AVD^{KBS} - Standing on the Shoulders of Giants

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Abstract

George Santayana is known for saying "*Those who cannot remember the past are condemned to repeat it*". Throughout the development history of aerospace engineering conceptual design, much knowledge has been generated although, to the best of our knowledge, no efficient system has been developed to help aerospace communities keep and use such valuable inheritance. In this context, we do routinely witness events such: (i) the failure of aerospace projects, like Titan IV, whose explosion has been deemed the responsibility of a design defect; (ii) the losing of valuable aerospace specialists and their expertise, like at Boeing, "*…more than half of the Boeing work force will be eligible for retirement within the next decade. That's roughly 80,000 employees' cumulative corporate wisdom walking out the door*."; (iii) the ostensibly well-kept but not easily accessible knowledge has seldom shown its value and contributed to activities, like the books and journals covered by dust in library.

In order to efficiently use energy, time and money, and apply previous precious design knowledge to current aerospace design problems, the key requirements on which a modern knowledge-based system (KBS) have to be based reads as follows: (i) accumulate and maintain aggregate knowledge; (ii) supply information relevant to any particular design effort; (iii) predict unavailable information based on trends from available knowledge.

To this end, a first of its kind aerospace conceptual design knowledge based system, AVD^{KBS}, is introduced in this paper. It provides researchers with a convenient way of storing, applying and predicting knowledge in a total systems approach. The categories of the system are differentiated by knowledge collection, exhibition, application, innovation and update. The structure of AVD^{KBS} is constructed according to the requirements of the AVD parametric sizing method - AVD^{SIZING}, providing an integrated iterative conceptual design capability. All those concepts are demonstrated by a novel proof of concept case study, such like the re-engineering of *Project Mercury*. This case study seeks to showcase AVD^{KBS} as a standalone system in addition to its integration into a multi-disciplinary parametric design environment.

Background

In the history of human society, the value of knowledge can never be over emphasized. Current human achievements, like exploring the Mars and moving at the hypersonic speed, are all based on massive findings and subsequent applications. Moreover, current age is often referred as an *Exponential Knowledge Explosion* age, and it is estimated "*a week's worth of New York Time's contains more information than a person was likely to come across in a lifetime in the 18th century*". Consequently, facing the already overwhelming and still exponentially growing amount of knowledge, a question comes into existence: how should we efficiently manage those valuable legacies and assets for future activities?

Besides the traditional ways of knowledge retention, like textbooks, journals and encyclopedias, benefiting from the development of computer science, researchers all over the world propose various Knowledge-Based Systems (KBS) to proficiently capture, store and apply knowledge. The following table is a succinct summarization of the KBSs developed during the past decades:

Table 1 Knowledge-Based Systems (KBS) Development

Researchers	**Year**	**Discipline**	**Contribution**
John F Gilmore[1]	1984	Computer Science	Discussion on system requirements of a KBS
Kunio Murakami[2]	1984	Computer Science	Preliminary research on inference engine and knowledge base
Fu Tong[3]	1985	Computer Science	Investigate environment for building KBS supporting various knowledge functions
Anton Bigelmaier[4]	1986	Computer Science	Discuss representation problems in CAD-system KBS building
Haruo Yokota[5]	1986	Computer Science	Propose a model and architecture of a KBS with unification applications
L. Marinos[6]	1989	Computer Science	Propose an architectural framework for integrating database and knowledge base
M.A. El-Kady[7]	1990	Electrical Engineering	Build a knowledge-based system for power cable design
O. Felix Offodile[8]	1991	Mechanical Engineering	Build a KBS for choosing assembly robot for mechanical assembly.
Stipe Fustar[9]	1992	Electrical Engineering	Develop a knowledge-based system for weekly power system operation scheduling
N. Sirilertworakul[10]	1993	Mechanical Engineering	Establish a knowledge-based system for selecting casting alloys and process

Bojan Dolsak[11]	1994	Mechanical Engineering	Build a KBS on deciding the appropriate mesh resolution
A.M. Buis[12]	1996	Geodetic Engineering	Develop a KBS to be combined with GIS to support parceling design task
Stewart Long[13]	2003	Computer Science	Build a knowledge-based system to automatically assess IT skills
Nobuhide Nishiyama[14]	2006	Computer Science	Develop a KBS for QoS service
Kihyeon Kim[15]	2007	Information Technology	Build a knowledge-based system for diagnosing ECG and heart disease
Ali Malkawi[16]	2007	Civil Engineering	Integrate KBS with a thermal simulation engine for replacement building features
S. Guo[17]	2009	Power Engineering	Build a KBS for Fault Diagnosis in Solar Power Tower plant
Shaobin Chen[18]	2010	Mechanical Engineering	KBS working with remote sensing module for target recognition tasks
Tomasz Kowalewski[19]	2010	Naval Engineering	Build KBS with hazard zone identification system for the ship power plants design
Yannick Naudet[20]	2011	Illuminating Engineering	Develop a knowledge-based system on daylighting performance in facade design

In 1980s, based on the evolution of artificial intelligence technologies, researchers from Computer Science field try to apply those technologies into a new application area – the knowledge-based systems. Those systems are supposed to manage certain domain knowledge using reasoning techniques, so that they can provide advice aiding human activities.

To build such systems, researchers first propose frameworks and models to clarify the problems like: what components the systems should possess in terms of both hardware and software and how they should work in order to perform the supposed functions. The aim of this effort is to point out a path to the functional knowledge-based systems, but no actual system is developed at this stage. In this era, John F. Gilmore[1] discusses the system requirements of KBSs, their relevance with computer-aided technology and points out a potential application. Kunio Murakami et al[2] do preliminary research on inference engine and the related knowledge base. Anton Bigelmaier[4] investigates the representation problems for geometrical knowledge in CAD-system knowledge base building, including rule knowledge and method knowledge, and he suggests they can be represented by operations and structures of operations.

After the initial theoretical preparations, researchers begin to build knowledge-based systems. Based on the development of operation systems and programming languages, like Prolog and Python, and more affordable and powerful computing hardware, many systems in a variety of fields are developed. Those systems are usually combined with the artificial intelligence techniques, such as Rule Based Reasoning and neural networks, so that they can perform the basic system functions, including interpretation, reasoning and retrieval. However, those systems can only provide advice to human users based on simple input and reasoning procedure, and the application and selection of those advices are performed by users, so the overall analysis process is still manual. That's why those systems are often referred as Expert Systems. The selected examples in this kind of knowledge-based systems are: a power cable design knowledge-based system from M.A. El-Kady et al[7] , it can both assist designers in design and educate fresh engineers; an assembly aiding knowledge-based system developed by O. Felix Offodile et al[8] , which can receive user demand and layout specifications to choose the mechanical assembly robotic systems based on the information in the assembly robots knowledge base; a work scheduling knowledge-based system from Stipe Fustar et al[9] , it can provide assistance for weekly power system operation scheduling including "load prediction, inflow prediction, possible run-of-river hydro production, storage hydro production, unit commitment, generator maintenance and power interchange between interconnected power systems".

Around the beginning of 1990s, researchers find the great potential of combining the newly developed knowledge-based systems with the existing systems, like databases or processing modules, so that they can work together to perform more complex tasks. L. Marinos et al[6] start proposing a framework for integrating the knowledge base and database, focusing on the knowledge and data representation problems. However, the real functional systems of this kind come into existence around 2000s. A.M. Buis et al[12] develop a knowledge-based system, which can work with the Geographical Information System to help finish more and more difficult parceling design work. Besides this, more systems in this kind are developed later on. Ali Malkawi et al[16] combine their knowledge-based systems with a thermal simulation engine and a database to assist the decision making for choosing replacement building features. Shaobin Chen et al[18] incorporate the knowledge-based system with a remote sensing module to conduct target recognition tasks. Because this kind of knowledge-based system are linked with either database or other functional modules, they can either use the collected data to enrich their knowledge source, or take advantage of past project experiences to make it as starting points for the new analysis, like Case-Based Reasoning (CBR). In this way, it saves human energy and time, but most of those systems are not totally automatic and they need human help to accomplish the analysis.

In current age, based on the mature of the knowledge-based systems, its application area has greatly expanded. Besides their traditional applications in Engineering and Computer Science fields, they quickly show their excellence in other industry and academic fields, like medical care, agriculture, business management, textile and so on. Kihyeon Kim et al[15] build a knowledge-based system for ECG and heart disease diagnosis. Yannick Naudet et al[20] develop a knowledge-based system to take both visual performance and visual comfort of the daylighting performance into the façade design. In some application field, the knowledge-based system can even automatically accomplish an analysis task. Stewart Long et al[13] use a knowledge-based system to automatically assess candidates' IT skills to check their qualification. To keep up with the internet developments, researchers also develop web-based knowledge-based systems, so that the application can serve remote customers. Nobuhide Nishiyama et al[14] use semantic web language to build an online knowledge-based system for QoS services.

However, until now, no effort has been spent on theoretically summarizing the development of the knowledge-based systems to offer a big picture of them, and few of the existing systems provides a knowledge update mechanism for updating purposes. Consequently, those systems easily become obsolete after a short amount of time.

Motivation

Due to the complexity and multi-disciplinary constraints in aerospace engineering conceptual design, the knowledge management methods are still traditional, consisting of textbooks, journals, engineering drawings, archives, report servers, lessons learned documents, etc. According to our literature search, there are only a few KBSs efforts proposed, none of them has produced a practical KBS for aerospace design application; see Table 2.

Table 2 Knowledge-Based Systems Development in Aerospace Engineering Design

Researchers	**Year**	**Discipline**	**Contribution**
Christian Freksa[21]	1986	Aerospace Engineering	Framework proposal of knowledge engineering for design expert systems.
Stewart Baily[22]	1987	Aerospace Engineering	Proposal of knowledge-based aeronautical conceptual design system.
W. A. Dos Santos[23]	2009	Aerospace Engineering	KBS for satellite conceptual design.
C. Gong[24]	2010	Aerospace Engineering	Knowledge-based tactical missile intelligent conceptual design environment.

For any KBS in engineering design, the first task is to collect the design knowledge, and then document and archive it. After that, some mechanism needs to be developed to utilize it. During the application process, if the current information available to the user is sparse, new knowledge needs to be generated to solve the unknown. Based on this, any successful KBS must be capable of (a) knowledge collection, (b) knowledge categorization, (c) knowledge application, (d) knowledge innovation and (e) knowledge update. This first-order KBS specification will be used as criteria to evaluate the KBS development in aerospace engineering design and decision-making.

Besides the latest work from W.A. Dos Santos and C. Gong (WDCG) in Table 2, three other widely used aerospace engineering resources are also selected for comparison: *Jane's All the World's Aircraft* (JAWA), *AIAA Electronic Library* (AIAA) and *CATIA V5* knowledge ware tools (CATIA).

Table 3. Current Aerospace Engineering Design KBSs Comparison

Item	JAWA	AIAA	CATIA	WDCG
Knowledge Collection	√	√	√	√
Knowledge Categorization	×	√	√	√
Knowledge Application	×	×	√	√
Knowledge Innovation	×	×	×	×
Knowledge Update	×	×	×	×

From the comparison in Table 3, it is obvious to conclude that none of the listed KBS is capable of storing, categorizing, applying, inventing and updating knowledge. A truly practical aerospace KBS implementation is still absent in the current aerospace engineering design community. The *AVD Laboratory* at UTA makes the very first effort in developing an industry-relevant thus practical aerospace KBS dedicated to the strategic conceptual design phase.

Methodology and Implementation

Introduction

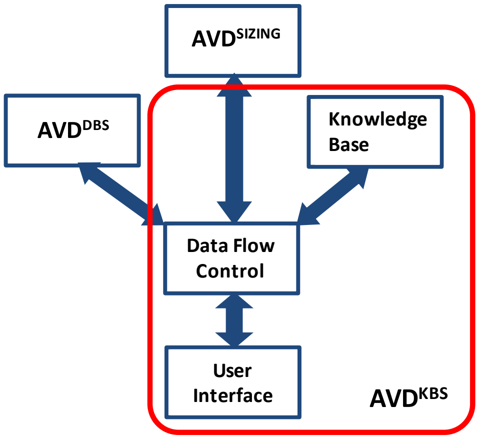


Figure 1. AVD^{KBS} Components and Logic Relationship to AVD^{DBS} and AVD^{SIZING}

AVD^{KBS} is developed to function in two primary modes: (a) a standalone system for knowledge storage, education and reference, and (b) as an interactive system with other AVD methodology modules to complement the parametric aerospace sizing process. The general relationship of AVD^{KBS} within the existing AVD design environment is:

AVD^{KBS} mainly contains three primary components: the (a) knowledge base, (b) data flow control unit, and (c) the user interface. The *knowledge base* resembles the actual knowledge pool. The *data flow control unit* consists of mechanisms which are designed to manipulate the data transfer between the knowledge base and the other logical modules, see Figure 1. This module is responsible for providing the system-logic to AVD^{KBS}; it performs all the system functions to connect previously independent systems in order to make them work as an integrated unit. The *user interface* provides a software connection between the user and the system to perform system functions (knowledge entry, knowledge manipulation) without getting into details of MS Access and Matlab coding.

System Level

In order to implement the capabilities of knowledge storage, classification, application, creation and update, we propose a five-level KBS classification and organization scheme:

1) *Knowledge Collection*: gather knowledge from various resources, which mainly contains the lessons learnt, design guidelines and past project experiences.
2) *Knowledge Categorization*: sort collected knowledge according to certain criteria, and express them in a variety of forms for further applications (tabular, numerical, graphical, text, etc.).
3) *Knowledge Application*: employ the categorized information in multiple tasks, including young engineer education, research reference and automatic parametric sizing process.
4) *Knowledge Innovation*: generate new knowledge through reasoning mechanisms (AVD^{SIZING} reasoning technique) to solve the unknowns.
5) *Knowledge Update*: manual/automated knowledge updating (dynamic KBS).

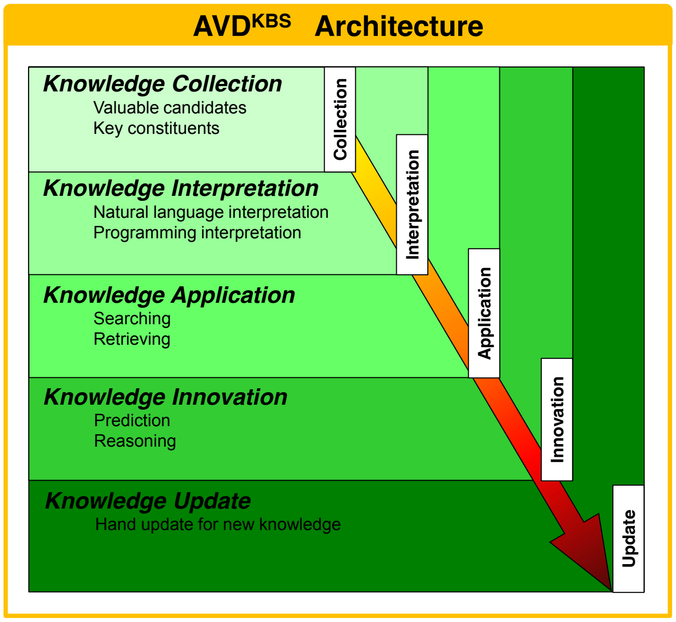


Figure 2. AVD^{KBS} Architecture and Hierarchy.

The prototype KBS implements the proposed concept by using the data and knowledge rich case study *Project Mercury*. The building process is introduced with the following sections.

Knowledge Collection

Knowledge collection is the first primary and non-trivial step in every KBS building process, and its aim is to identify and obtain all the required information. Its completeness and correctness directly influence the KBS quality and functions. This process lasts throughout the whole KBS life cycle, thus it resembles the notion of 'life-long learning'. Any newly collected or generated knowledge has to update the system manually or automated.

The knowledge base assembled for the *Project Mercury* launcher consists of conceptual design level methods, experiences and lessons learnt, all spanning *Project Mercury* from launch until completion. This information is valuable, because it contains the key points of how the problems have been solved during the conceptual design phase. It directly does mirror what mistakes can be avoided.

The knowledge sources are mainly formally published project report. *Project Mercury* is an especially rich data, information and knowledge case study. The general *Project Mercury* information resources available can be divided into the following categories:

1) NASA reports: such as NASA SP-4001, NASA SP-4201, contract report NAS 1-430, etc.
2) NASA project conferences: such as *Project Mercury* presented at the Fourth Annual Meeting of the Human Factors Society and Press Conference at Washington D.C. on 9 April 1959.
3) NASA news releases: such as Fact Sheet MA-8.
4) Reports, papers and presentations from other institutions: such as the AIAA space flight testing conference.

The knowledge needed for the parametric sizing process is first identified. Then it is searched and located in the resource. And after that, detailed information, like author, application field, descriptions and so on are extracted and documented in the our own format for following applications.

Knowledge Categorization

After gathering the main part of information available from all resources, the knowledge is classified according to the primary engineering disciplines of relevance. For each discipline,

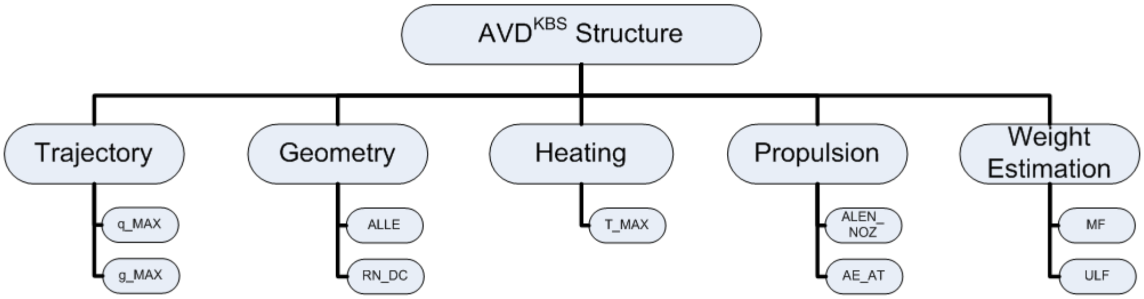


Figure 3. Project Mercury AVD^{KBS} Disciplinary Sub-structure.

gross design variables are identified for numerical knowledge harvesting purposes, see Figure 3. The five knowledge-rich disciplines of relevance for early design of *Project Mercury* are: trajectory, geometry, aero-thermo-dynamics-heating, propulsion and weight estimation, see Figure 3.

This early categorization of knowledge is providing a pragmatic structure to search, retrieve, document and utilize the knowledge available. Furthermore, the five disciplinary categories are directly interfacing with the needs of the 'reasoning technique' employed, the AVD sizing method and software AVD$^{\text{SIZING}}$. Considering the system's generic potential for any other project of interest, the AVD$^{\text{KBS}}$ storage structure facilitates both, the required disciplinary categories and the knowledge itself, overall providing a platform with growth potential for future expansion.

Each knowledge entry is classified to consist of two parts:

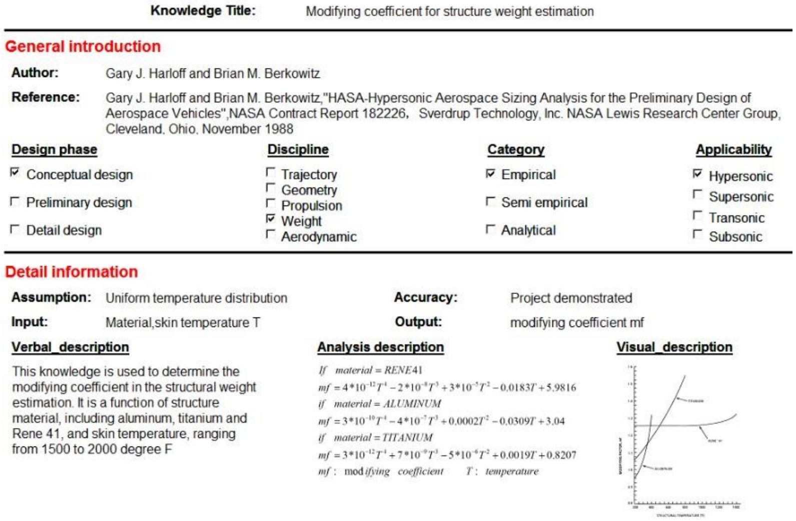
1) General Information: author, source and application area
2) Detailed Information: application assumptions, input & output, and complete knowledge contents.

For the knowledge *general information*, it summarizes who proposes the knowledge and in which publication. It also specifies its application area by differentiating the design phase, discipline, categories and applicability.

For the knowledge *detailed information*, since the original expression can be mathematical equations, engineering drawings, or only experience descriptions, then the original description will be expanded into either of the following three expression forms:

1) *Verbal Expression*: Engineering language employed to describe the details of the knowledge targeting the three primary user categories (a) decision-maker, (b) systems integrator, and (c) technologist.
2) *Mathematical Expressions*: Mathematical formulas in the form of numerical guidelines are used to illustrate trend-patterns in the knowledge available, targeting the reasoning technique AVD$^{\text{SIZING}}$ by aiding the automatic parametric sizing process. Again, the knowledge contents is prepared for targeting the three primary user categories (a) decision-maker, (b) systems integrator, and (c) technologist
3) *Visual Expressions*: Meaningful engineering drawings, figures and tables are used to express the knowledge contents at hand, targeting the three primary user categories (a) decision-maker, (b) systems integrator, and (c) technologist.

The above specification has been translated into a MS Access knowledge overview card and template, see Figure 4.



Knowledge Title: Modifying coefficient for structure weight estimation

General introduction

Author: Gary J. Harloff and Brian M. Berkowitz

Reference: Gary J. Harloff and Brian M. Berkowitz,"HASA-Hypersonic Aerospace Sizing Analysis for the Preliminary Design of Aerospace Vehicles",NASA Contract Report 182226, Sverdrup Technology, Inc. NASA Lewis Research Center Group, Cleveland, Ohio, November 1988

Design phase	Discipline	Category	Applicability
☑ Conceptual design	☐ Trajectory ☐ Geometry	☑ Empirical	☑ Hypersonic ☐ Supersonic
☐ Preliminary design	☐ Propulsion ☑ Weight	☐ Semi empirical	☐ Transonic
☐ Detail design	☐ Aerodynamic	☐ Analytical	☐ Subsonic

Detail information

Assumption: Uniform temperature distribution **Accuracy:** Project demonstrated

Input: Material,skin temperature T **Output:** modifying coefficient mf

Verbal_description

This knowledge is used to determine the modifying coefficient in the structural weight estimation. It is a function of structure material, including aluminum, titanium and Rene 41, and skin temperature, ranging from 1500 to 2000 degree F

Analysis description

$If \quad material = RENE41$

$mf = 4*10^{-12}T^4 - 2*10^{-8}T^3 + 3*10^{-5}T^2 - 0.0183T + 5.9816$

$if \quad material = ALUMINUM$

$mf = 3*10^{-10}T^4 - 4*10^{-7}T^3 + 0.0002T^2 - 0.0309T + 3.04$

$if \quad material = TITANIUM$

$mf = 3*10^{-12}T^4 + 7*10^{-9}T^3 - 5*10^{-6}T^2 + 0.0019T + 0.8207$

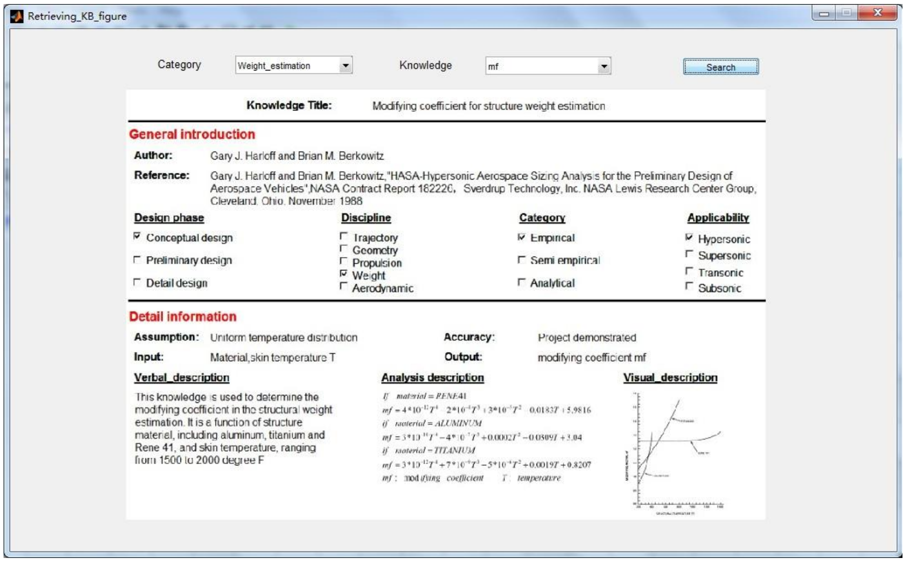
$mf: \quad modifying \quad coefficient \qquad T: \quad temperature$

Visual_description

Figure 4. Knowledge Overview Card and Template for *Project Mercury*.

Knowledge Application

Having prepared the available knowledge entries as described in the sections above, the knowledge application section builds mechanisms to pragmatically utilize the knowledge. This section provides two primary functions aimed at knowledge management: (a) knowledge searching and (b) knowledge retrieving.



Retrieving_KB_figure

Category: Weight_estimation Knowledge: mf

Knowledge Title: Modifying coefficient for structure weight estimation

General introduction

Author: Gary J. Harloff and Brian M. Berkowitz

Reference: Gary J. Harloff and Brian M. Berkowitz,"HASA-Hypersonic Aerospace Sizing Analysis for the Preliminary Design of Aerospace Vehicles",NASA Contract Report 182226, Sverdrup Technology, Inc. NASA Lewis Research Center Group, Cleveland, Ohio, November 1988

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Input: Material,skin temperature T **Output:** modifying coefficient mf

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This knowledge is used to determine the modifying coefficient in the structural weight estimation. It is a function of structure material, including aluminum, titanium and Rene 41, and skin temperature, ranging from 1500 to 2000 degree F

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$If \quad material = RENE41$

$mf = 4*10^{-12}T^4 - 2*10^{-8}T^3 + 3*10^{-5}T^2 - 0.0183T + 5.9816$

$if \quad material = ALUMINUM$

$mf = 3*10^{-10}T^4 - 4*10^{-7}T^3 + 0.0002T^2 - 0.0309T + 3.04$

$if \quad material = TITANIUM$

$mf = 3*10^{-12}T^4 + 7*10^{-9}T^3 - 5*10^{-6}T^2 + 0.0019T + 0.8207$

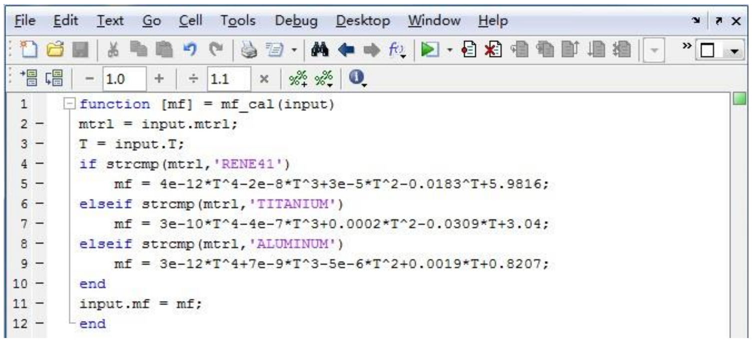
$mf: \quad modifying \quad coefficient \qquad T: \quad temperature$

Visual_description

Figure 5. Knowledge Searching Screen.

The knowledge searching function fulfills the research reference and education objectives. It facilitates the three primary user categories (a) decision-maker, (b) systems integrator, and (c) technologist to quickly find useful information and apply them to the problem at hand. Thus, it provides the learner relevant knowledge entries 'at the fingertips' in a filtered and clean format. A graphic searching window is created to identify relevant knowledge entries stored in the system. Figure 5 shows an example of knowledge entries related to a weight estimation method.

The retrieving function serves the automatic parametric sizing process AVD^{SIZING}. It automatically retrieves relevant knowledge entries from AVD^{KBS} and directly feeds the parametric formulation into the parametric sizing process. During the analysis, if a necessary variable is missing, a search mechanism will first go through a lookup table. If the variable is found, the name of the sub-function able to solve for the missing variable will be retrieved. The function will be executed and feeds its result directly into the parametric sizing process.

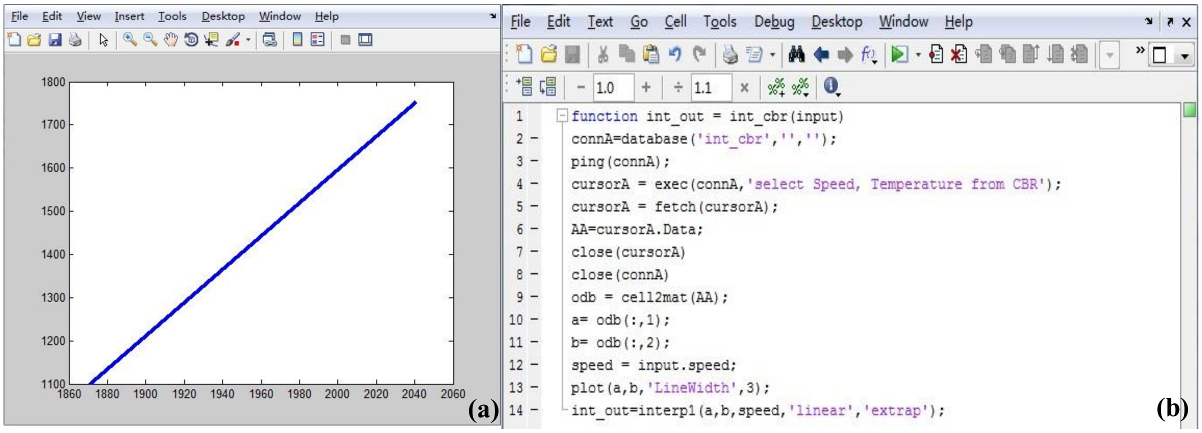


```
function [mf] = mf_cal(input)
mtrl = input.mtrl;
T = input.T;
if strcmp(mtrl,'RENE41')
    mf = 4e-12*T^4-2e-8*T^3+3e-5*T^2-0.0183^T+5.9816;
elseif strcmp(mtrl,'TITANIUM')
    mf = 3e-10*T^4-4e-7*T^3+0.0002*T^2-0.0309*T+3.04;
elseif strcmp(mtrl,'ALUMINUM')
    mf = 3e-12*T^4+7e-9*T^3-5e-6*T^2+0.0019*T+0.8207;
end
input.mf = mf;
end
```

Figure 6. Retrieving Sub-function Programming.

Knowledge Innovation

The knowledge retrieving functions can solve most of the missing information in the automatic parametric sizing process. However, if some necessary variable cannot be found in the lookup table thus AVD^{KBS}, the knowledge innovation mechanism has to be applied. It mainly conducts a Case Based Reasoning (CBR) process. The CBR will search the AVD^{DBS}; if the variable is found as applied for a past project, data related with the variable will be retrieved. Then, a regression



```
function int_out = int_cbr(input)
connA=database('int_cbr','','');
ping(connA);
cursorA = exec(connA,'select Speed, Temperature from CBR');
cursorA = fetch(cursorA);
AA=cursorA.Data;
close(cursorA)
close(connA)
odb = cell2mat(AA);
a= odb(:,1);
b= odb(:,2);
speed = input.speed;
plot(a,b,'LineWidth',3);
int_out=interp1(a,b,speed,'linear','extrap');
```

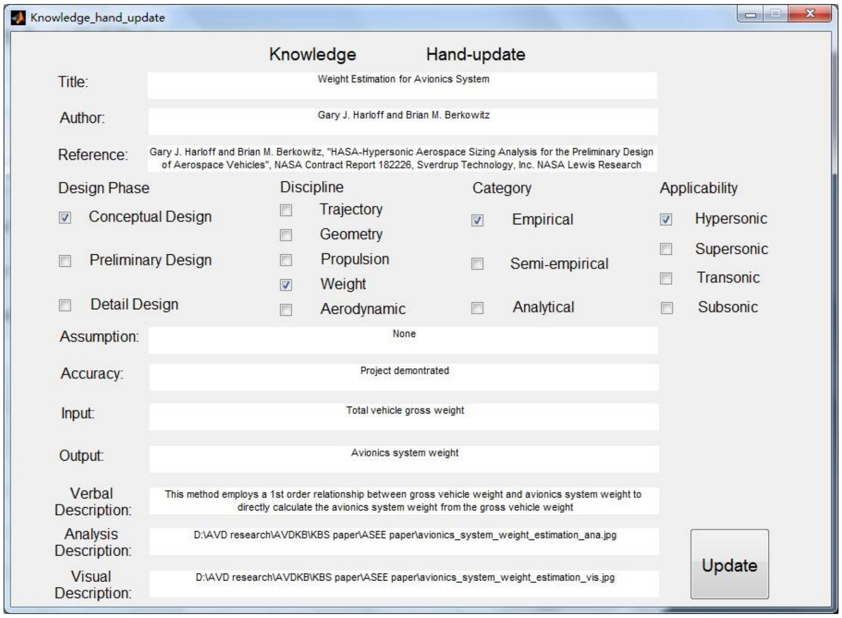
Figure 7. Knowledge Innovation using CBR (a) Regression Line, and (b) Sub-function.

line will be drawn and an interpolation method will be used to identify a value for the unknown variable. Obviously, the user is tasked to determine if the starting point identified serves the problem at hand.

Within the *Project Mercury* case study, the team identified a lack of understanding related to the capsule maximum (peak) temperature during re-entry. Consequently, past projects' maximum temperatures and speeds have been retrieved from AVD^{DBS}, a regression line has been constructed for review. The trend information provided educated the team on the subject. The relationship has been judged to adequately represent the physical phenomena as a starting point for the analysis of the capsule maximum (peak) temperature during re-entry. Consequently, the interaction between AVD^{KBS} and AVD^{DBS} resulted in a parametric approach delivering the input requested by AVD^{SIZING}. A sub-function is written to perform this process.

Knowledge Update

For the *Project Mercury* case study, AVD^{KBS} can be considered sufficiently proficient due to its rich legacy knowledge contents embedded for the parametric sizing analysis. However, even the execution of an independent reverse-engineering study results in the generation of never-before-seen understanding. This new knowledge can be due to flawed knowledge identified in the past, different technology assumptions, difference in the integration approach, etc. Clearly, AVD^{KBS} has to be a dynamic system capable of internalizing new entries while the project is in progress. An efficient knowledge update mechanism or learning function has been devised. In other words, AVD^{KBS} is integrated in the iterative development cycle during the entire project forecasting life-cycle.



Title: Weight Estimation for Avionics System

Author: Gary J. Harloff and Brian M. Berkowitz

Reference: Gary J. Harloff and Brian M. Berkowitz, "HASA-Hypersonic Aerospace Sizing Analysis for the Preliminary Design of Aerospace Vehicles", NASA Contract Report 182226, Sverdrup Technology, Inc. NASA Lewis Research

Design Phase
☑ Conceptual Design
☐ Preliminary Design
☐ Detail Design

Discipline
☐ Trajectory
☐ Geometry
☐ Propulsion
☑ Weight
☐ Aerodynamic

Category
☑ Empirical
☐ Semi-empirical
☐ Analytical

Applicability
☑ Hypersonic
☐ Supersonic
☐ Transonic
☐ Subsonic

Assumption: None

Accuracy: Project demontrated

Input: Total vehicle gross weight

Output: Avionics system weight

Verbal Description: This method employs a 1st order relationship between gross vehicle weight and avionics system weight to directly calculate the avionics system weight from the gross vehicle weight

Analysis Description: D:\AVD research\AVDKB\KBS paper\ASEE paper\avionics_system_weight_estimation_ana.jpg

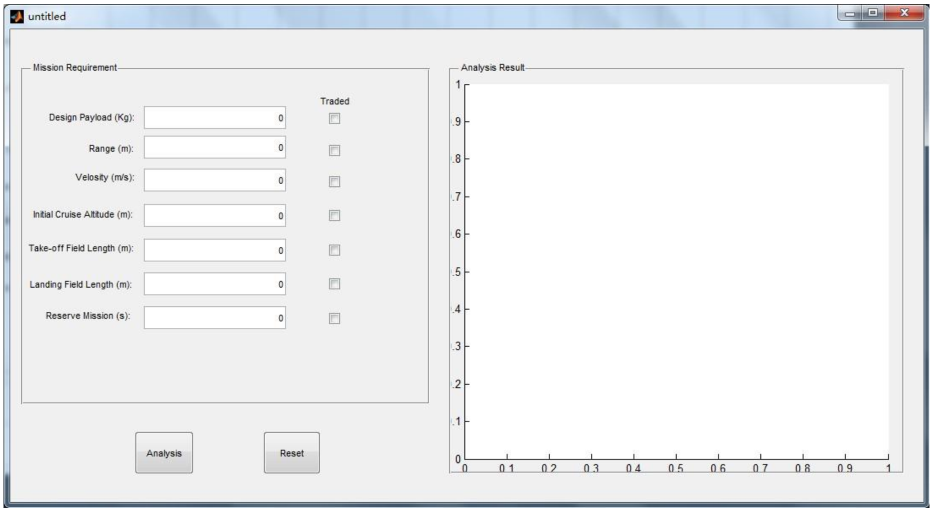
Visual Description: D:\AVD research\AVDKB\KBS paper\ASEE paper\avionics_system_weight_estimation_vis.jpg

Figure 8. AVD^{KBS} Manual or Hand-update Screen.

A graphic knowledge update window has been developed to enable the operator to manually update new knowledge into the AVD^{KBS}; this sequence simply resembles ‘learning’. Detailed information related to the new knowledge entry can be directly entered via the GUI shown with Figure 8. The ‘Update’ button formally accepts the knowledge entry into AVD^{KBS}.

Other Interfaces and Mechanisms

An important function of AVD^{KBS} is to aid AVD^{SIZING} to perform the automatic parametric sizing task. Thus, an interface is developed for the operator to specify the sizing mission requirements, see Figure 9.



untitled

Mission Requirement

Traded

Design Payload (Kg): 0 ☐

Range (m): 0 ☐

Velosity (m/s): 0 ☐

Initial Cruise Altitude (m): 0 ☐

Take-off Field Length (m): 0 ☐

Landing Field Length (m): 0 ☐

Reserve Mission (s): 0 ☐

Figure 9. Mission Input Screen.

According to previous AVD Laboratory parametric sizing projects, the mission requirement inputs consist of seven key parameters: design payload (kg), range (m), velocity (m/s), initial cruise altitude (m), take-off field length (m), landing field length (m), and reserve mission duration (s). It is not required to completely fill in all of these parameters; the user is free to define the mission statement as practical. AVD^{KBS} provides a ‘Traded’ option, see Figure 9. If specific mission parameters are not checked, the system will consider the parameter as a hard requirement, or it will be considered as a traded requirement in the vehicle selection process. This function is of significance since it enables the design team to explore the mission solution space resulting in the correct mission definition.

$$\text{Vehicle Points} = \sum \left\{ \overset{1^{st}\text{ Step}}{\begin{cases}\text{Match} & 1\\ \text{not} & 0\end{cases}} \times \overset{2^{nd}\text{ Step}}{\begin{cases}\text{Not traded} & 7\\ \text{Traded} & 1\end{cases}} \right\}$$

Figure 10. Two-step Grading Mechanism

Having defined the either ‘rigid or flexible’ mission requirement trade space, the system will go through a ranking or ‘Grading’ process with the aim to identify the baseline vehicle and mission combo. During the process, each vehicle documented in AVD^{DBS} will be ranked (graded); the vehicle with superior ranking is going to be selected as the baseline vehicle for a given mission statement.

The ‘Grading’ mechanism is a two-step process. For the first step, the parameter from documented vehicle will be compared with the users’ input value chosen; if they match within a tolerance, the vehicle receives one point for this parameter; if they don’t match, the vehicle will get zero points. For the second step, the point will be multiplied by a coefficient whose value is determined by the ‘Traded’ option. If it is untraded, the point will be multiplied by seven, which makes sure the vehicle satisfying the hard requirement always gets the most points. For the parameters with the ‘Traded’ option checked, any point will only be multiplied by one. The same process is repeated for the other six input parameters. The sum of those points is the vehicle’s total points. After all the vehicles are graded, the vehicle with the most points is selected as the baseline vehicle.

After the baseline vehicle is selected, its technical representation will be drawn from AVD^{DBS}; this input-deck then starts the sizing code AVD^{SIZING}.

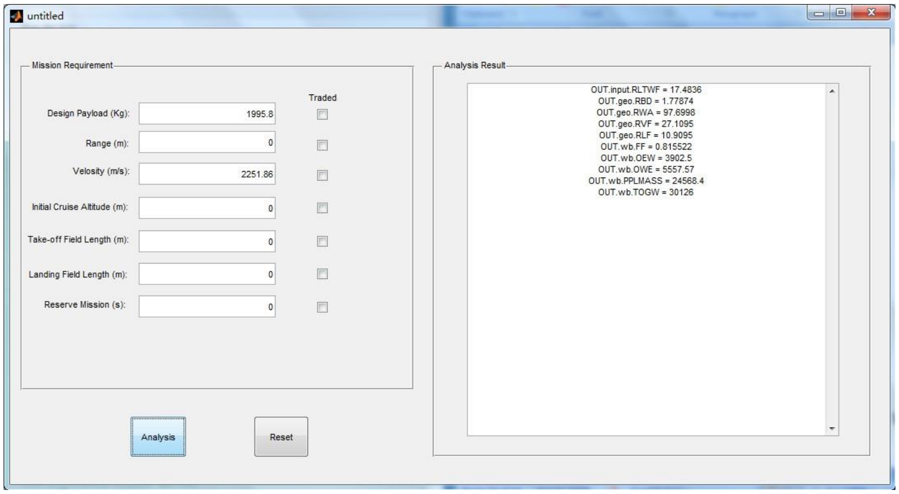
Project Mercury Launcher Case Study

The *Project Mercury* launcher case study serves to evaluate the performance of AVD^{KBS} in cooperation with the other AVD system modules. Objective is to achieve an automatic parametric sizing process. Having already introduced the interplay between the individual modules AVD^{DBS}, AVD^{KBS} and AVD^{SIZING} with preceding sections, we focus with the following on the automatic sizing process and the results. The process is automatic, thus the user is only required to input the mission requirements; the analysis result will be directly displayed in the analysis result window. The mission requirements of the *Project Mercury* launcher are defined as follows:

Table 3. *Project Mercury* Launcher Mission Requirement

Item	Value
Design Payload (Kg)	1995.8
Range (m)	0
Velocity (m/s)	2251.86
Initial Cruise Altitude (m)	
Take-off Field Length (m)	0
Landing Field Length (m)	
Reserve Mission (s)	

The payload is defined by the gross weight of the *Project Mercury* capsule, which is 1,995.8 kg. Since we are concerned with only the launcher, the range is defined as zero; the velocity is chosen as the separation speed, which is 2,251.86 m/s; it is a vertical take-off launcher, the take-off field length is chosen as zero. The rest of the mission requirement parameters are left blank, and none of the 'Traded' options is checked, see Figure 11.



Mission Requirement

		Traded
Design Payload (Kg):	1995.8	☐
Range (m):	0	☐
Velosity (m/s):	2251.86	☐
Initial Cruise Altitude (m):	0	☐
Take-off Field Length (m):	0	☐
Landing Field Length (m):	0	☐
Reserve Mission (s):	0	☐

Analysis Result

```
OUT.input.RLTWF = 17.4836
OUT.geo.RBD = 1.77874
OUT.geo.RWA = 97.6998
OUT.geo.RVF = 27.1095
OUT.geo.RLF = 10.9095
OUT.wb.FF = 0.815522
OUT.wb.OEW = 3902.5
OUT.wb.OWE = 5557.57
OUT.wb.PPLMASS = 24568.4
OUT.wb.TOGW = 30126
```

Figure 11. Parametric Sizing Result for *Project Mercury* Launcher.

Having finished the input formulation, the analysis button is clicked and the sizing process begins. After the grading process is executed, the *Project Mercury* launcher will be selected as the baseline vehicle and its technical details are stored at AVD^{DBS}, serving as the input deck for the execution of the sizing process. The unknown variables will be solved by the methods described in either Section 3.5 *Knowledge Application* or 3.6 *Knowledge Innovation*. Finally, the sizing result will be displayed in the analysis result window.

Although much more design results can be retrieved from the analysis, the results selected in Table 4 aim to show the important AVD parametric sizing characteristic of concurrently converging both launcher volume and weight. The results presented in Table 4 show agreement with published *Project Mercury* launcher data and the chosen design point. This case study demonstrates the overall functioning of AVD^{KBS} in concert with AVD^{DBS}, both aiding the AVD^{SIZING} code to complete an automatic parametric sizing analysis.

Table 4. *Project Mercury* Launcher Design Study Results

Sizing Code Output	Design Variable	Unit	Design Point	Project Mercury	Error (%)
Geometry					
RLTWF	$L_{booster}$	m	17.48	17.48	0
RBD	$D_{booster}$	m	1.78	1.78	0

RWA	S_{wet}	m^2	97.70	97.66	0.04
RVF	V_{tank}	m^3	27.11	26.96	0.005
RLF	L_{tank}	m	10.91	10.86	0.005
Performance					
FF	FF		0.815	0.815	0
OEW	OEW	Kg	3902.5	3875.49	0.007
OWE	OWE	Kg	5557.57	5530.65	0.005
PPLMASS	W_{fuel}	Kg	24568.4	24436.38	0.005
TOGW	TOGW	Kg	30126	29967.03	0.005

Summary and Future Work

This paper introduces the motivation for the development of a dedicated aerospace knowledge-based system. AVD^{KBS} can work as both, a standalone system for knowledge storage, education and reference, and alternatively as an interactive system with other AVD system modules to complete an automatic parametric sizing process. Its main functions can be summarized by knowledge collection, categorization, application, innovation and update. Graphic interfaces are developed to aid the user to conveniently retrieve knowledge and conduct parametric sizing analysis without getting into the details of MS Access and Matlab coding. A case study is conducted to demonstrate the primary system functions and functionality. Consequently, AVD^{KBS} provides us with an efficient tool to employ previous legacy knowledge such to making us stand on the shoulders of giants.

Due to the characteristics of the sizing method employed at the AVD Lab, both new knowledge and new vehicles thus knowledge are generated during the analysis process. Consequently, a mechanism has been developed to document not just legacy *but* new knowledge with the system for future references. It is a requirement that this knowledge-updating mechanism should be ideally automatic since the generation of new knowledge and vehicles is fast when employing an automatic sizing process when compared to the interruptions caused due to hand manipulations. Since not all knowledge is of relevance nor appropriate for the problem at hand, a mechanism needs to be developed to appropriately select the correct knowledge-entry.

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