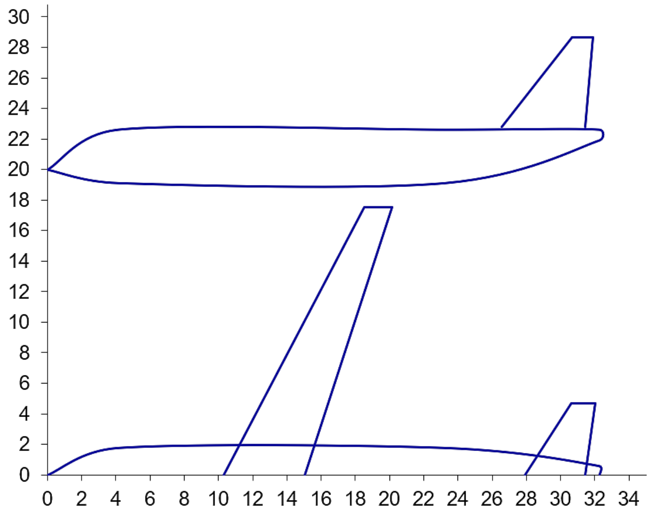

Figure 13 – The aircraft's initial geometrical layout (all dimensions are shown in meters) which has been obtained by inserting the SVD analysis values together with minor changes to the sweep angles of all lifting surfaces.

Fig. 2. Subsequently, engines and kink have been added to the wing, as shown to the right in Fig. 14.

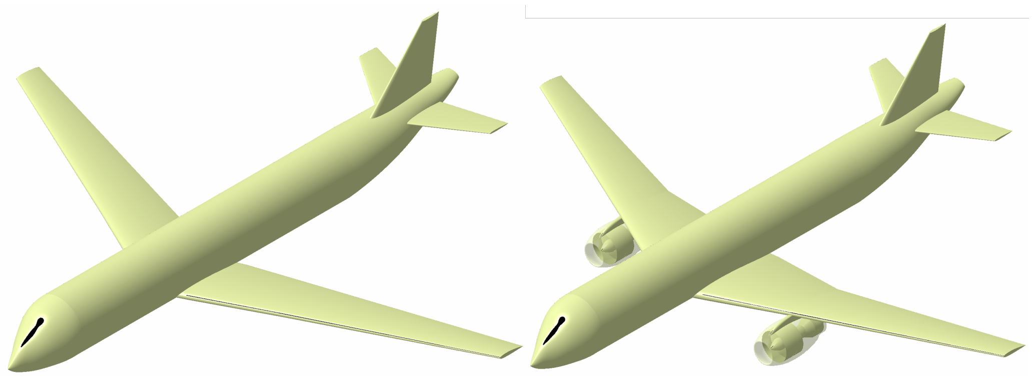

Figure 14 – The 3D geometry in *Robust Aircraft Parametric Interactive Design* (RAPID); initial geometry obtained by inserting the SVD analysis values (left) and the updated geometry with a kink wing (right).

4.5 Results and Feedback to Ontology

The results from the initial geometrical sizing can now be reintroduced and added to the original knowledge base in the ontology representation. The resulting concept is, however, before that checked against the relevant requirements in the excel implementation to see if these are still fulfilled and that the concept thereby still is valid. For this case study, the number of passenger and range requirements are the only ones used and are therefore considered as fulfilled by this concept. The newly obtained information about the concept from the SVD analysis and geometrical sizing can consequently be used to automatically update the OWL-file and the corresponding individual with, for example, new data properties describing the sizing results. Figure 15 shows a new and identical individual to the *A220 Estimation Concept* but with some of the sizing results added as additional data properties.

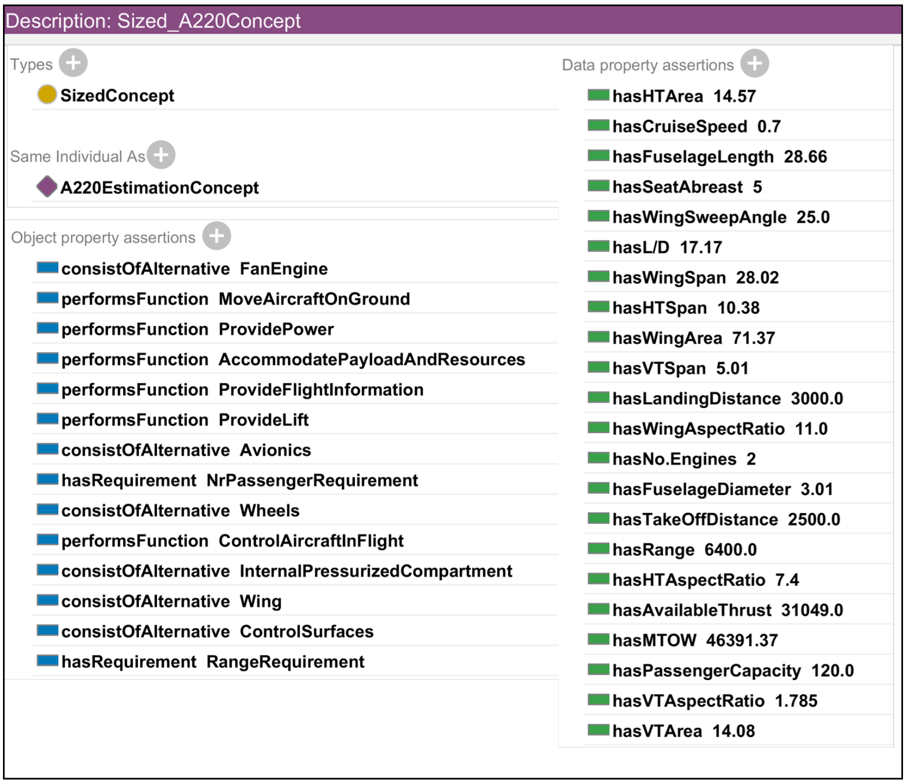

Figure 15 – The description of the new *Sized_A220Concept* individual.

5. Discussion and Outlook

The case study presented in the previous section has been used to test and illustrate the proposed method of this paper. It has consequently showed how an ontology can be used to represent a design space of functions and their alternatives and how that can be used to generate concepts for further analysis outside the ontology. *Singular Value Decomposition* (SVD) was chosen as the approach for expanding the requirement information from the ontology and to perform the *Approximate Concept Properties* step in Fig. 3. An SVD provides cheap and fast estimations from a computational point of view. However, there are many other techniques that can be used to approximate a concept's properties as well. One way of doing this would be to use more traditional statistical methods, such as single or multiple regression analyses. This would, however, require a more extensive build-up of calculations models from the underlying data. The SVD analysis did, nevertheless, give results that corresponded to the characteristics of the Airbus A220 relatively well. As the main idea was to expand the information from the ontology and to get first estimates for the continued sizing, this was deemed as sufficient for this study. The continued sizing was mainly performed in order to obtain a geometrical representation of the aircraft. However, this step could just as well have been continued with, for example, the guidelines presented in [15] to get a more detailed evaluation of the aircraft design overall. This would consequently lead to even more information that could be added to the ontology and overall knowledge base.

The ontology representation was kept relatively simple in the presented case study. The involved functions to be fulfilled could, however, be expanded in the future. For example, with different functions coming from an overarching *System-of-Systems* (SoS) perspective. These functions could then be allocated to different concepts that later can be evaluated together, for example, using *Agent Based Simulations* (ABS) to identify the most suitable SoS solutions. This is a prominent topic for future work that would enable design and trade space explorations on all levels presented in Fig. 1. Moreover, one of the purposes with the method in Fig. 3 was to be able to perform numerical calculations outside the ontology description and then reinsert the results again. It could, however, be possible to perform some simple "calculations" directly in the ontology using languages such as the *Semantic Web Rule Language* (SWRL) and the *Semantic Query-Enhanced Web Rule Language* (SQWRL) to transition between the closed and open world assumptions. Consequently, such an investigation is another important topic for future work. An additional observation is that the ontology part of this work also could be represented in a UML or SysML format, as the ontology simply represents entities and their relationships. However, as described earlier, this would imply that description logic reasoning cannot be used, and that overall expressiveness is reduced. There are, however, various approaches and tools for converting UML representations to ontologies. This is consequently also something that could be investigated in the future to, among other things, get more comprehensive representations of relevant requirements. It could, in that case, also be possible to connect the overall workflow to existing requirement specifications in UML or SysML format directly instead of modelling them in the ontology.

Only two SVD datasets were represented in the current ontology. This is also a possible topic for future work as more details can be added to narrow down the selection of relevant datasets based on the chosen alternatives for a concept. For example, if an *Internal Non-Pressurized Compartment* is chosen as the alternative for the *Accommodate Payload and Resources* function, a reasoner could suggest that an SVD dataset based on aircraft without pressurized cabins only would be an appropriate choice for a continued analysis. This would, however, require several different datasets and mappings to corresponding design alternatives. The design alternatives to the represented functions in the case study were mainly used to illustrate the workflow and possibilities with the presented approach. There are most likely more alternatives to each function in the *Interactive Reconfigurable Matrix of Alternatives* (IRMA) from Fig. 6 that could be used to create a larger selection of possible concepts. It is also possible to expand the listed functions with sub-functions, and thereby even more design alternatives in general. This was not done in the current case study in order to keep the overall work easier to follow. This is, however, something that easily can be added in the future thanks to the flexibility and scalability of ontologies. The concept selection could have been performed without the IRMA in this study, as the functions and corresponding alternatives were relatively few. However, an IRMA is a powerful tool that can facilitate the concept selection process in studies with more functions to realize. It provides a good overview of existing alternatives and their compatibilities depending on the designer's selections. This can be very helpful in design studies with more alternatives and for decision makers that do not necessarily have expert knowledge about the domain in question. An IRMA thereby also provides a visual representation of the available design space and how it changes depending on different design choices.

The method in Fig. 3 is currently not fully automatic and some steps have been manually applied. Consequently, an automatic implementation of the workflow from Fig. 3 is a planned addition to the presented work. This would thereby enable automatic expansion of a chosen concept's properties and characteristics which subsequently can be found as reinserted knowledge in the ontology representation. This could in that case also include, for example, uncertainty measures from the different estimation steps so that such aspects would be accounted for in the ontology as well. A design space of initially sized concepts would thereby be available and description logic reasoning could consequently be used once again to process it and, for example, give suggestions on suitable solutions given different needs and overarching requirements from an SoS perspective.

Lastly, the effective parameterization represented in Fig. 2 is the methodology implemented for creating both 2D and 3D geometries. This way of parametrization avoids any poor performance of the geometric model after its design. The number of parameters that were obtained from the SVD analysis was sufficient for creating a 2D geometry, however, more parameters are needed to create a 3D geometry. It is to be noted that for creating an improved ontology-based design, the 3D geometry needs to be thoroughly evaluated beforehand. The flow of parameters, or the relationships between the parameters, needs to be well established before creating the geometry. As the intention of this work was to present a method for aircraft concept generation with the help of an ontology description, only the needed details on the geometry and its build-up are presented, and more details and information on geometry build-ups are found in Munjulury et al. [22]. Improvements on the existing ontology are needed to accommodate more parameters to create a more detailed geometry in the future. The geometry also needs to be improved in order to skip the 2D geometry part and be able to generate a 3D geometry directly using standardized formats, such as the *Common Parametric Aircraft Configuration Schema* (CPACS) [28] or the *System Structure and Parameterization* (SSP) [29].

Consequently, a framework that uses one of the standards just mentioned, to generate the geometry with the help of an ontology description, needs to be developed in the future.

6. Conclusion

This paper has proposed a method for generating an aircraft concept from an ontology represented design space, where relevant information subsequently can be extracted and expanded through approaches such as a statistical *Singular Value Decomposition* (SVD) analysis. This resulting information has thereafter been used as inputs for an initial geometrical sizing procedure, which has generated a first sized version of the chosen concept. The obtained information from the sizing procedure has finally been reintroduced into the ontology in order to expand the original knowledge base. A case study was used to show how the method could be utilized in order to estimate the characteristics of an Airbus A220 aircraft from basic configuration and requirement information. The resulting estimated aircraft showed good agreement with publicly available data of the A220, and the case study has consequently illustrated the workflow, as well as the utility, of the method proposed in this paper.

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8. Copyright Statement

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