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An Investigation of a Relational Database Approach to a Multidisciplinary Conceptual Design for the HSCT

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ABSTRACT

New aerospace designs will incorporate new concepts as a result of advances made in the scientific and engineering technologies. These new concepts will afford the aircraft designer with an interesting and somewhat envious dilemma. The aircraft designer will have unprecedented flexibility in design concepts. However, this new flexibility will often be paralleled in ever increasing design complexity. Aircraft such as the High Speed Civil Transport (HSCT) will provide a design environment which will require the efficient use of new technologies in an arena which has historically proven to have stringent performance and cost goals which must be met in order to result in a successful design. The complexity of the HSCT design will dictate a close multidisciplinary effort requiring large amounts of data exchange. Moreover, with the enormous development costs associated with such a design, corporate teaming is essential. It is critical to the success of the HSCT and future aircraft design that a new approach be taken toward the management and exchange of information. A top-down data management design structure should be developed and implemented in the early stages in order to optimize the design process. A small scale multidisciplinary relational database management design has been developed for the HSCT in order to gain a better understanding of how efficient data management can optimize the aircraft design process.

NOMENCLATURE

CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
CE	Concurrent Engineering
EXPRESS	An object-flavored information model specification language
FAR 25	Federal Aviation Regulation 25
HPC	High Performance Computing
HSCT	High Speed Civilian Transport
ICAM	Integrated Computer Aided Manufacturing Program
IDEF	ICAM Definition
IDEF0	ICAM definition used to produce a function model that is a structured representation of activities or functions and the relationships between those activities within a system.
IDEF1X	ICAM definition used to produce a data model that represents the information within the environment or system. IDEF1X is a design method for automated systems implementation of relational databases.
IGES	Initial Graphic Exchange Specification
IPPD	Integrated Product and Process Development
MDO	Multidisciplinary Design Optimization
MDT	Multidisciplinary Design Technology
PDES	Product Data Exchange Using STEP
RFP	Request for Proposal
SQL	Structured Query Language
STEP	Standard for the Exchange of Product Model Data

INTRODUCTION

It is common in the design process for the aircraft designer/configurator to begin with a set of aircraft specifications defined by the customer. A study is made of various configurations which have the qualities which satisfy these specifications. As the designer/configurator nears completion of the design iteration, the design is chosen which first satisfies the major constraints which define the aircraft geometry such as overall span for airport gate access, cruising speed, passenger load, cargo capacity, etc.. Reliance must then be placed on the expertise of other disciplines in order to determine whether or not the configuration meets performance and cost goals. The exchange of data in this stage of the design could often be characterized as a "specific need" exchange. In order to calculate aircraft lift and drag, the aerodynamicist might request planform and cross-sectional geometric data. However, the structural engineer might want geometric data that defines crucial stress and load points such as the geometry that defines door and landing gear locations. The terminology of "specific need" is chosen because the designer/configurator typically provides each discipline with only that data which is required in performing the specific task of that discipline. A very common problem with this method of data exchange is data consistency. It is not uncommon to find that during the conceptual design phase a particular discipline's updated calculations have not been effectively communicated with other disciplines involved in the design effort. This breakdown in the data exchange process results in inconsistent predictions among the various disciplines and valuable design time is lost in the process of redefining a common basis for evaluation. Other problems with this approach are redundancy and the lack of a standard data format. It is quite common to find that the data exchanged between disciplines and supplied by the designer/configurator are often duplicated in a slightly different format for the various discipline's use.

Due to the complexity in design and the use of advanced technologies, the HSCT will require a multidisciplinary effort. Multidisciplinary Design Optimization (MDO), or Multidisciplinary Design Technology (MDT), will take advantage of the evolving High Performance Computing (HPC) environment and will be a critical component in the design of the HSCT. The concept of Integrated Product and Process Development (IPPD)/Concurrent Engineering (CE) as a means of improving the product development process is now becoming more critical. In order to ensure design success, it is crucial that a top-down data management design structure be in place in the early phases of the design. This structure will provide consistency in data format and allow ease of data exchange between the various disciplines involved in the design process. It will minimize data redundancy and provide a logical central data location.

DATA MANAGEMENT AS A DISCIPLINE

Advances in the aircraft technologies have resulted in an increase in the amount of data required to define a design during the conceptual stages. A conceptual design team today often includes disciplines which did not exist in earlier times. Aircraft systems have become more sophisticated and complex and now are critical in the early phases of the aircraft design process. Although the database management technologies have been rapidly evolving in recent years, implementation into the aircraft design process has not proceeded with the same speed. This apparent lack of enthusiasm in introducing data management as a technology into the conceptual design process can be explain in some part due to the level of maturity with which database technology has advanced. Another reason is that the design processes developed by the various aircraft manufacturers have evolved over many years and are the result of these many years of experience.

Another issue is cost. The cost of introducing a new technology into a tried and proven process is time consuming and often expensive. The arguments against the introduction of a new method into the design process serves somewhat as a check and balance. However, with the enormous amounts of money spent and effort that will be expended on the design of future aircraft, more efficient methods must be in place. The design of the HSCT provides an unique opportunity for the introduction of a data management structure. The HSCT is unlike any aircraft previously built. The performance requirements for the HSCT make it an unique design challenge where no design precedent exists. The complexity in design, the new technologies required, and the need for high speed computing early on make the HSCT an excellent candidate for the implementation of new database technologies.

DATA FLOW

Figure 1 diagrams a data flow structure that is logically centralized. This data flow structure could be represented by a relational database management system with the exception of CAD and solid model information. The disadvantage of using a relational model in aircraft design is that most geometric data is defined in the form of CAD and solid model data. However this structure will serve as the model for use in development of the relational database for conceptual design of the HSCT in order to illustrate both the benefits and the detriments when using a relational model in the conceptual design phase.

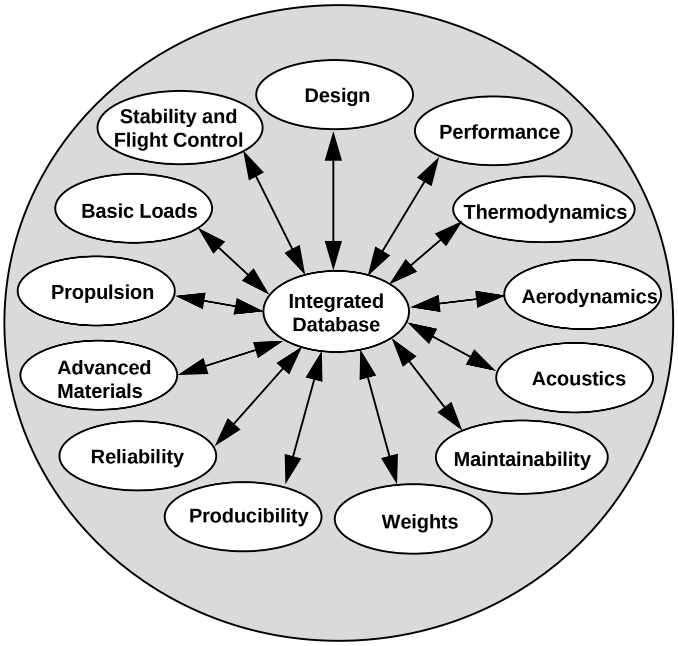

Figure 1. Data Flow for Conceptual Design.

An important point to note from figure 1 is the inclusion of the disciplines of maintainability, reliability, and producibility. Traditionally, these disciplines have not been represented in the earlier phases of aircraft design (i.e. the conceptual stage). However, there has been an increased realization that while MDO presently addresses the integration of the traditional aerospace disciplines such as aerodynamics, propulsion, structures, and controls earlier in the design process, Concurrent Engineering (CE), which is concerned with the earlier integration of product life cycle phases such as manufacturing and support should be addressed in order to optimized the aircraft design process[2].

GEOMETRIC DATA

Although the focus of this paper is primarily on the use of a relational database management system for a multidisciplinary conceptual design, the area of aircraft geometry is a somewhat unique problem which must be addressed. In order to exchange geometric models, the relational model falls short.
In order to exchange geometric data among varying disciplines, a standard must exist which provides a centralized and shared location from which aircraft geometry can be used. The technology of graphics exchange is rapidly evolving. However, these standards along with the understanding of the problem is still changing. The most common platform currently in use by the aircraft designer/configurator is CAD/CAM systems. IGES (Initial Graphic Exchange Specification) is a graphics data exchange specification which is supported by the major CAD/CAM system vendors. IGES is an attempt to simplify the data exchange problem between CAD/CAM systems by providing a standard neutral format that different software tools can communicate through. Figure 2 shows an example of how geometry data is transferred through the use of IGES. Although IGES does provide a means in which common geometric data can be shared, it has yet to mature and stabilize. Other development efforts are currently underway which could supplement or completely replace IGES such as STEP (Standard for the Exchange of Product Model Data).

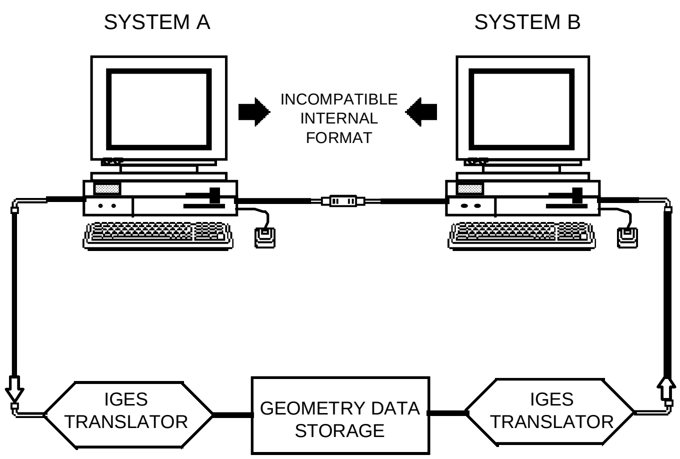

Figure 2. IGES Translation.

PRODUCT DATA MODELS

With the ever increasing complexity of aircraft design, Concurrent Engineering (CE) has become essential. CE is concerned with the earlier integration of product life cycle phases such as manufacturing and support. Due to the uniqueness in specifications and requirements, the design of the HSCT cannot solely rely on the precedence set by previous designs. The systems and parts necessary in producing the HSCT will be based on advanced technologies and will often be untested. The disciplines of maintainability, reliability, and produceability become major factors early in the design. An optimum design from an aerodynamic and structural prospective might prove to be a maintenance nightmare. Moreover, some parts and systems resulting from the conceptual and preliminary phases might even prove to be unproduceable from a manufacturing standpoint. Checks such as these early in the design will save valuable redesign time and will certainly prove cost effective. The problem of how information for a part or system is disseminated into the design process must be addressed.

Standardized product data models are gaining acceptance in industry. Numerous activities are currently underway that address the problem of how to manage product data from both a design and manufacturing viewpoint. One such activity is PDES (Product Data Exchange Using Step).

PDES

PDES is an activity whose goal is to create an international standard for the exchange of product model data. The resulting standard is also a process whereby knowledge is created, shared, and documented[1]. PDES is focused on exchanging complete product models with sufficient information content so as to be interpretable directly by CAD/CAM application program. It is the intent of the PDES project to fully support the needs of a complete product model as required by generative process planning systems, by CAD directed inspection, and by automated numerically control (NC) data generation[5]. PDES is an ongoing activity which started off as a spin-off of the IGES activity discussed earlier. STEP (Standard for the Exchange of Product Model Data) is a set of international standards (drafts) that provide a product data exchange standard to support life-cycle processes.

PROCESS MODELING

The distinction between conceptual design and preliminary design is sometimes fuzzy. However, for the purposes of this paper a distinction will be made in order to provide a better understanding of how the process model for the design of a HSCT was developed. For discussion, the term conceptual design refers to the development of global concepts. Global is used here to represent macro or "big picture" concepts. The conceptual design phase of aircraft is the process in which the outer moldlines of the aircraft are created with minimal internal systems and refinements. Preliminary design refers to the development of specific concepts. Specific is used to represent micro concepts, which are the concepts for the individual parts and systems leading toward final design. The beginning of the preliminary design phase includes the basic testing of "Will everything work? Will everything fit together? Will everything work together?". During the preliminary design phase, conceptual parts are properly placed within the moldlines of the aircraft. It is in this phase that the conceptual design is validated from more detailed perspective. These parts are further developed and refined in the final design phase. It is in this phase that detailed drawings are produced for the manufacturing of the aircraft systems and parts. The overall process for the HSCT design is represented by the IDEF0 model presented in figure 3.

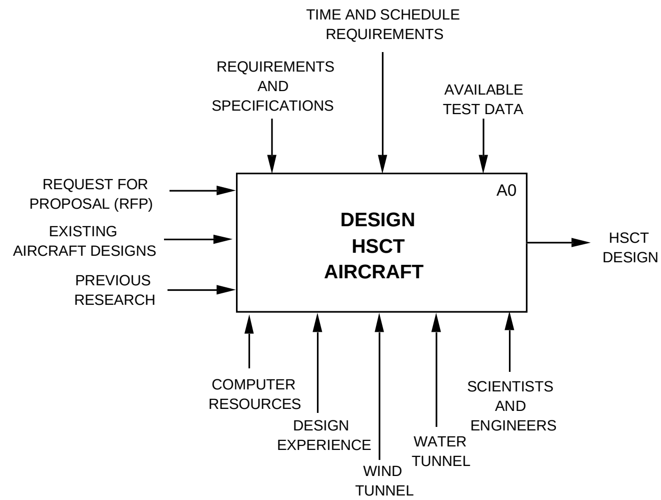

Figure 3. IDEF0 Diagram - Level 0.

This zero-level view shows that the design of the HSCT is limited by design requirements and specifications, time and schedule, and available test data. The design study is usually initiated by a request for proposal or (RFP). Figure 4 presents the level-one IDEF0 diagram which shows the process flow required in developing a HCST design up to the preliminary design phase. Figure 5 shows a further breakdown of the A1 node. In order to develop conceptual 3-view baseline designs, the aircraft designer/configurator must first research the databases of comparable or relevant aircraft. The next step is to develop design concepts which would potentially fulfill the requirements and develop layouts of the prospective configurations.

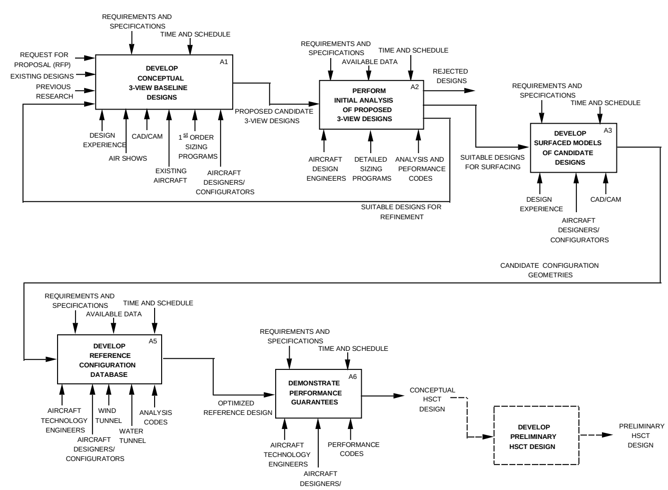

Figure 4. IDEF0 Diagram - Level 1

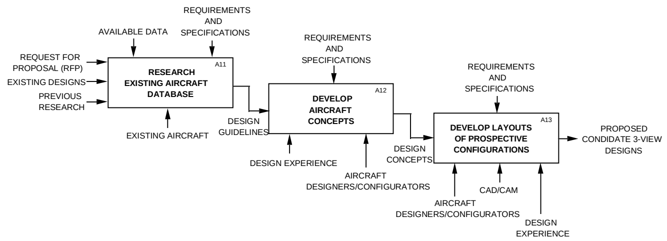

Figure 5. IDEF0 - Level 2 Block A1

A 3-view layout is a way in which the aircraft designer/configurator can present candidate designs without going to the level of creating surfaced models. This takes time and is unnecessary during a down selection process.

Figure 6 shows the IDEF0 level 2 process for the A2 node. During this phase of the design process, early performance, produceability, reliability, maintainability, and cost analysis are performed based upon the proposed 3-view designs. This is an initial analysis to provide the aircraft designer/configurator with crucial information regarding the validity of the design in meeting the requirements and specifications before the labor intensive job of creating a surfaced model begins.

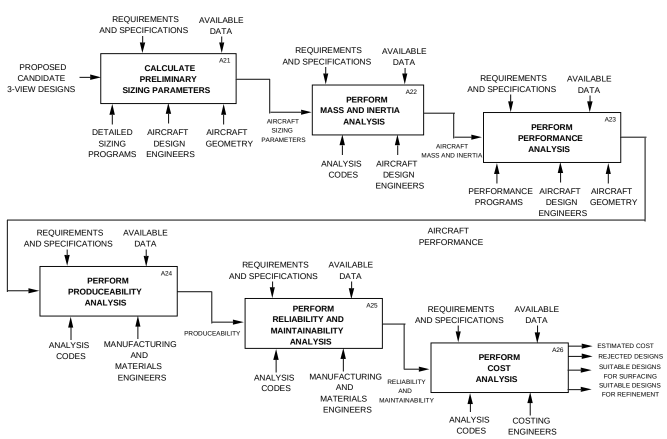

Figure 6. IDEF0 - Level 2 Block A2

As a preliminary tool, the aircraft design engineer typically uses preliminary aircraft performance and sizing programs which attempt to optimize the design based on the inputs of the various disciplines involved. However, care should be taken when using these codes. There has been a growing realization that in complex engineering systems the mastery of the interactions among the disciplines and subsystems is as important for successful designs as technologies used in any individual discipline or subsystem. Early attempts to solve the problem by wrapping an optimization loop around a set of computer programs corresponding to the governing disciplines proved disappointing for reason clear in retrospect[3]. The approach used tended to exclude the human intellect from the process, and the computational time and cost of repeated executions of coupled disciplinary analyses was prohibitive[4].

Figure 7 shows a further breakdown of the A3 node. In order to develop surfaced models of candidate designs that are in an usable format for the technology engineers, the designer/configurator must first create the lofted surfaces. The geometric model must then be validated to insure the tangency and abutments of all surfaces before being converted to an IGES format. Once in an IGES format, other technologies can pull the geometric models into other CAD/CAM systems for use.

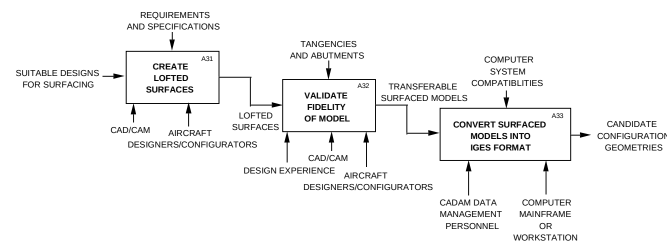

Figure 7. IDEF0 - Level 2 Block A3

Figure 8 shows the processes involved in the creation of a configuration database in which more detailed analysis can be based upon.

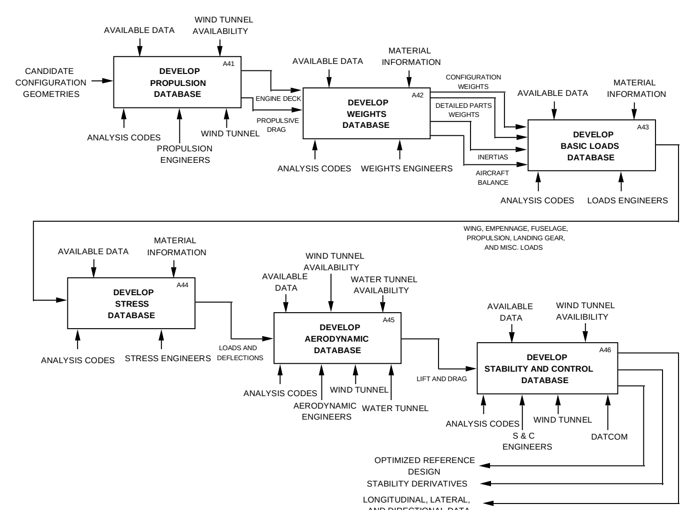

Figure 8. IDEF0 - Level 2 Block A4

Figure 9 represents the final stage in the conceptual design process in which the design is validated against the requirements and specifications defined by the customer. In the case of the HSCT, a proposed commercial transport, these requirements would be found in the Federal Aviation Regulation 25 (FAR 25). After validation, the design is ready for the preliminary design phase where detailed systems and subsystems will be integrated into the surfaced model of the validated conceptual design.

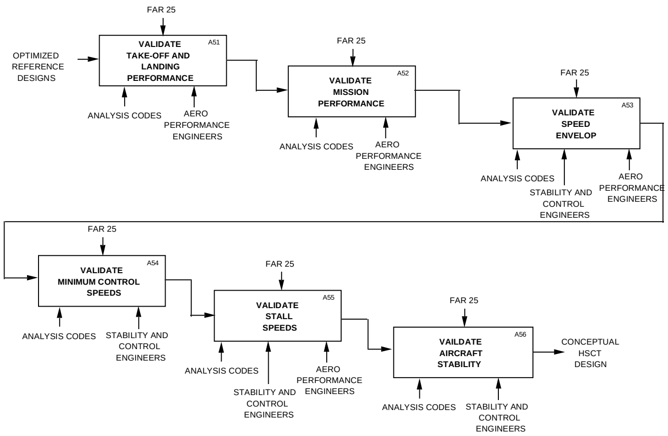

Figure 9. IDEF0 - Level 2 Block A5

DATABASE DESIGN APPROACH

Data Relationships Modeling

The HSCT design process model includes the database schema and a data dictionary. The specific categories for the database design are as follows:

1. Aerodynamics
2. Aircraft Components
3. Cost
4. Materials
5. Performance
6. Stability and Control
7. Weights

The specific data management tools that were used in modeling the design process for the HSCT are presented below. Also included are the other available tools which could be used. These are appear in italics.

Data Management Tools

Process Modeling	Data Modeling	Database Implementation
IDEF0	IDEF1X	SQL
	EER	*RDB*
	EXPRESS	*INGRES*

excerpts from a comprehensive data dictionary are shown below. A portion of the propulsion section describing the inlet of the design has been chosen for example.

Data Dictionary

Attribute	**Definition**
PROPULSION	
Inlet	
DESIGN_M_INLET	Design Mach number
RAMP_ANG_INIT_INLET	Initial ramp angle (degs)
RAMP_ANG_FIN_INLET	Final ramp angle (degs)
IN_LIP_ANG_INLET	Internal lip angle (degs)
CONTR_RATIO_INLET	Contraction ratio
THROAT_M_INLET	Throat Mach number
APER_AR_INLET	Aperture aspect ratio (BL/WL)
CAP_AREA_INLET	Capture area inlet (sq ft)
PRESS_RECOV_INLET	Main inlet average pressure recovery
FACE_RECOV_INLET	Engine face recovery
CORR_AIRFLOW_INLET	Corrected engine airflow (lbm/sec)
CORR_ECS_AIR_INLET	Corrected environmental control system airflow (lbm/sec)
BLEED_AREA_INLET	Bleed (% capture area)
SPILL_AREA_INLET	Spillage (% capture area)
LEAK_AREA_INLET	Leakage (% capture area)
BYPASS_AREA_INLET	Bypass (% capture area)
SUBSONIC_DIF_LD	Subsonic diffuser L/D
AREA_RATIO_INLET	Area ratio (throat:face)

Logical Database Design

Figure 10 presents the $IDEF1_X$ model for engine, inlet, and nozzle of the HSCT design database.

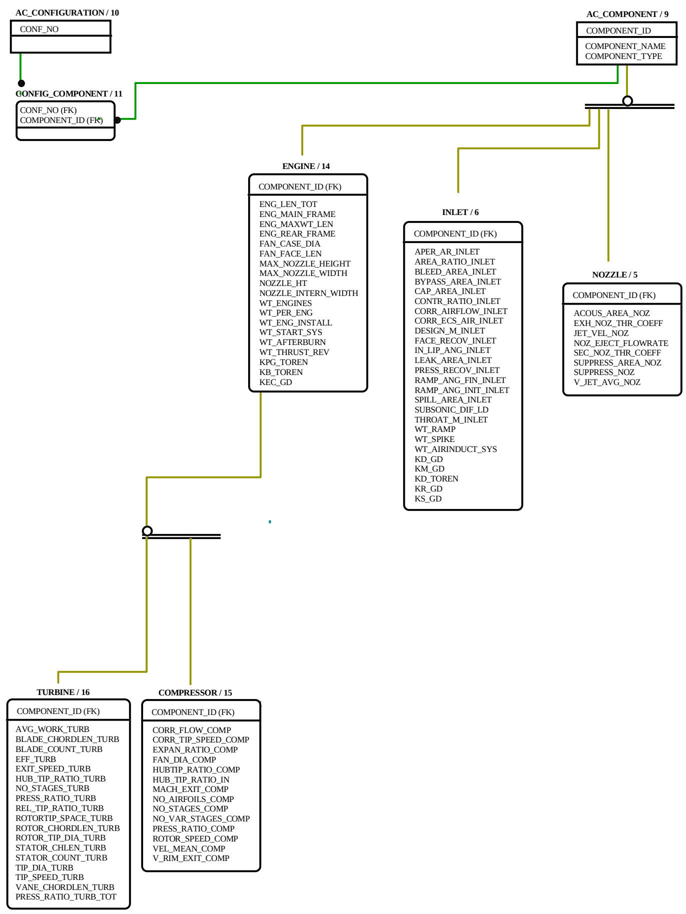

Figure 10. IDEF1$_X$ Diagram of the HSCT Multidisciplinary Design Database.

Implementation of Database

Implementation of the database model presented in figure 10 can be on any of the available relational database management systems such as ORACLE.

CONCLUSIONS

New aircraft designs have become increasingly advanced and complex. Advances made in the scientific and engineering technologies have resulted in nontraditional aircraft designs using high technology materials. Multidisciplinary Design Optimization (MDO) will take advantage of an evolving high speed computing environment and will be a critical component in the design of the HSCT. A major emphasis is also being placed on using concepts such as Integrated Product and Process Development (IPPD) and Concurrent Engineering (CE) as a means of improving the product development process.

The multidisciplinary design effort of the HSCT will require large amounts of data exchange. The advancements made in computing technology will further this enormity of data. It is critical that a data management system be in place very early in the design process, preferably before the process begins. The design of a data management system should command the same level of priority as that given to other disciplines involved in the process. Moreover, customers have been independently developing data management structures for use internally in order to streamline processes and costs. In today's environment, the customer wants to be directly involved in the design process. This has certainly been proven with the design of the Boeing 777. In order to be responsive to customer requirements, a data management system must be in place.

This independent study has focused on the design of a multidisciplinary relational database in order to gain a better understanding of how efficient data management can optimize the aircraft design process. A design process has been developed and the data requirements identified. A relational database management system was chosen due the level of maturity of relational database technology. However, in the development of this database design in became apparent that current database design approaches are typically limited to the detailed design phase where the data organization is fixed. A major problem is the development of a database design approach to support the conceptual design of complex engineering products where the database organization is evolving.

Object-Oriented data management systems now exist, and the level of maturity is increasing rapidly. Product Data Management (PDM) systems are becoming the new evolution in competitive strategies for companies. Emphasis is being placed on the integration of manufacturing early in the design process. The work performed for this study will serve as a base for further research which will be conducted investigating the benefits of using STEP and PDM systems early in the conceptual design process.

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