IMPACT OF DATA MODELING AND DATABASE IMPLEMENTATION METHODS ON THE OPTIMIZATION OF CONCEPTUAL AIRCRAFT DESIGN

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IMPACT OF DATA MODELING AND DATABASE IMPLEMENTATION METHODS ON THE OPTIMIZATION OF CONCEPTUAL AIRCRAFT DESIGN

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SYMBOLS AND 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
OODBMS	Object-Oriented Database Management System
PDES	Product Data Exchange Using STEP
RDBMS	Relational Database Management System
RFP	Request for Proposal
SQL	Structured Query Language
STEP	Standard for the Exchange of Product Model Data
1NF	First Normal Form
2NF	Second Normal Form
3NF	Third Normal Form
BCNF	Boyce-Codd Normal Form
DKNF	Domain Key Normal Form

SUMMARY

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 dictates a close multidisciplinary effort requiring large amounts of data exchange. In order to optimize the design process, 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. In the conceptual design phase, consideration must be given to the changing structure of the of the database as the product design evolves. Current database design approaches are typically limited to the detailed design phase where the data organization is fixed.

The goal of the research was to develop a database design approach to support the conceptual design of complex engineering products where the database organization is evolving. The research investigates the relative merits of a relational and object-oriented approach to database design for a multidisciplinary aircraft design effort. The target application will be the conceptual design of the HSCT wing. On a conceptual level, complete database design methodologies have been developed that include all disciplinary data required in the conceptual design phase. The relational and object-

oriented design methodologies were applied directly to the stability and control section of the design. This research documents these proposed approaches and recommends possible database design strategies.

CHAPTER I

THE CONCEPTUAL AIRCRAFT DESIGN PROCESS AND DATA MANAGEMENT

Introduction

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.

The Design Process

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. Moreover, each discipline is typically concerned with “its data requirements” only, and not much thought or concern is given as to how the data will be used by another discipline. Figure 1 shows the data management problem that currently exists in aircraft conceptual design. The figure is somewhat comical in the way in which it portrays each discipline involved in the conceptual design process. However, this representation is not far from reality.

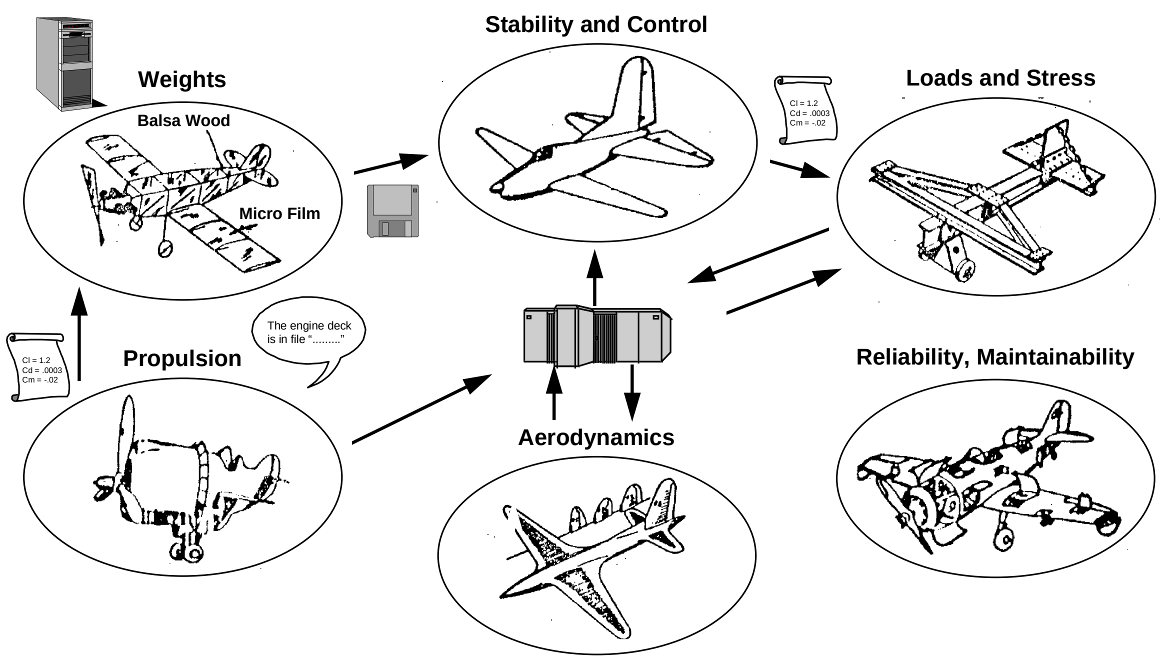


Figure 1. The data management problem.

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.

Database 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 2 diagrams a data flow structure that is logically centralized around a shared database and will serve as the model for use in development of proposed approaches and possible database design strategies for aircraft conceptual design data. This logically centralized database could also exist as a distributed database.

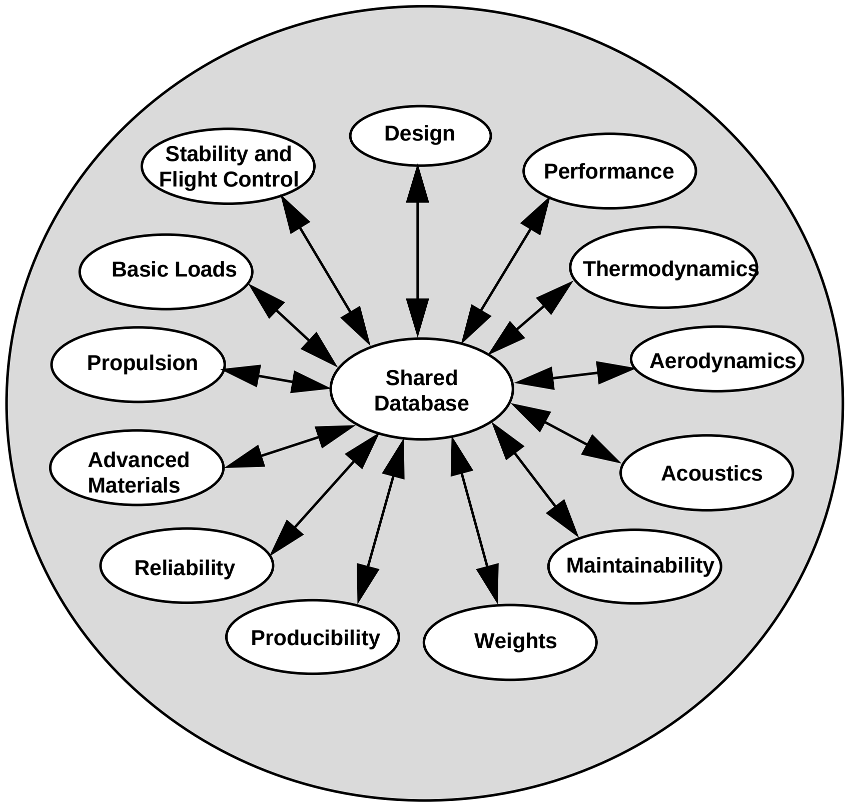


Figure 2. Data flow for conceptual design.

An important point to note from figure 2 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 research investigates database design methodologies, the area of aircraft geometry is a somewhat unique problem which must be addressed. In order to exchange geometric models, most available data models fall 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 3 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).

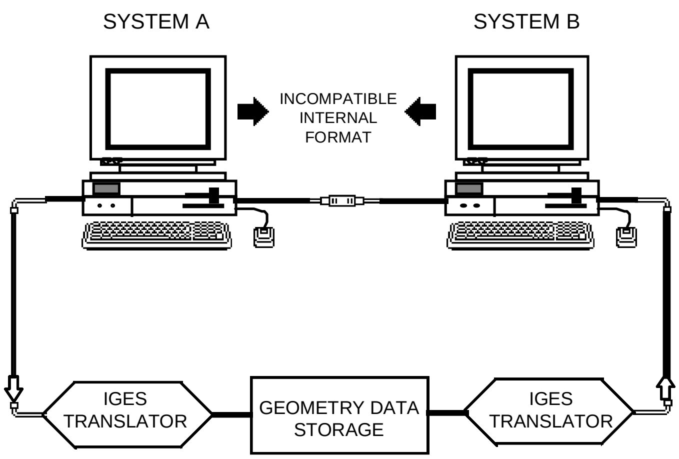


Figure 3. IGES translation.

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 producibility become major factors early in the design. An optimum design from an aerodynamic and structural perspective 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.

CHAPTER II

PROCESS MODELING

Surfaced Models

In the earliest phases of a conceptual design, the designer/configurator must create the geometric lines of the aircraft which define the configuration called a 3-View drawing. Although still widely used, the 3-View drawing is rapidly being superseded by 3-D models. The following discussions and the process models presented will include the creation of the 3-View but it should be noted that this step is being eliminated by most of the major airframe manufacturers. The 3-View drawing of the configuration definition is a major product of the design group and serves as the basis for the products provided by the other technology disciplines (i.e. aerodynamic performance, propulsion, systems, weight, cost, etc.). Creation of 3-View drawings is an extremely important aspect of the aircraft process. The 3-View is important in determining the basic design shape of the aircraft and provides the designer/configurator with a visual representation. The 3-View also serves as the basis for early performance predictions. Validity of design can be estimated and candidate configurations can be refined or rejected at this stage. Moreover, an experienced aircraft designer/configurator can create an aircraft 3-View within a short time frame and the process is not typically labor intensive. However, with the advancements made in 3-D modelers, a complete 3-dimensional model can be created with approximately the same effort as the 3-View.

Once the design is partially finalized, the 3-View drawing is then converted into a surfaced model. An aircraft surfaced model is typically the most common geometric model supplied by the designer/configurator and used by the technology disciplines and is very labor intensive to create (this is rapidly becoming less true). However, each discipline requires differing levels of detail. The aerodynamicist is concerned with predicting the lift and drag of an aircraft. In order to calculate a preliminary lift and drag, the aerodynamicist starts with cross-sections created from the surfaced model. The wing can be collapsed into a planform and used in the various vortex lattice programs available. Fuselage cross-sectional cuts are used in the prediction of aircraft wave drag. The structures group is typically interested in a surfaced model which defines the crucial stress and load points on the aircraft and the "cleanness" of the model is not always critical. However, the computational fluid dynamist requires a model where line tangency and abutment are almost always required. Therefore, the surfaced model provides the various disciplines with a variety of required information.

IDEF0 Model

The distinction between conceptual design and preliminary design is sometimes fuzzy. However, for the purposes of this research 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 4.

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 (RFP). Figure 5 presents the level-one

IDEF0 diagram which shows the process flow required in developing a HCST design up to the preliminary design phase. Figure 6 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.

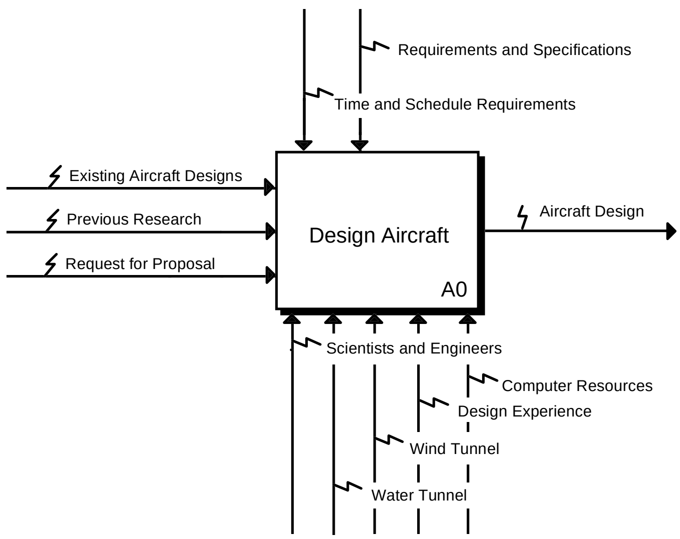


Figure 4. IDEF0 diagram - level 0.

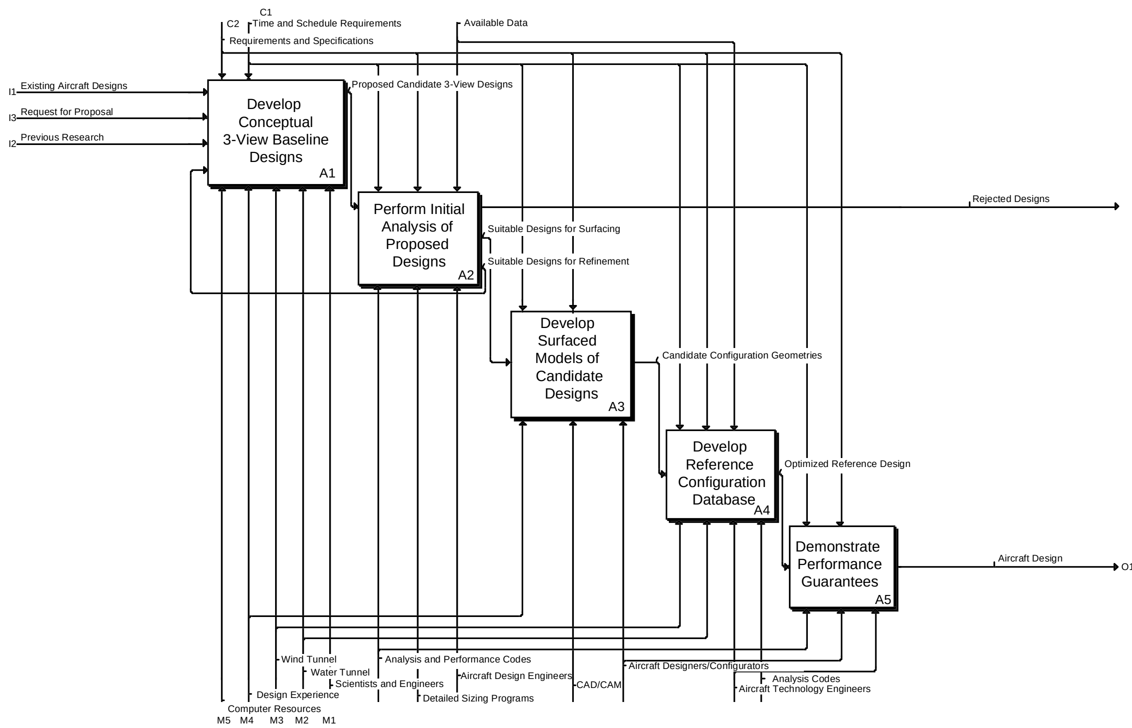


Figure 5. IDEF0 diagram - level 1

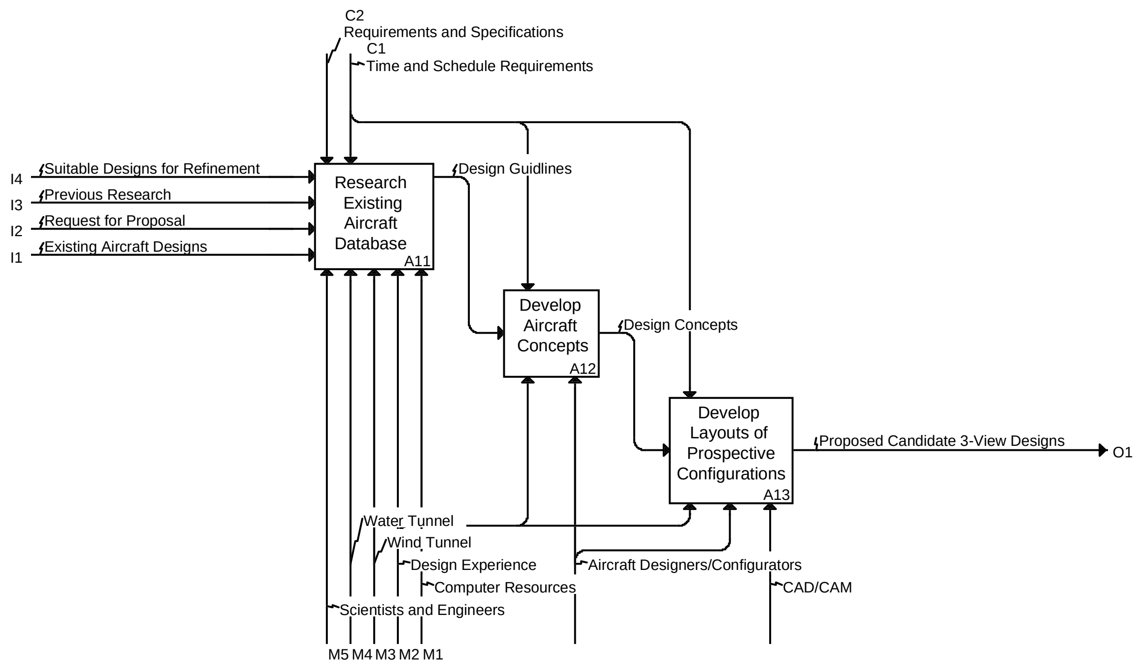


Figure 6. IDEF0 diagram - level 2 block A1.

Figure 7 shows the IDEF0 level 2 process for the A2 node. During this phase of the design process, early performance, producibility, 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.

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].

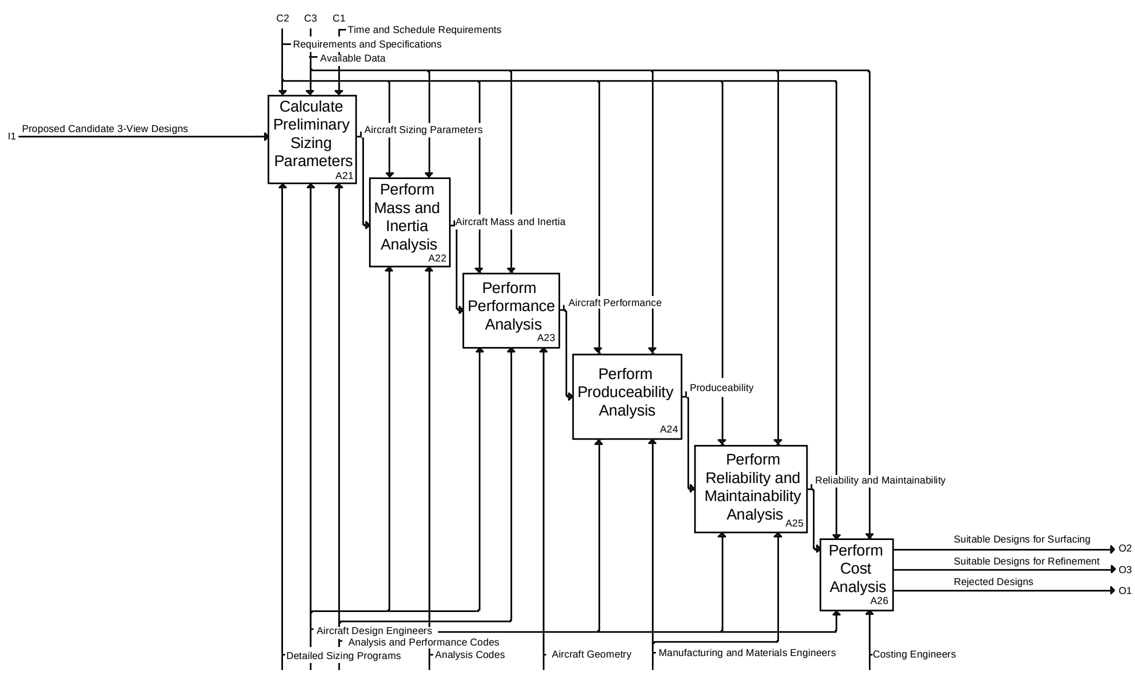


Figure 7. IDEF0 diagram - level 2 block A2.

Figure 8 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 9 shows the processes involved in the creation of a configuration database in which more detailed analysis can be based upon.

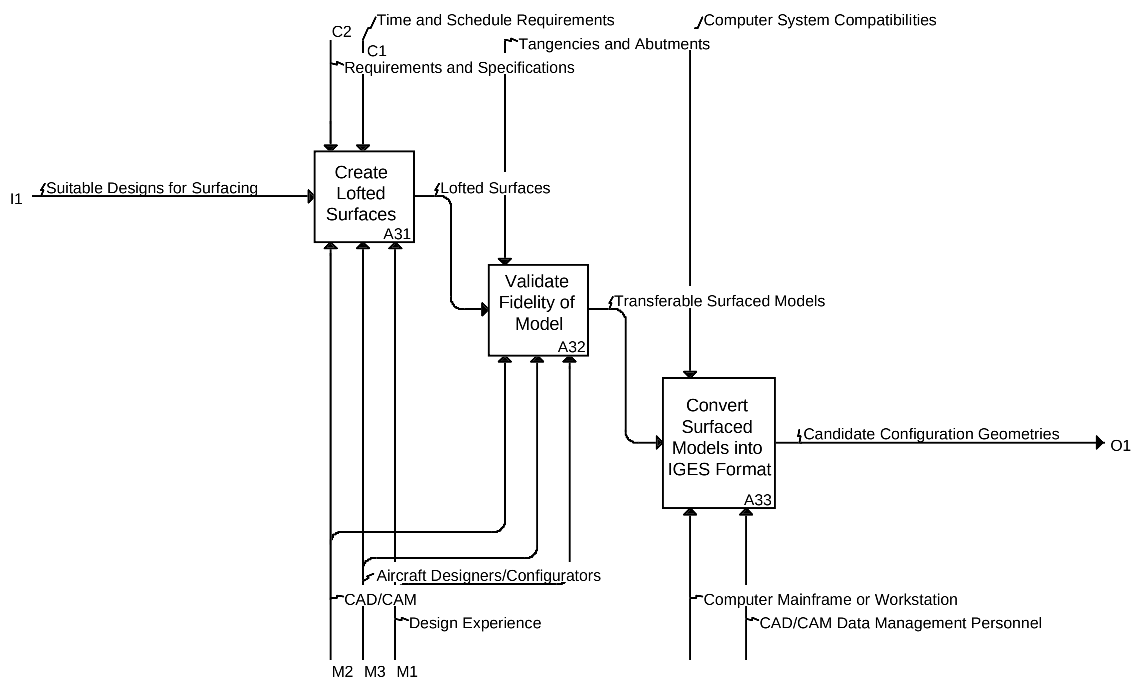


Figure 8. IDEF0 diagram - level 2 block A3.

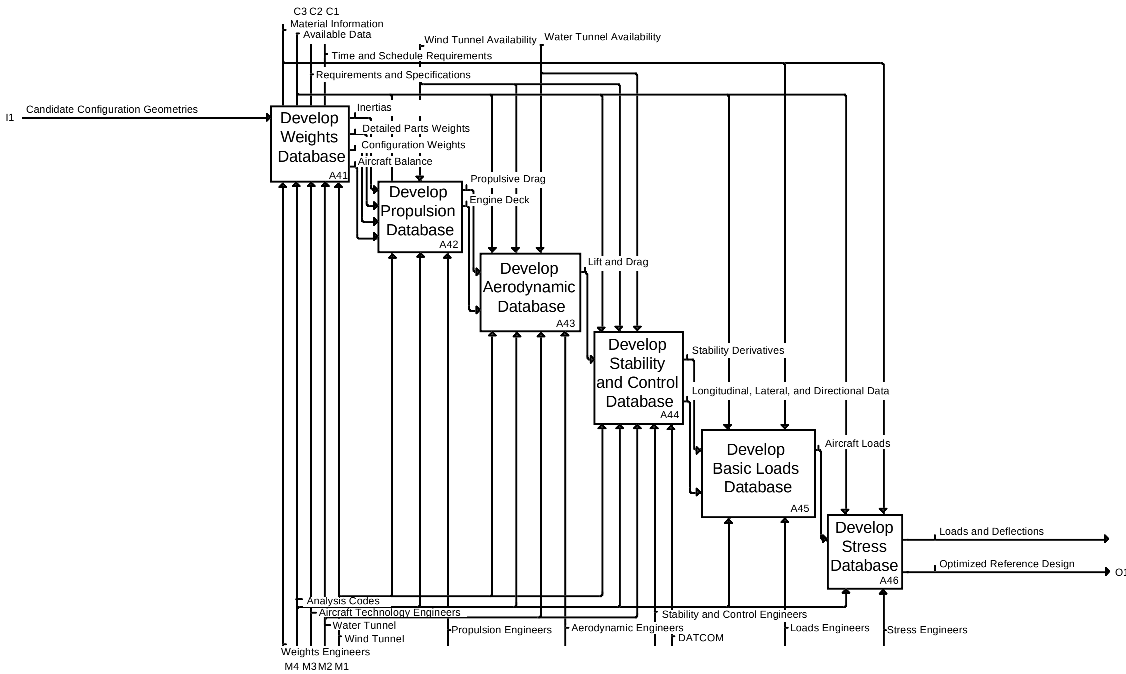


Figure 9. IDEF0 diagram - level 2 block A4.

Figure 10 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.

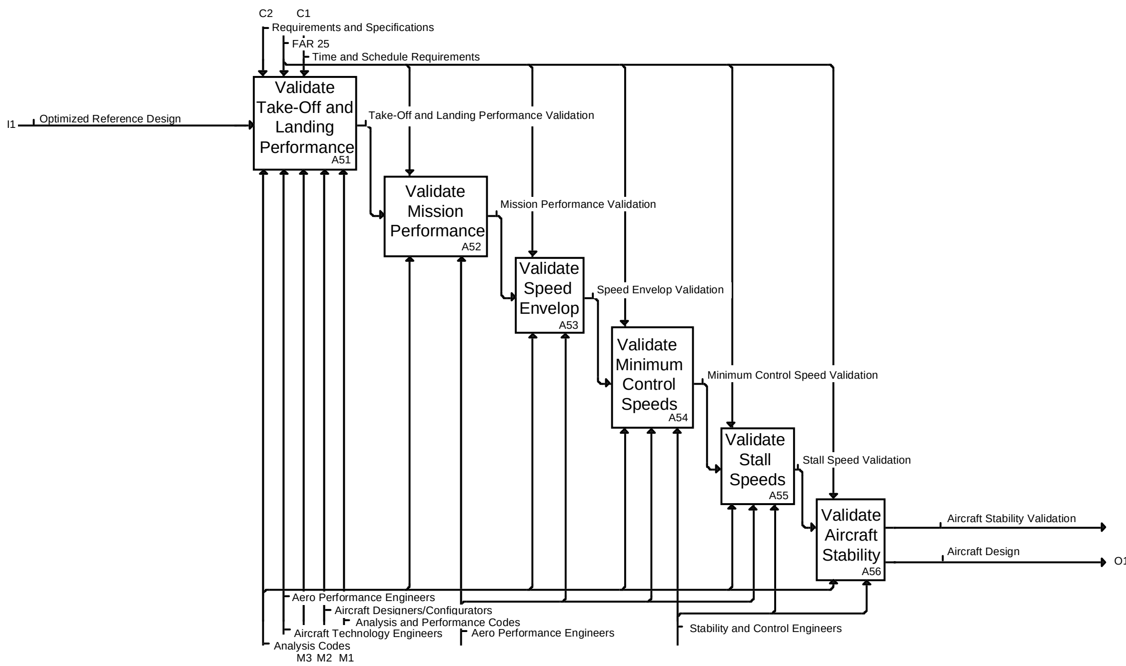


Figure 10. IDEF0 diagram - level 2 block A5.

CHAPTER III

RELATIONAL DATABASE DESIGN APPROACH

Data Relationships Modeling

The HSCT relational design data 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 function model identifies a common process in order to ascertain what the data requirements are for the conceptual design process. Figure 11 shows examples of the types of data that are required during the aircraft conceptual design phase.

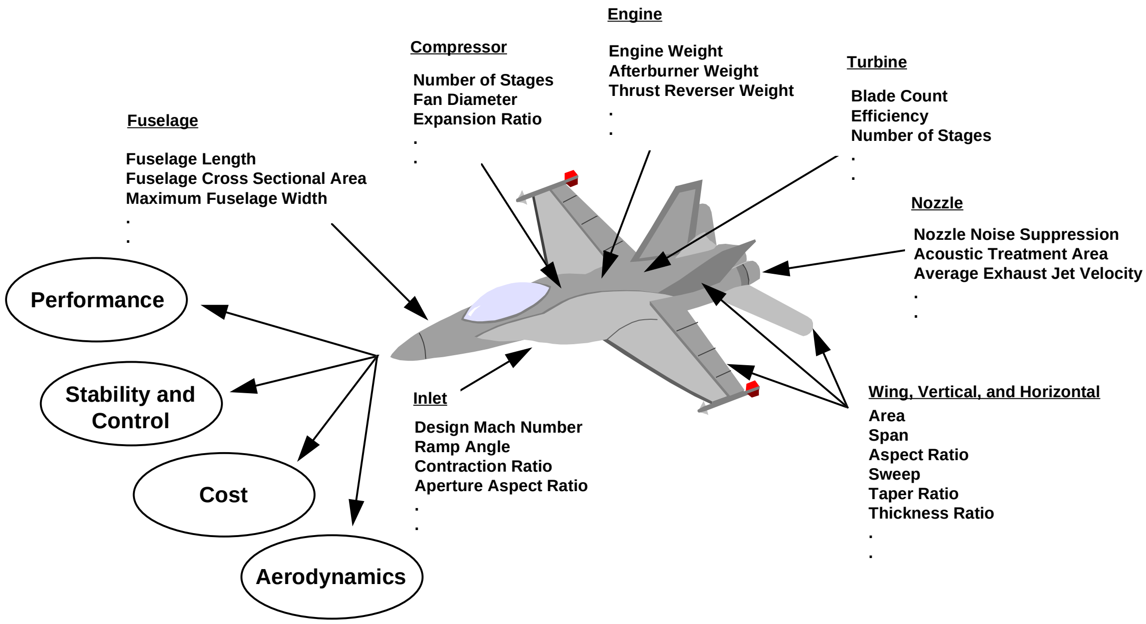


Figure 11. Example data required for aircraft conceptual design.

Database Schema

The database schema for the relational database design are listed in Appendix A.

Data Dictionary

A comprehensive data dictionary for the relational database design is shown in Appendix B. A total of 461 variables were defined for this conceptual aircraft design database.

Normal Forms in Relational Design

In order to avoid data redundancy in the relation design, relational tables are further normalized beyond the first normal form (1NF). The first normal form is defined as a relation that has atomic or single-valued attributes, i.e. only one value for a given row and column in a relational table. This normalization alleviates many problems that typically arise during updates when data redundancy exists. C. J. Date describes a good relational design principle as “one fact in one place”.[21] Numerous normal forms have been defined by relational database experts. The first three normal forms (1NF, 2NF, 3NF) were defined by Codd in reference 22. The motivation behind Codd’s definitions was that 2NF was “more desirable” than 1NF, and 3NF in turn was more desirable than 2NF. That is, the database designer should generally aim for a design involving relations in 3NF, not relations that are merely 2NF or 1NF.[21] However, Codd’s original definition of 3NF turned out to suffer from certain inadequacies. These inadequacies led to the revision of Codd’s original 3NF definition and the creation of a stronger definition known as the Boyce-Codd normal form (BCNF). Table 1 shows the ascending series of normal forms.

Table 1. Normal form definitions.

A relation is in this normal form	*... if it is in all more basic normal forms and obeys these constraints:*
First normal form (1NF)	It has atomic (single-valued) attributes.
Second normal form (2NF)	All of its nonkey attributes are functionally dependent on all of its keys.
Third normal form (3NF)	It is free of transitive dependencies.
Boyce-Codd normal form (BCNF)	Every one of its determinants is a candidate key.
Fourth normal form (4NF)	It is free of multivalued dependencies.
Domain/key normal form (DKNF)	All logical restrictions on its contents are logical consequences of its key and its attributes' domains.

Date expands on the definition of 3NF by stating that a relation is in third normal form if and only if the nonkey attributes (if any) are: (a) mutually independent, and (b) irreducibly dependent on the primary key.[21] Relations in first or second normal form have anomalies concerning modifications and those in third normal form do not. Therefore, third normal form was chosen as a minimum normalization for this research.

Logical Database Design (IDEF1X)

Figure 12 shows the IDEF1X model for the aircraft components. An aircraft configuration is made up of components. For this application those components are the: engine, fuselage, gear, inlet, nozzle, canard, horizontal, vertical, and wing.

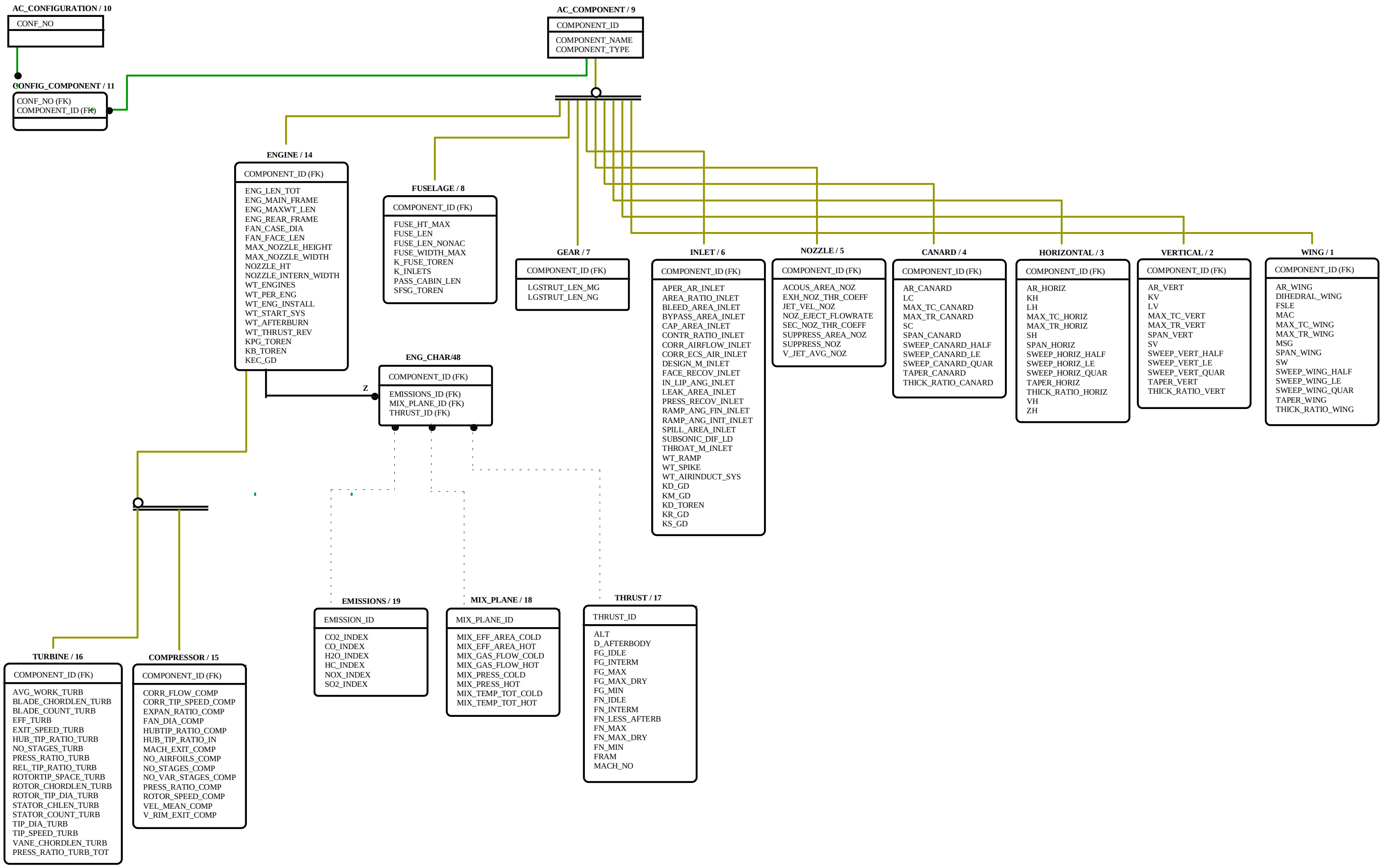


Figure 12. IDEF1X diagram of aircraft components.

Figure 13 shows the IDEF1X model describing an aircraft member along with member material, and load and stress characteristics.

Aircraft stability and control, aerodynamic, performance, cost, and weight data have been modeled as a function of the aircraft configuration. This relationship between aircraft configuration and this calculated data is parent to child. For example, an aircraft configuration has a given weight. This weight can be made up of many different fixed equipment combinations, fuel systems, etc. Figures 14 - 19 shows the IDEF1X models for the weight, stability and control, cost, performance, and aerodynamic data respectively.

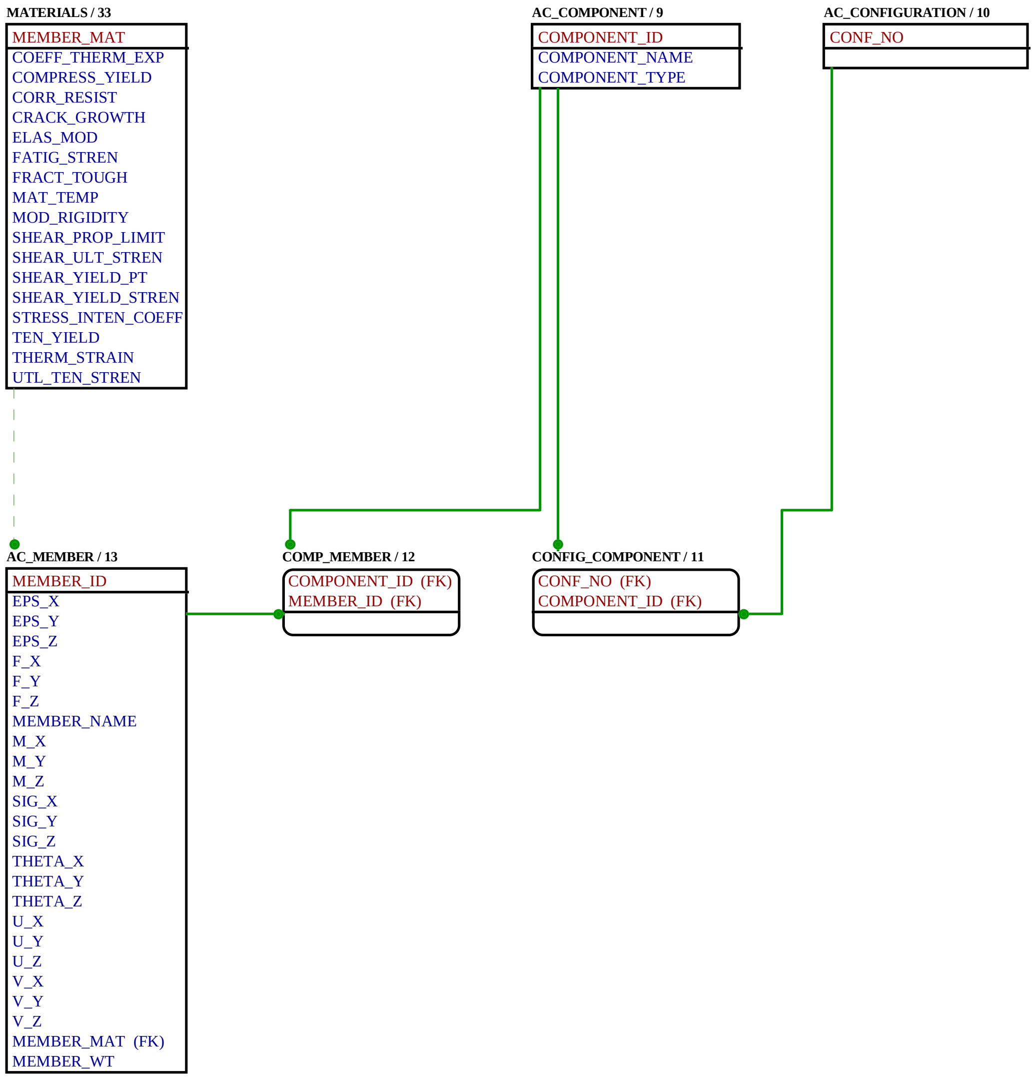


Figure 13. IDEF1X diagram of aircraft component members and the respective material, load, and stress.

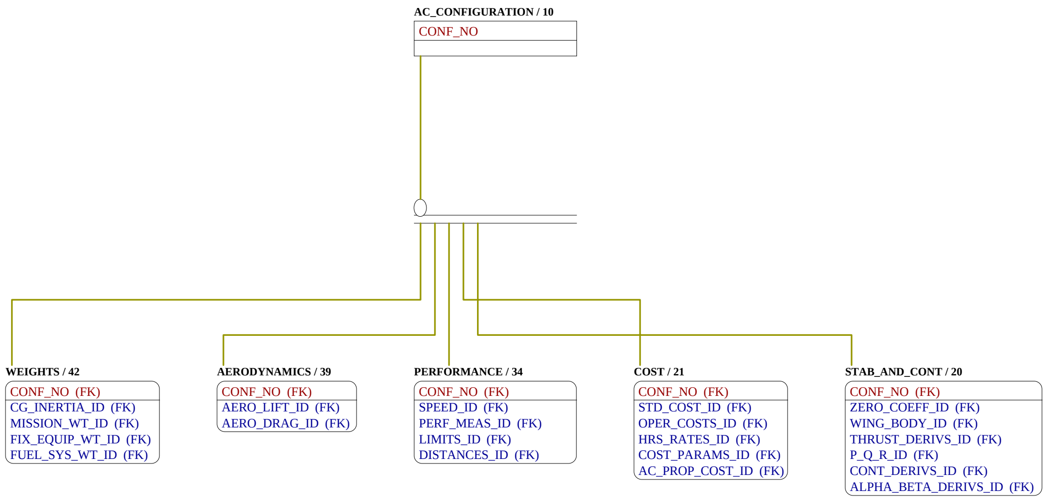


Figure 14. IDEF1X diagram of aircraft discipline calculations.

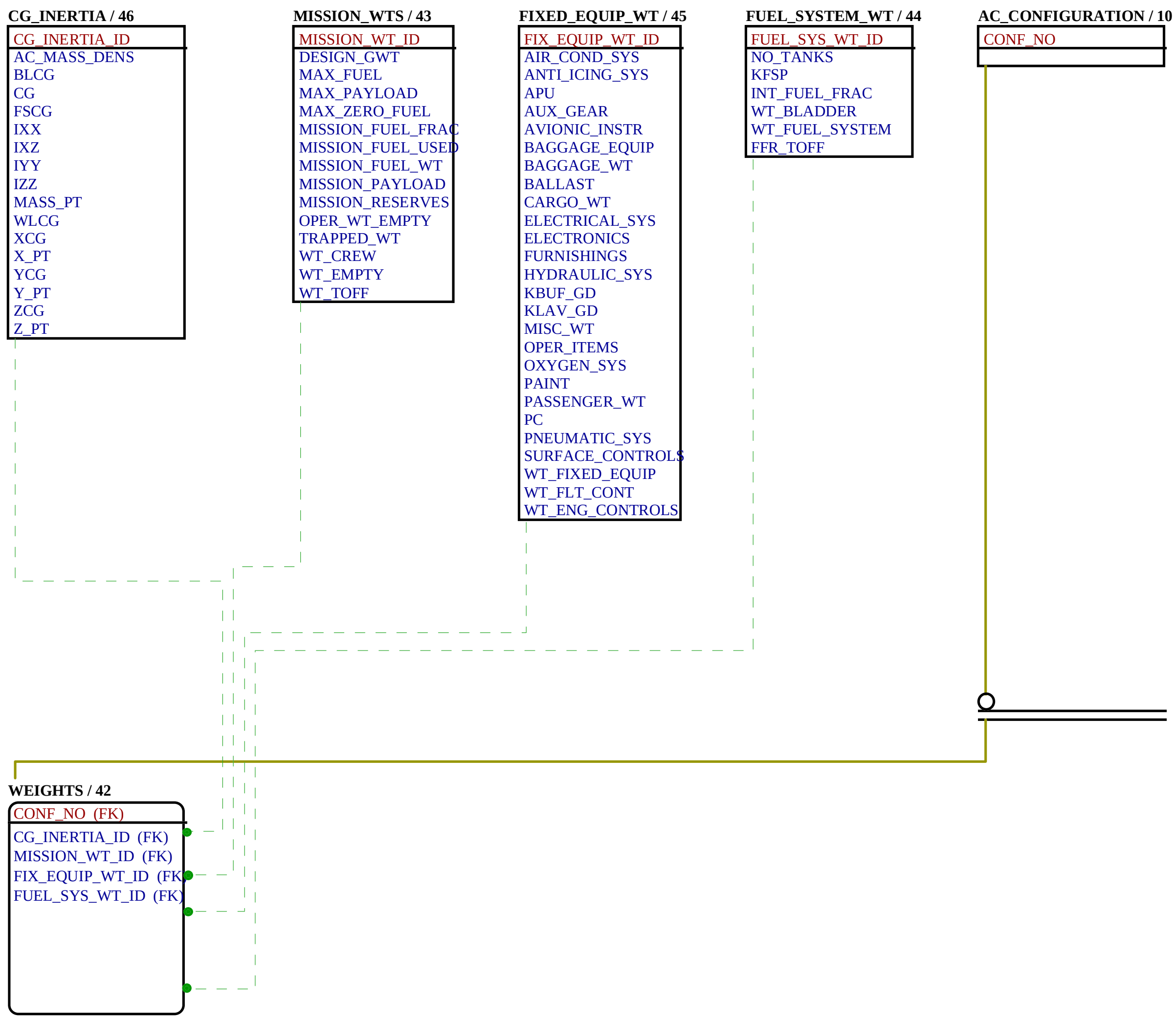


Figure 15. IDEF1X diagram of aircraft weights.

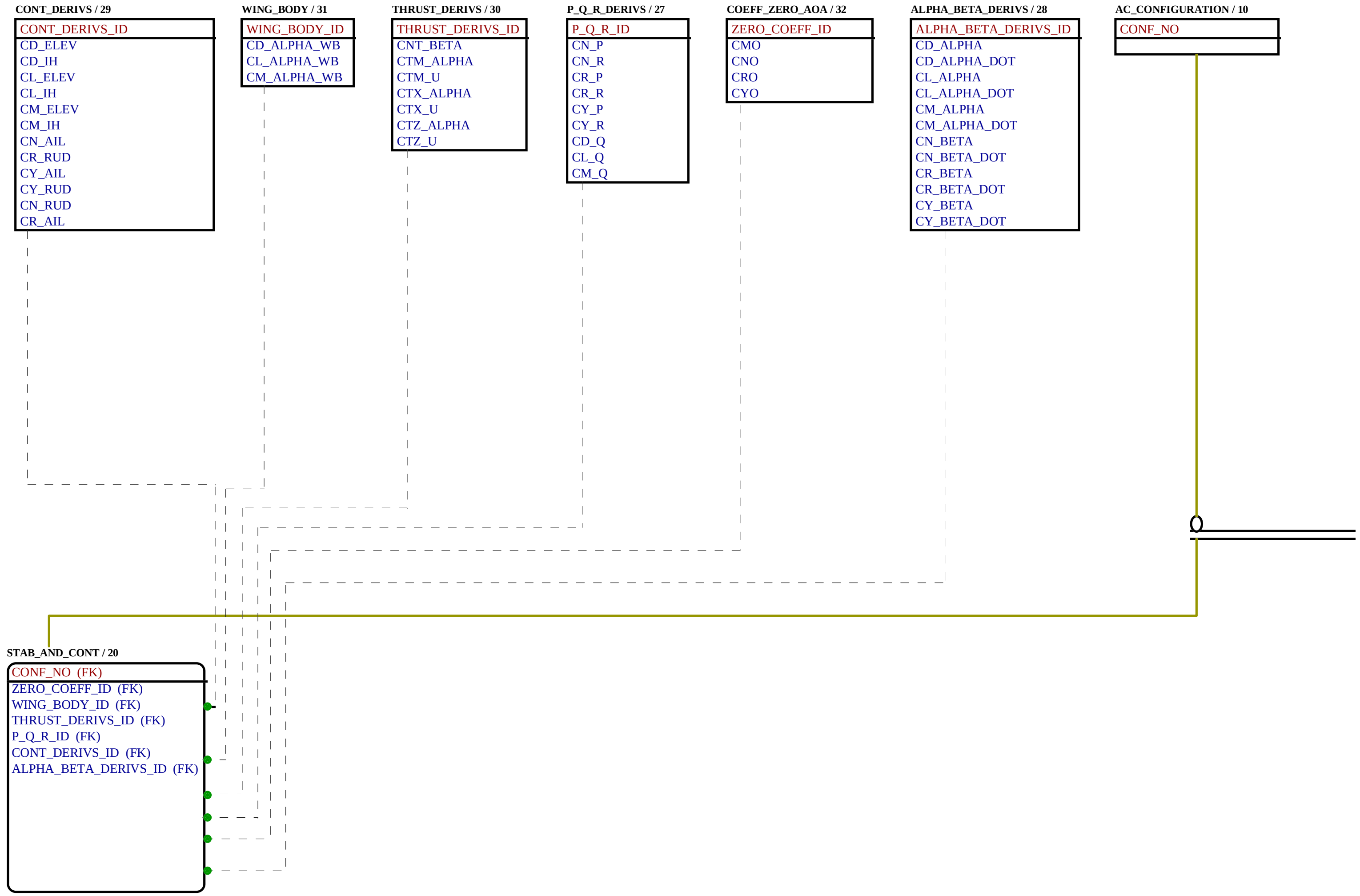


Figure 16. IDEF1X diagram of aircraft stability and control.

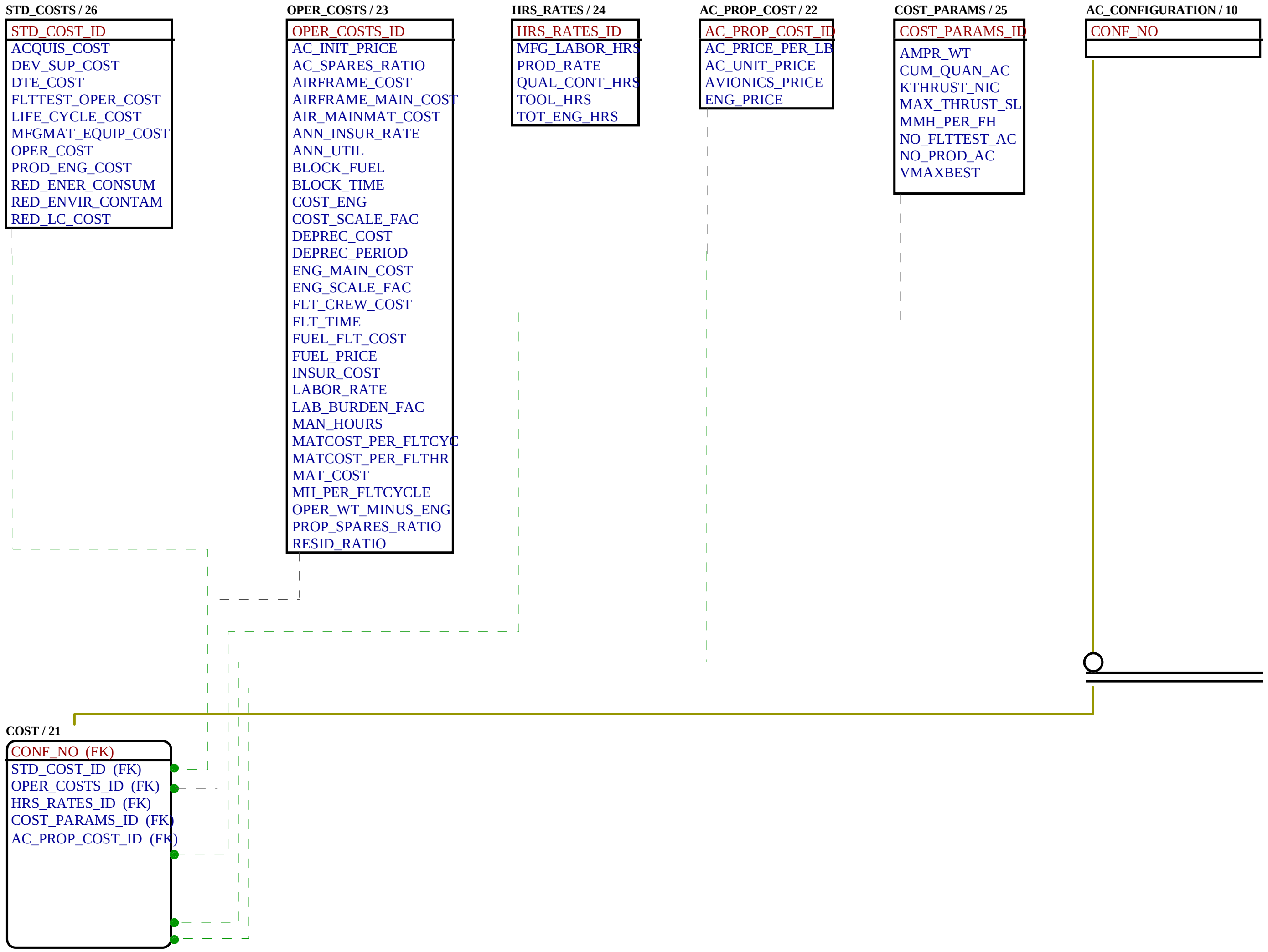


Figure 17. IDEF1X diagram of aircraft cost.

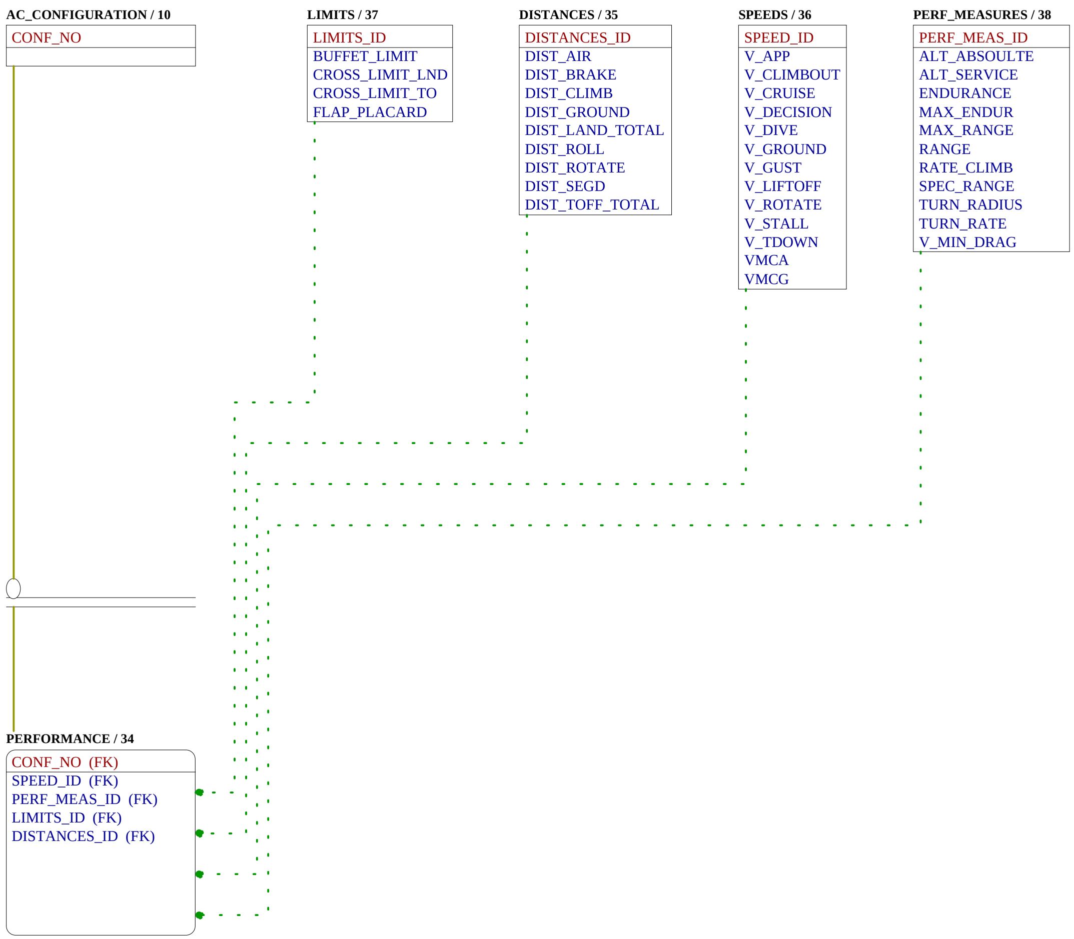


Figure 18. IDEF1X diagram of aircraft performance.

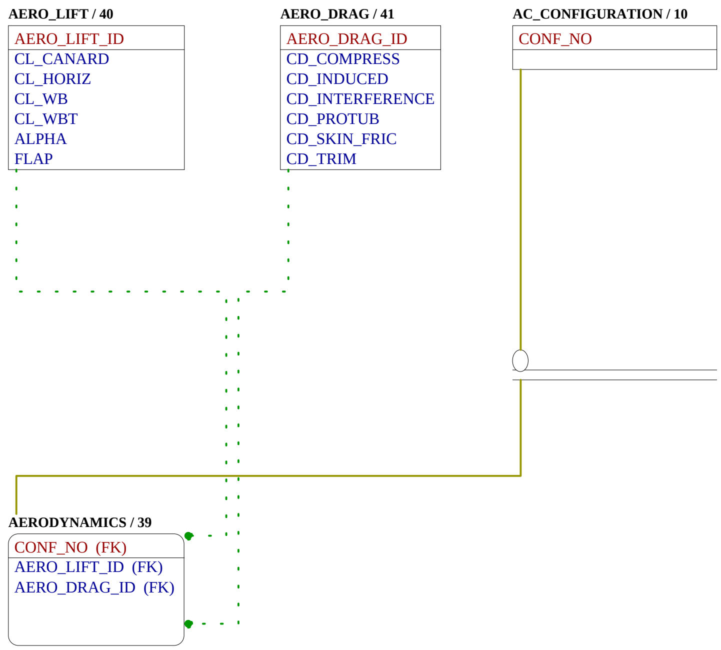


Figure 19. IDEF1X diagram of aircraft aerodynamics.

Implementation of Database

Implementation of the database model can be on any of the available relational database management systems such as ORACLE, SYBASE, or INGRES.

CHAPTER IV

OBJECT-ORIENTED DATABASE DESIGN APPROACH

Data Relationships Modeling

The design treats an aircraft configuration as a object which is composed of other component objects. The objects making up an aircraft configuration are a: wing, horizontal, vertical, canard, fuselage, engine, nozzle, inlet, and gear. An engine is made up of a compressor and a turbine. Each of the aircraft component's objects are made up of member objects which have load, stress, and material characteristics. The typically disciplinary calculations of aerodynamics, cost, weights, performance, and stability and control are treated as objects of an aircraft configuration. This seems a little unnatural, however, these calculations have been traditionally grouped by discipline and it is probably a good guess that they will continue to be associated in this manner for some time to come.

Database Schema

The lexical EXPRESS model for the Object-Oriented design is shown in Appendix C.

Data Dictionary

The HSCT object-oriented design data model utilizes the same data dictionary as the relational design found in Appendix B.

Logical Database Design (EXPRESS)

Figure 20 shows the EXPRESS model for the aircraft components. Different from the relational design, the aircraft configuration object (ac_configuration) has attributes that extend beyond simple data types. The disciplinary calculations of costs, weights, aerodynamics, performance, and stability and control are considered attributes of aircraft configuration. Another important point is that a uniqueness constraint exists for the simple data type of identification_no. This identification number is inherited by the disciplinary calculation objects as well as the aircraft components (ac_component).

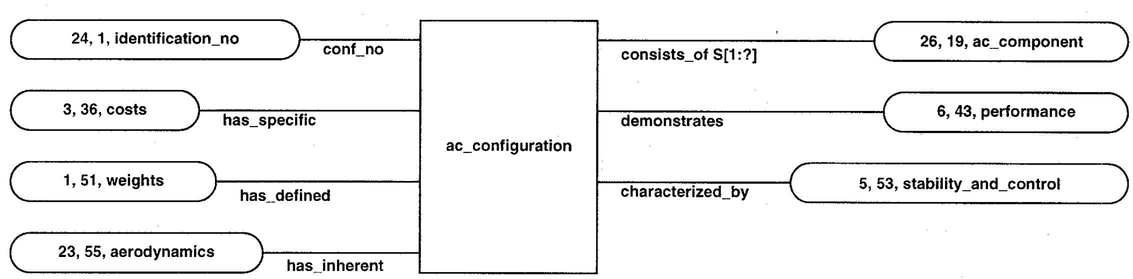


Figure 20. EXPRESS model -aircraft configuration (EXPRESS page 19)

Figure 21 shows that an aircraft component can be an: engine, fuselage, gear, inlet, nozzle, canard, horizontal, vertical, and wing, with each object being a subtype of aircraft component (ac_component) and therefore the heavier black lines.

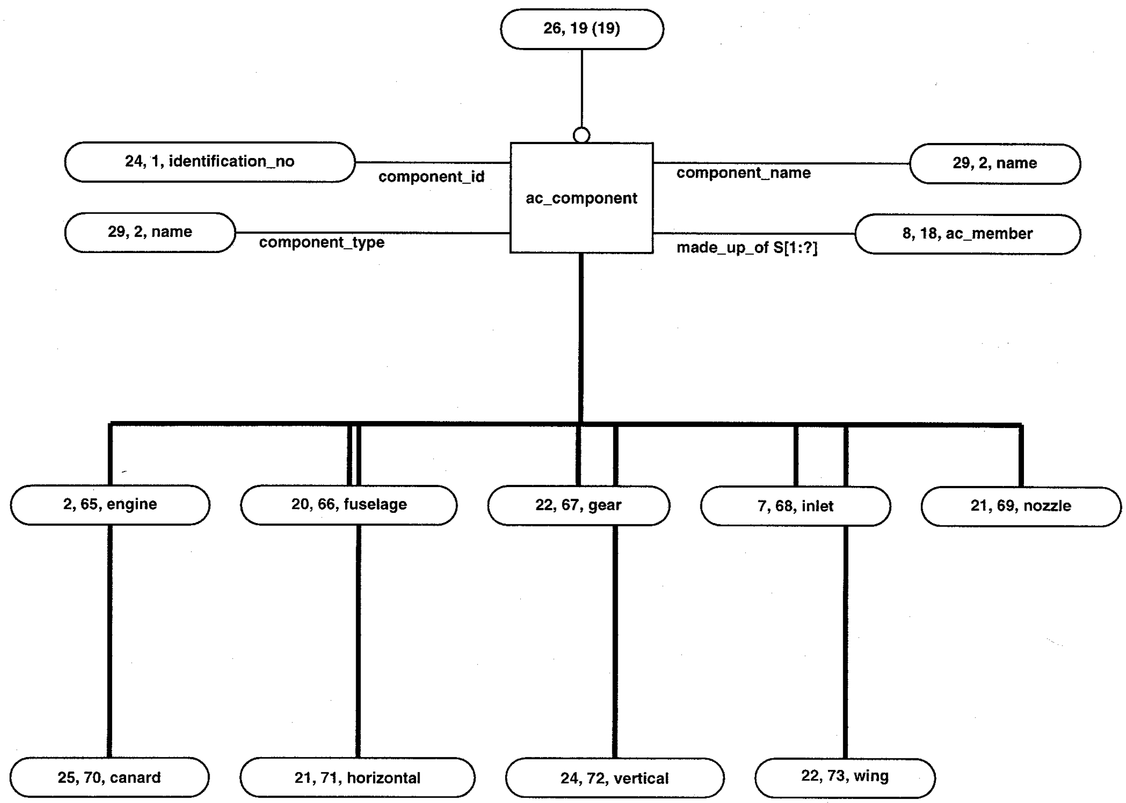


Figure 21. EXPRESS model - aircraft components (EXPRESS page 26)

An aircraft component is made up of aircraft members. Figure 22 shows that an aircraft member (ac_member) is made from materials and therefore the material object is considered an attribute of aircraft member (ac_member). The figure also shows that an aircraft member has load and stress characteristics which are considered part of the member object.

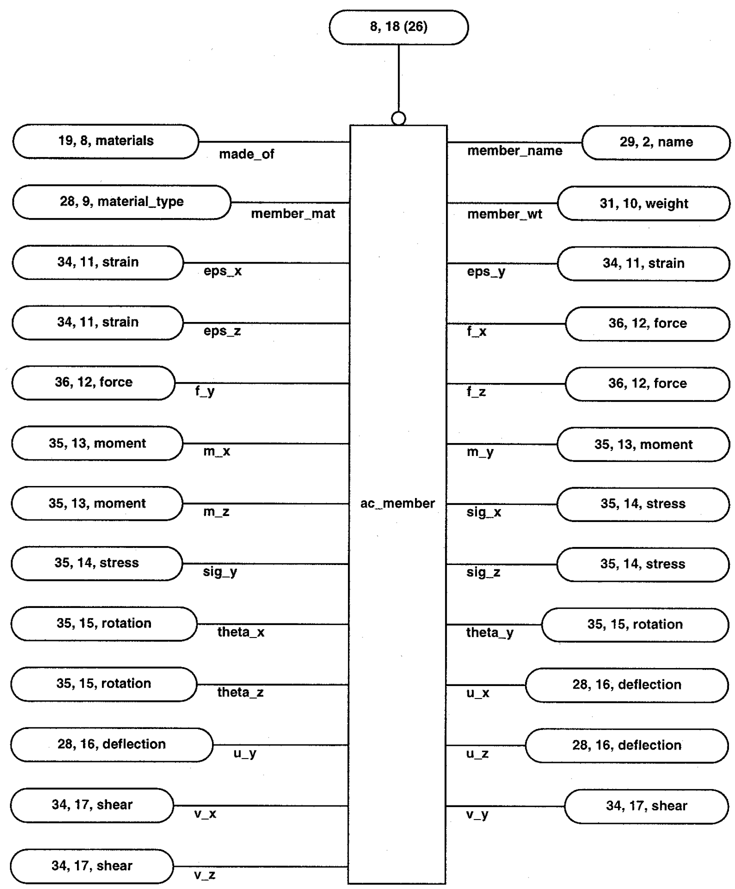


Figure 22. EXPRESS model - aircraft member (EXPRESS page 7)

Figures 23 - 34 show the aircraft component objects that make up an aircraft configuration such as the wing, horizontal, fuselage, etc.

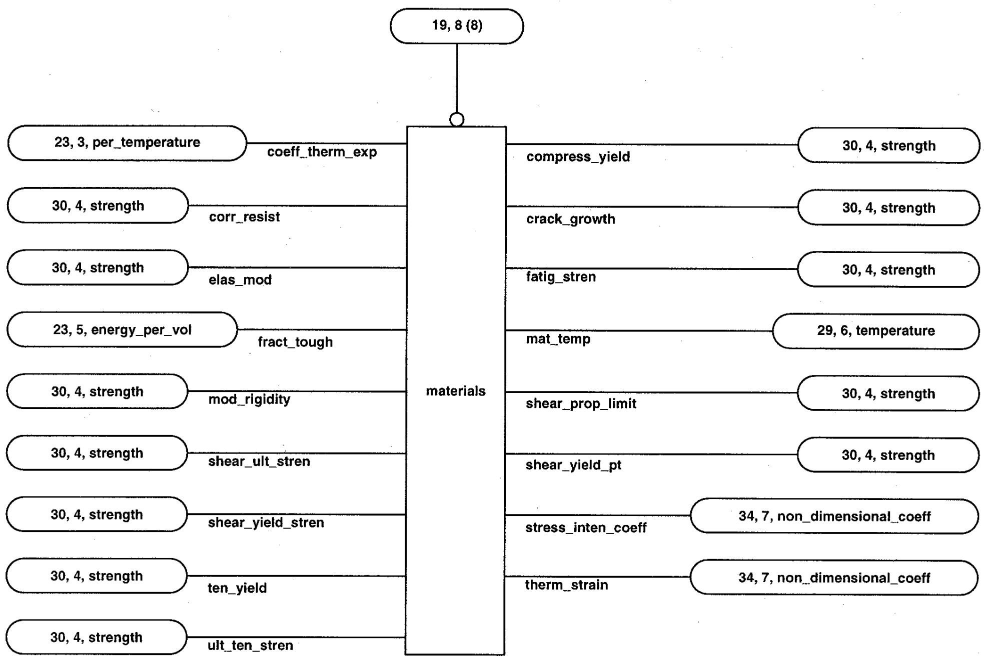


Figure 23. EXPRESS model - member material (EXPRESS page 19)

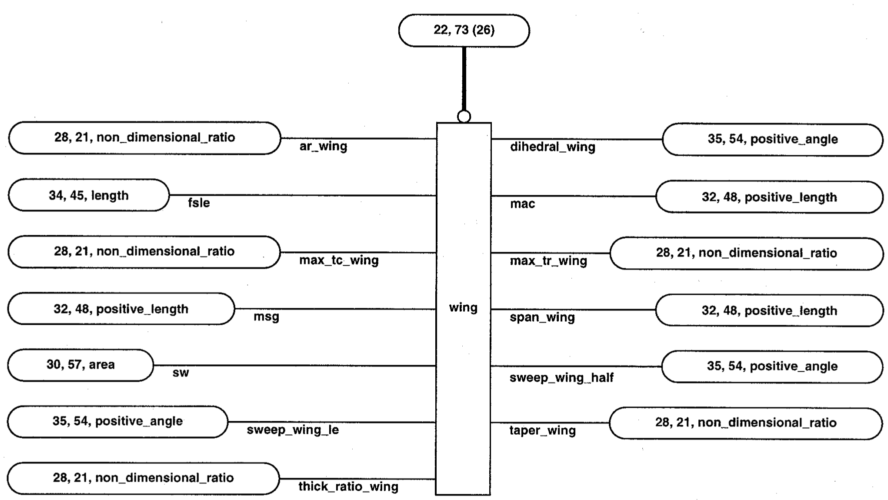


Figure 24. EXPRESS model - wing (EXPRESS page 22)

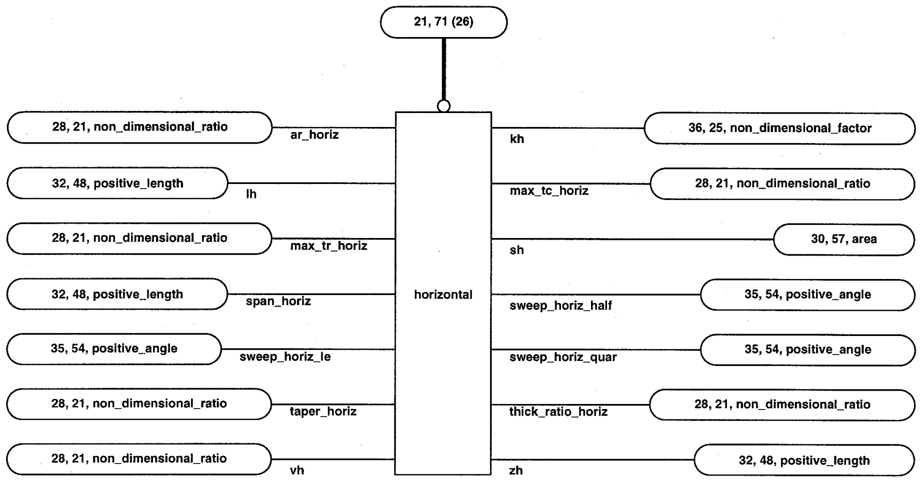


Figure 25. EXPRESS model - horizontal (EXPRESS page 21)

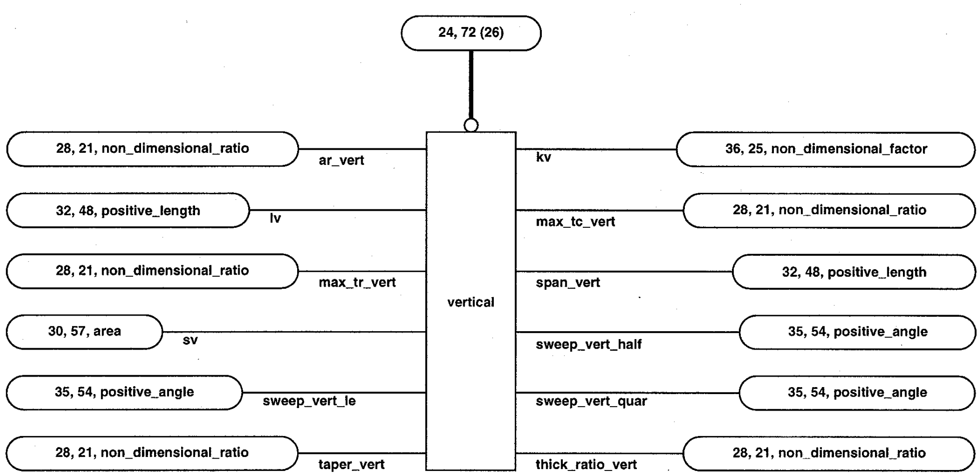


Figure 26. EXPRESS model - vertical (EXPRESS page 24)

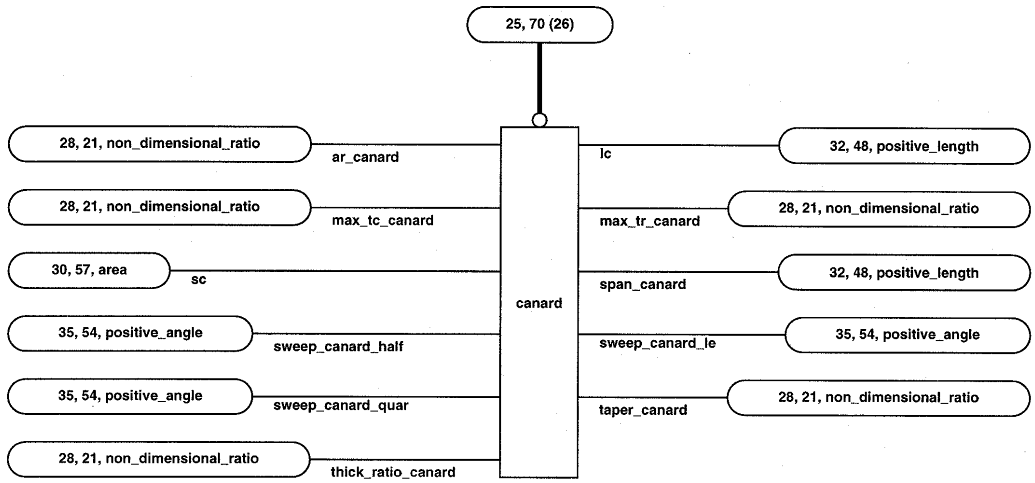


Figure 27. EXPRESS model - canard (EXPRESS page 25)

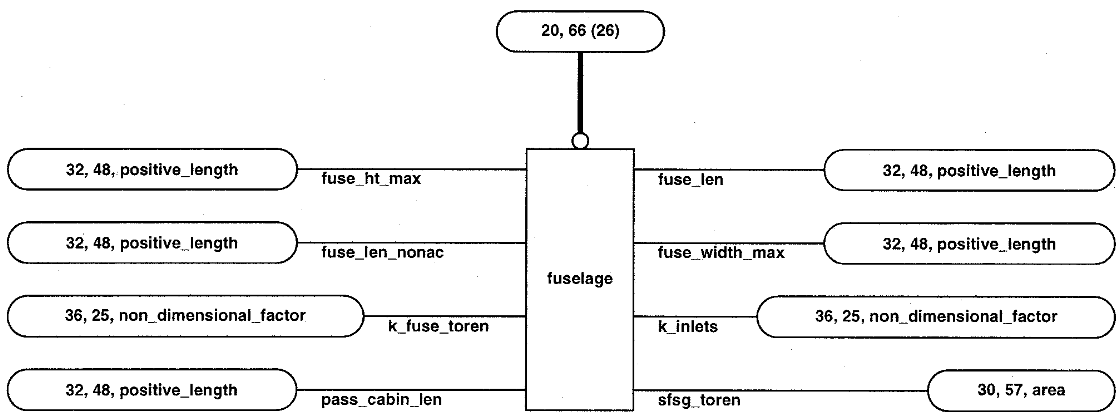


Figure 28. EXPRESS model - fuselage (EXPRESS page 20)

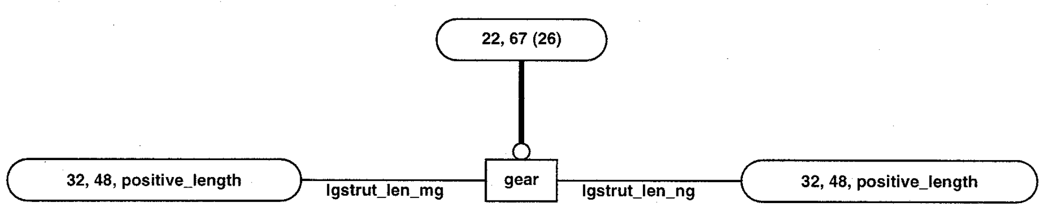


Figure 29. EXPRESS model - gear (EXPRESS page 22)

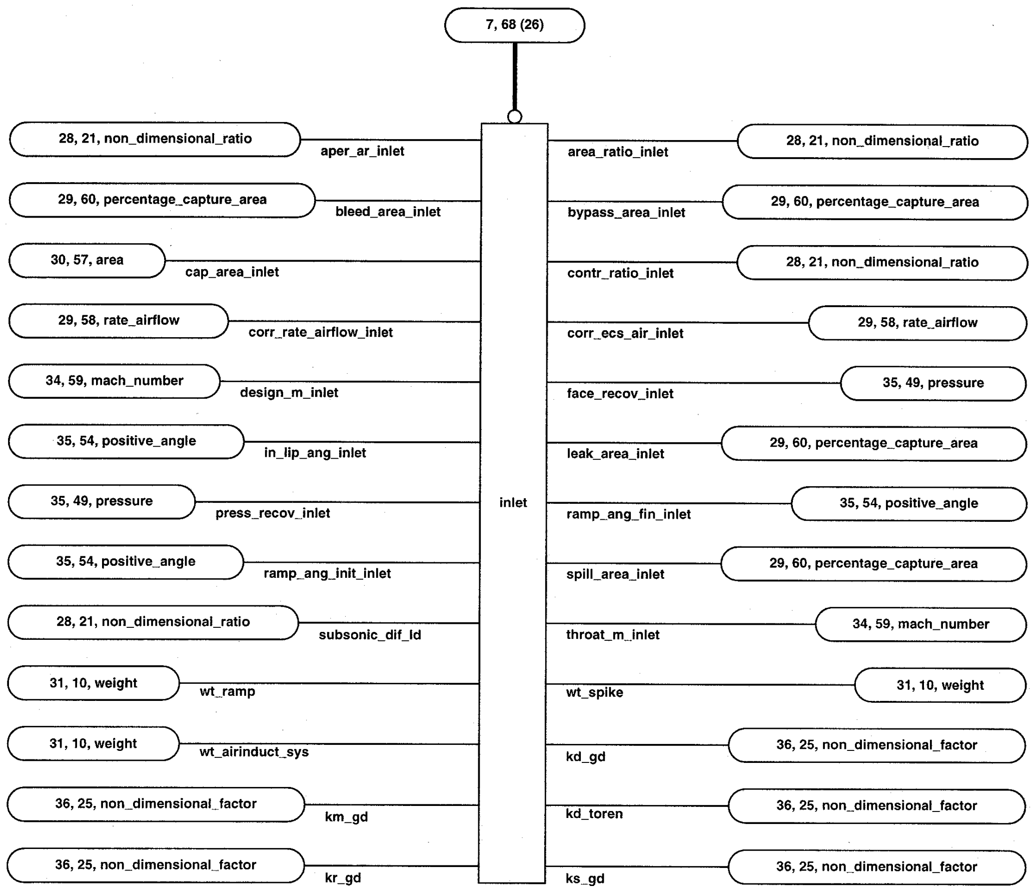


Figure 30. EXPRESS model - inlet (EXPRESS page 6)

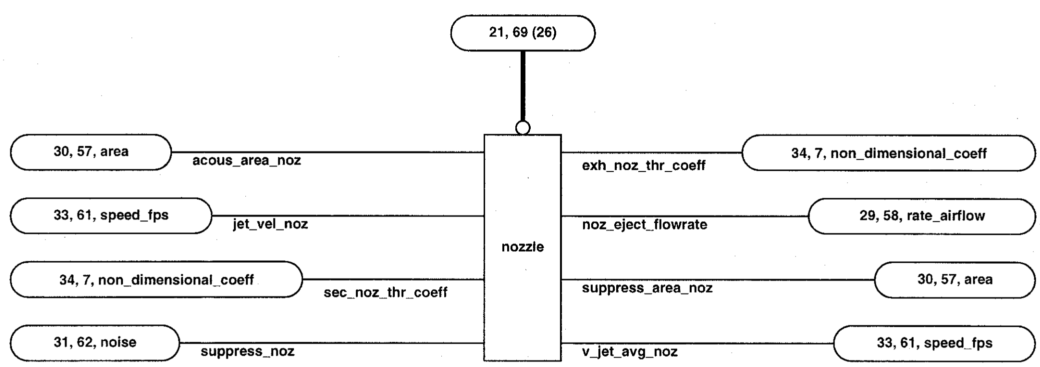


Figure 31. EXPRESS model - nozzle (EXPRESS page 21)

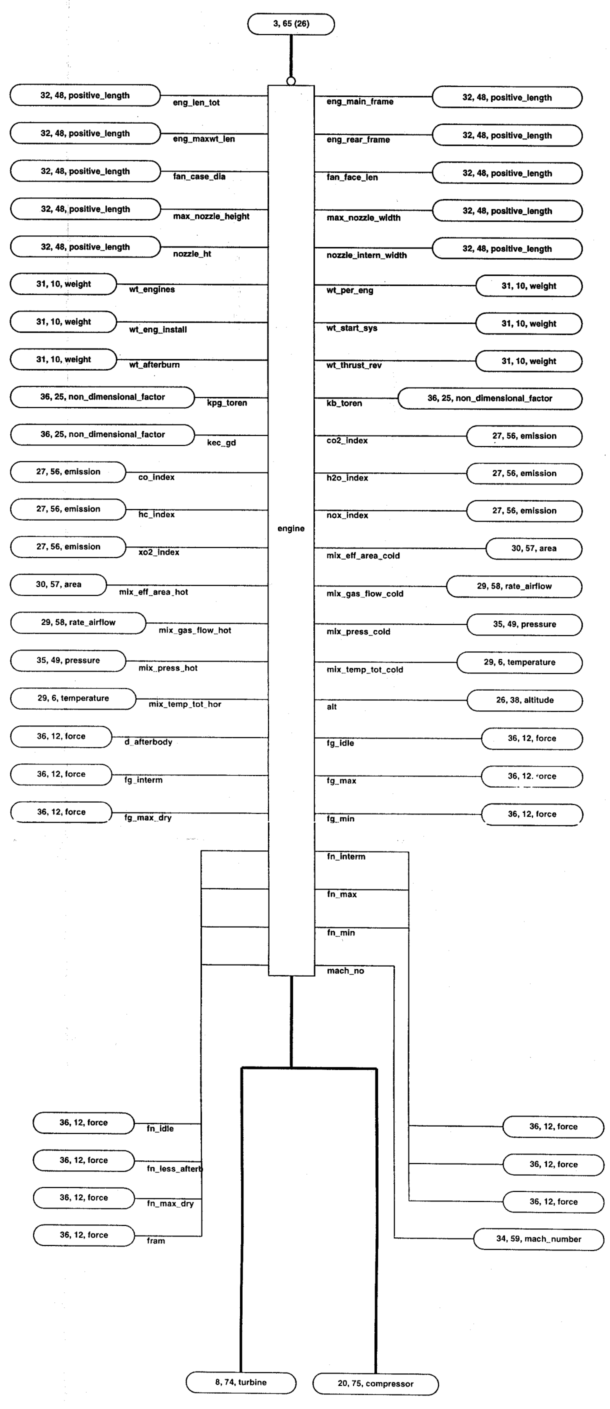


Figure 32. EXPRESS model - engine (EXPRESS page 3)

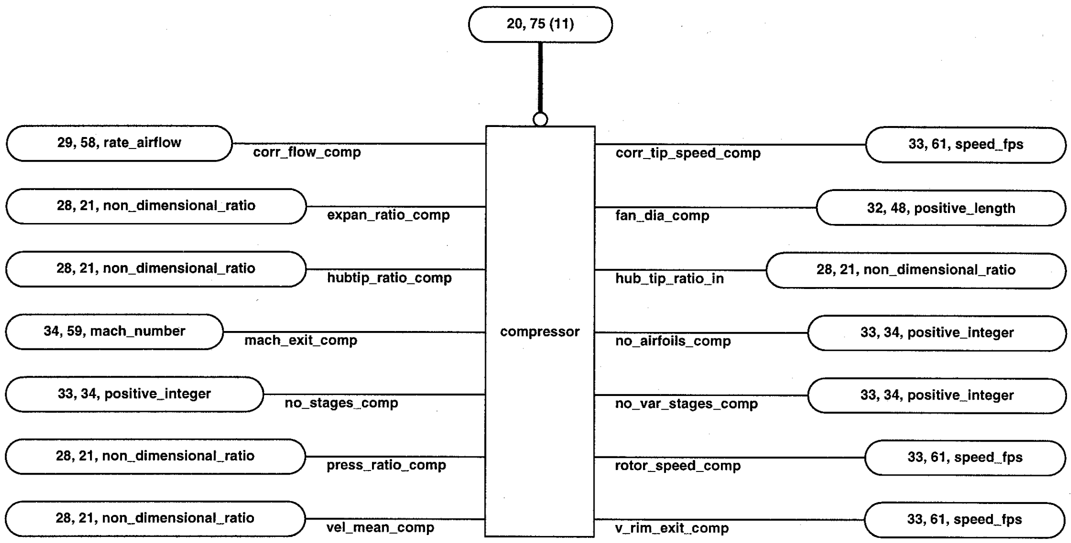


Figure 33. EXPRESS model - compressor (EXPRESS page 20)

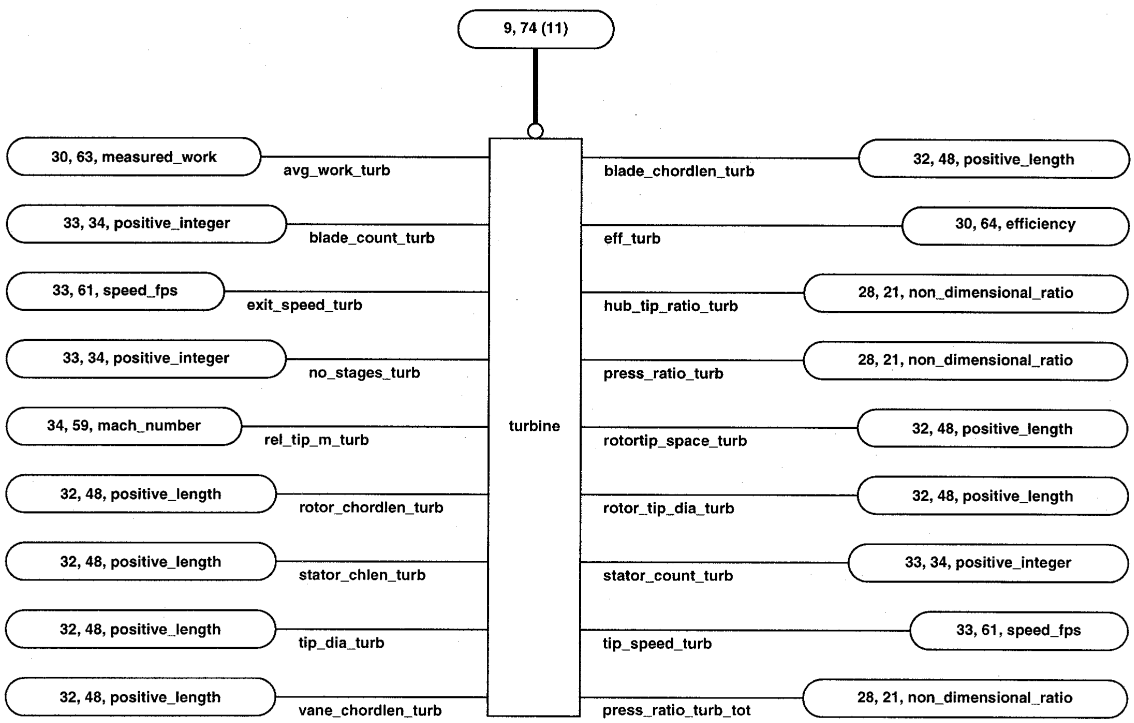


Figure 34. EXPRESS model - turbine (EXPRESS page 8)

Figures 35 - 39 shows the aircraft disciplinary calculation objects: cost, aerodynamics, weights, performance, and stability and control.

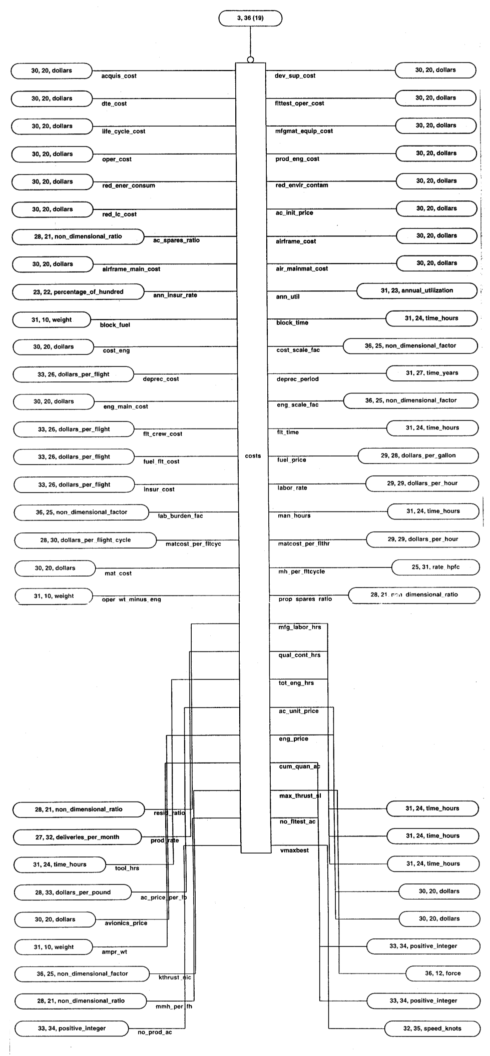


Figure 35. EXPRESS model - cost (EXPRESS page 2)

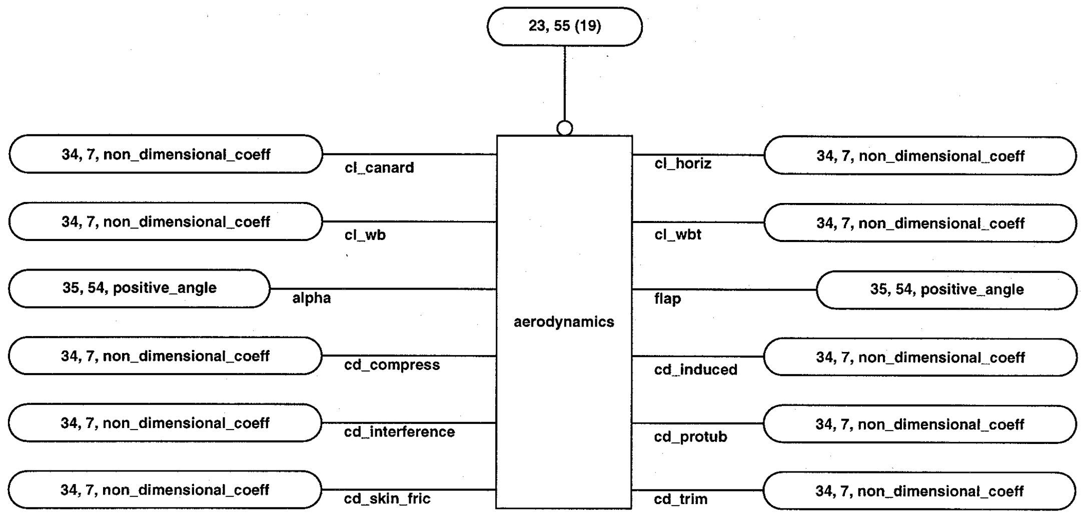


Figure 36. EXPRESS model - aerodynamics (EXPRESS page 23)

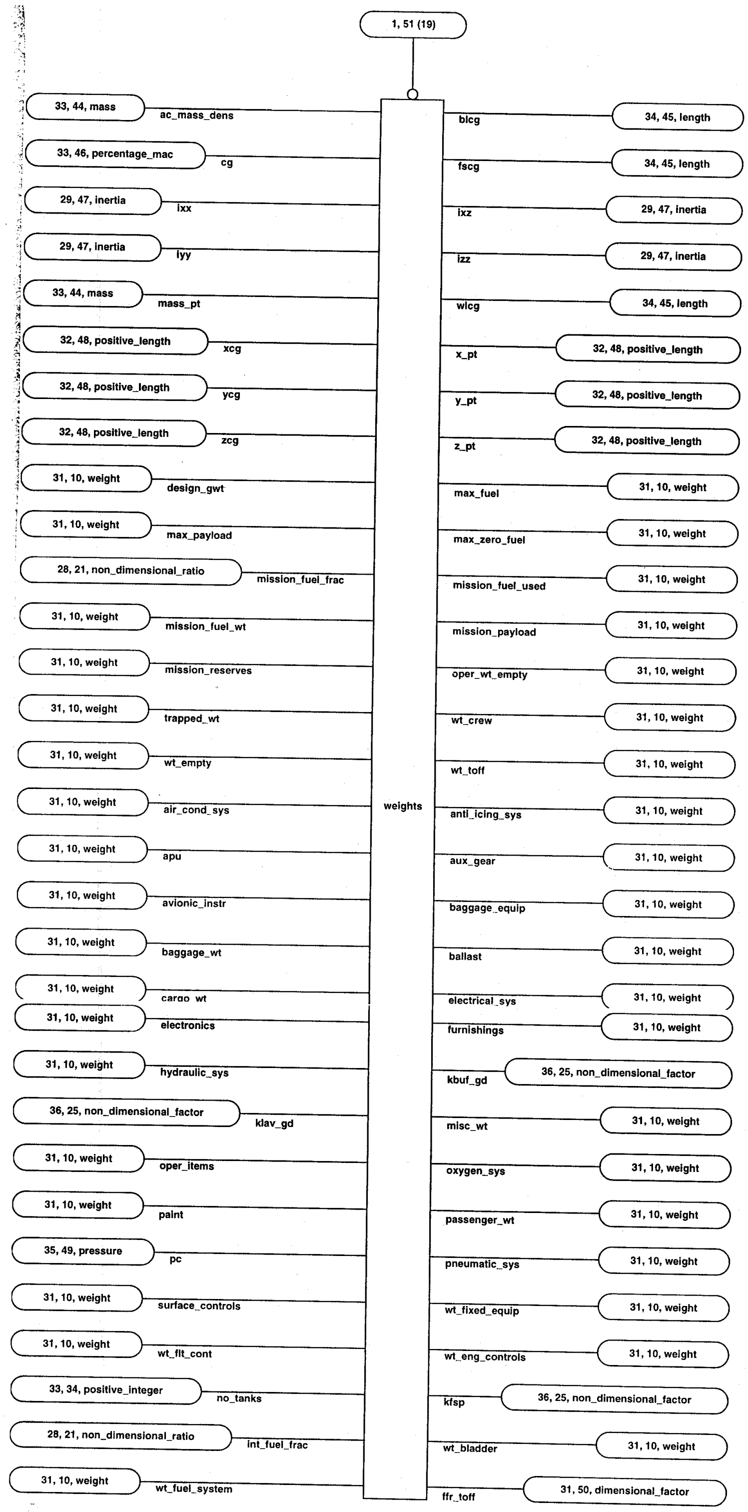


Figure 37. EXPRESS model - weights (EXPRESS page 1)

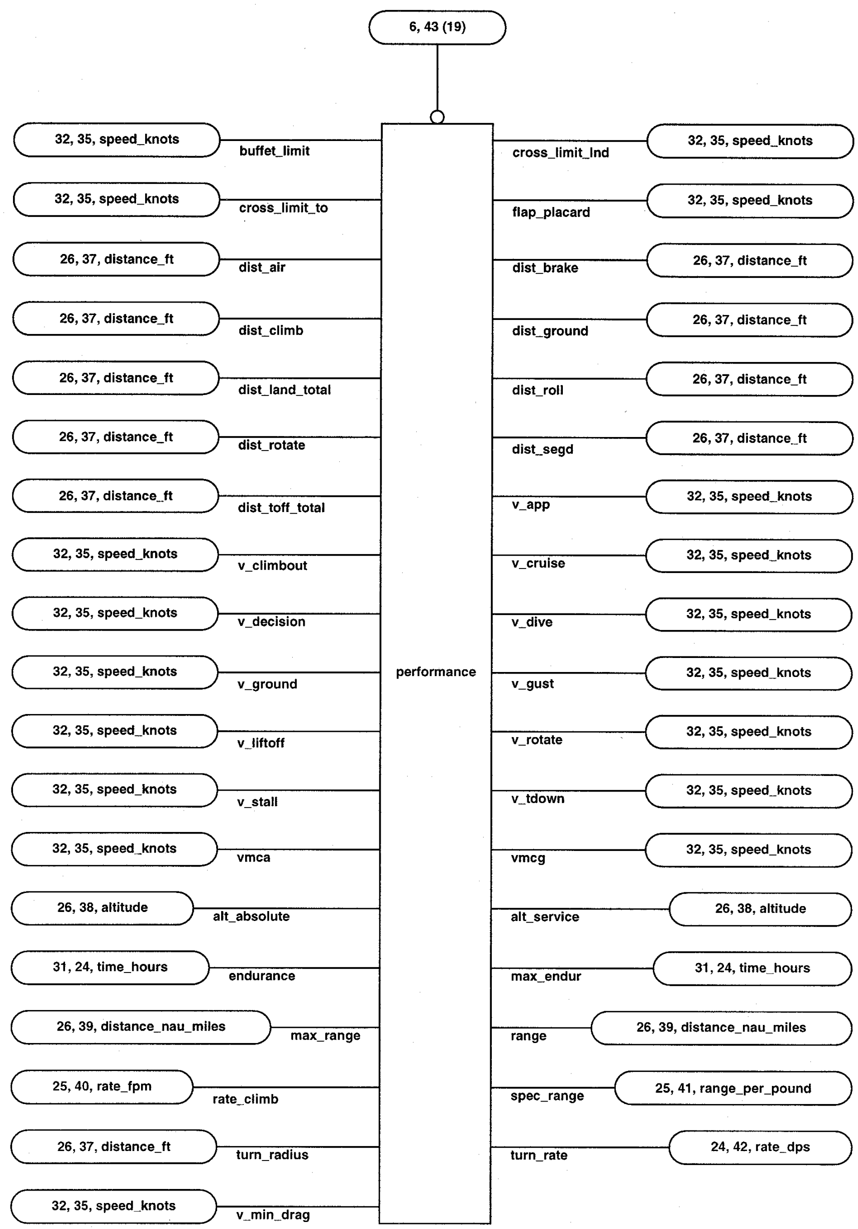


Figure 38. EXPRESS model - performance (EXPRESS page 5)

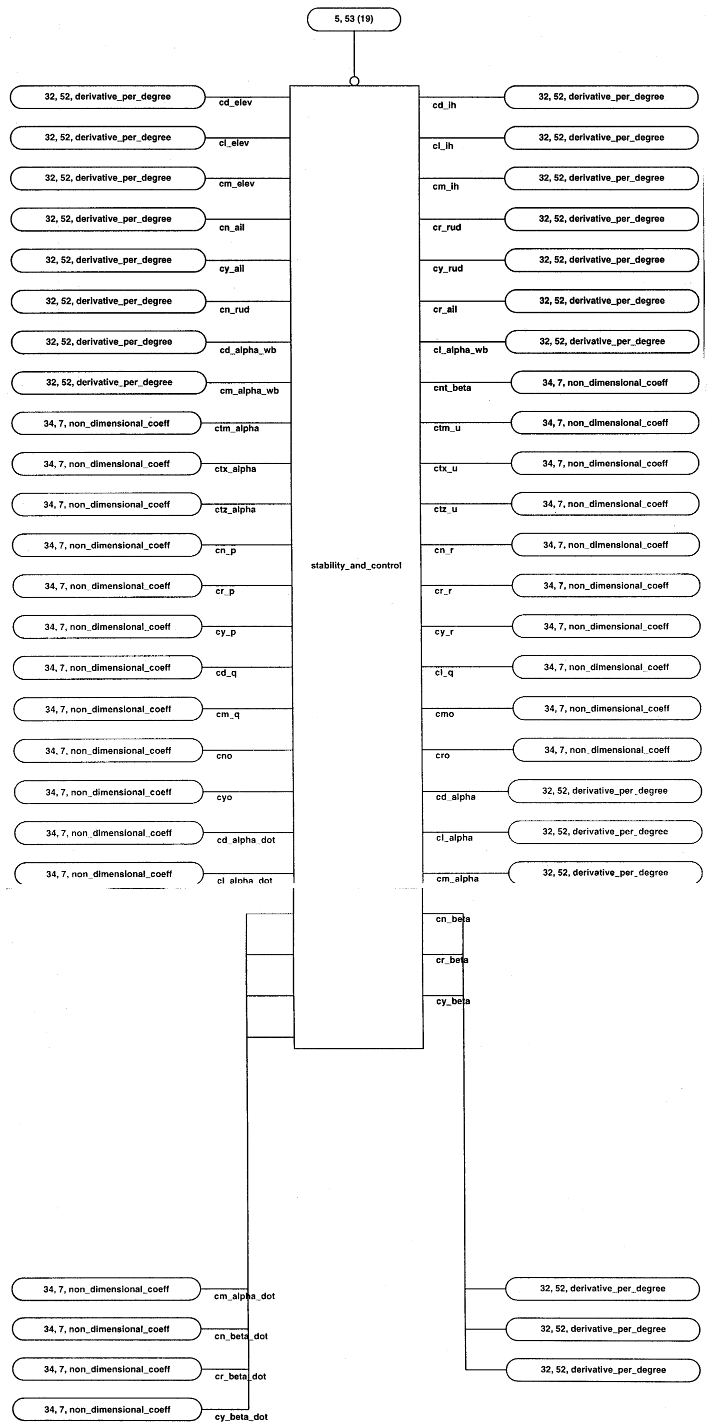


Figure 39. EXPRESS model - stability and control (EXPRESS page 4)

Implementation of Database

Implementation of the database model can be on any of the available object-oriented database management systems or object-oriented database programming languages such as Objectivity/DB, ONTOS, ObjectStore, VERSANT, and GemStone.

CHAPTER V

DATABASE PERFORMANCE METRICS

<u>Benchmarks</u>

Little work has been done on performance in the field of object data management, despite its importance to most applications.[15,16] Moreover, there seems to be even less research in the area of performance comparisons between relational and object-oriented DBMSs. One difficulty lies in the understanding of what constitutes performance? In his book, R. G. G. Cattell discusses two kinds of DBMS performance issues, model-based and architecture-based.

> *Model-based:* In some cases, performance is limited by the data model, regardless of how good the implementation. For example, relational-model implementations have an impedance mismatch between programming and query language, forcing an application to represent a list (such as the chapters of a book) as a table, and to copy the data wholesale from the table to a list in the programming language at runtime in order to manipulate the elements efficiently.
>
> *Architecture-based:* ... the implementation of specific ODMS features can have major performance implications. In some cases, the implementation choices for two particular features, such as concurrency control and remote databases, can interact favorably or very badly for overall speed. Thus, it is important to consider the overall view.[14]

Application speed is still considered one of the most important performance metrics when comparing DBMSs. Cattell and Skeen developed the OO1 (Object Operations, Version 1) benchmark to address some of these performance issues. The OO1 benchmark is intended as a generic measure of ODMS performance. It was designed to approximate database needs of CAD, CASE, and similar applications. A simple database of parts is used with a many-to-many connection relationship between the parts. Three kinds of operations were performed on the parts and connections: lookup, traversal, and insert.[17] Figure 40 shows the results of Cattell and Skeen's work using the OO1 benchmark for a cold start and with database caching. The benchmark operations were run on a database of approximately 4 megabytes, with 20,000 parts and 60,000 connections. Cattell and Skeen showed that with database caching, the OODMBS was 30 times faster overall than the RDBMS. The OO1 benchmark was run on the object-oriented database programming languages Objectivity/DB, ONTOS, ObjectStore, VERSNAT, and GemStone, as well as the relational database products SYBASE and INGRES at a later time. Cattell and Skeen's findings were again consistent with the results shown in figure 40. They attribute the differences in relational and object-oriented DBMS performance to be to architecture-based rather than model-based.

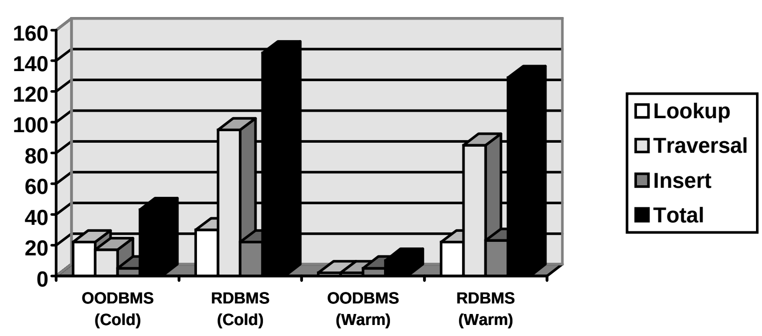


Figure 40. OO1 benchmark comparison of traditional relational DBMS against object-oriented database programming language in seconds.

Performance Comparisons of ORACLE and ROSE/C++ Database Models

In order to evaluate the performance of the conceptual IDEF1X and EXPRESS designs, the stability and control portion of the database design was populated with data. Figure 41 shows that the relational representation of the stability and control data requires seven (7) tables in order to adhere to strict third normal form. Figure 42 shows the object representation of the same data where stability and control data is an attribute of aircraft configuration. An experiment was set up to conduct table lookups for all 47 variables representing the stability and control data. The number of variable lookups was then doubled and tripled, and the system CPU time in seconds required to carry out the task was recorded. The ORACLE and C++ models were ran on Sun SPARC stations 2000 and 20 respectively, with Solaris 2.4 operating systems. A better comparison would have been to run each model on the same machine. However, due to limitations in the availability of software for given machines, this was the only available option. Figure 43 shows the results of the experiment. The question immediately arises as to how to separate out the two performance issues, model-based and architecture-based. From the work done by Cattell and Skeen it was determined that it is not possible to compare the performance of different implementations through abstract analysis except in some simple cases.[17] A better comparison might be to emulate the relational tables in an object environment (and on the same machine), then using C++ as the query language. This would possibly eliminate the architecture-based performance issue, but the model-based issue would still remain. The focus of this research is evaluating database design methods and how these methods are impacted by an evolving database design. The conclusion is that for this domain (i.e. aircraft conceptual design), the measure of performance that is deemed most important is how the methodology performs in the environment in which it was designed. It would be quite unnatural to model objects like relational tables in order to provide a more neutral ground from which to evaluate performance. The bottom line is that the aircraft designer is interested in how easy it is to introduce changes to a data schema and implement those changes.

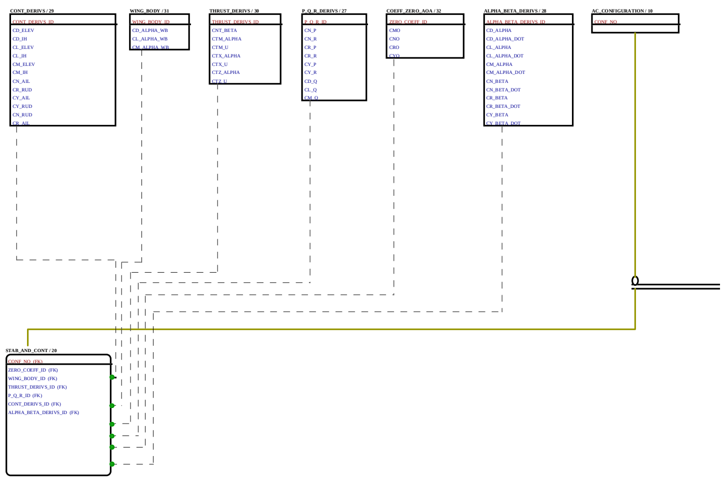


Figure 41. Relational schema for the stability and control data.

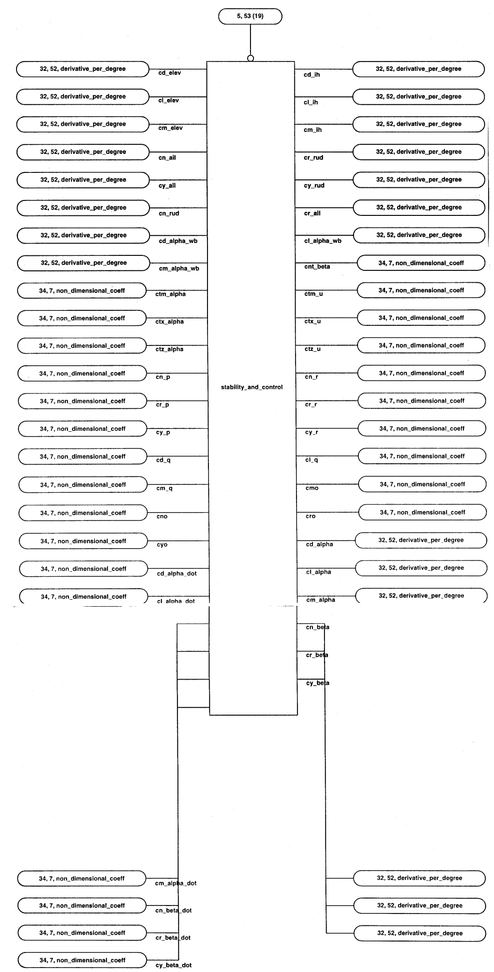


Figure 42. Object-oriented schema for the stability and control data.

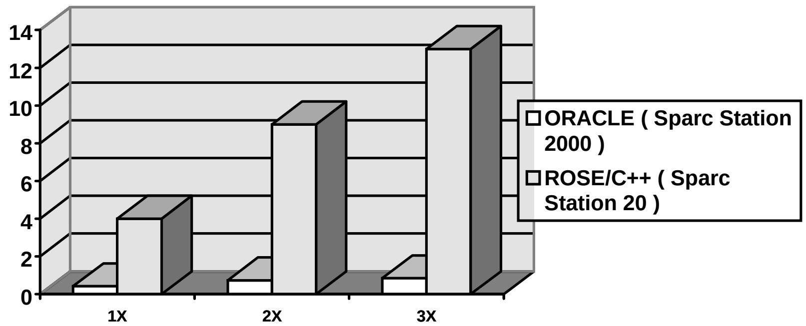


Figure 43. Comparison of ORACLE against object-oriented database programming language (C++) for table lookups in seconds.

CHAPTER VI

DESIGN COMPARISONS

Evaluation of IDEF1X and EXPRESS (General)

Eastman and Fereshetian have developed an excellent set of design product-modeling criteria. Table 2 shows this criteria for the IDEF1X and EXPRESS data models. Eastman and Fereshetian found that IDEF1X lacks adequate support for object-oriented concepts and does not address operator semantics provided by abstract data types of methods. EXPRESS provides strong capabilities for defining the structures often developed in object-oriented databases. Both IDEF1X and EXPRESS fail to reflect the dynamic and evolutionary nature of design, because of the varied sequence of applications and the possibly dynamic definition of the database schema as the design proceeds. The IDEF1X and EXPRESS models appear to address more the manufacturing end of the product development process, where the issues of change are less important.[19] The domain for this work was derived from the structure and function of walls.

Evaluation of IDEF1X and EXPRESS (Specific)

Database designs have been generated using both the IDEF1X and EXPRESS data models. Through this work certain benefits/detriments of the IDEF1X/Relational and

Table 2. Evaluation of information models according to design product-modeling criteria.

Concept	Design Need	IDEF1X	EXPRESS
Full abstract data types	Needed for object semantics	Missing operators	Yes, with operating constraints
Multiple specialization’s	Important for abstraction	Yes, supports partial orders	Yes, supports partial orders
Composite objects	Important for abstraction	Supported	Supported
Relations within compositions	Important for abstraction	Not supported	Supported with precedence on relations
Relations on object structure	Needed for semantics	Supported	Supported
Relation between variables	Needed for semantic definition	Not supported	Supported
Variant relations	Needed for schema evolution	Not supported	Not supported
Variant relations defined operationally	Needed to define state of integrity	Not supported	Partial support
Integrity management of external applications	Needed for applications management	Not supported	Partial support
Management of partial integrity	Needed for iterative design	Missing - assumes total integrity	Missing - assumes total integrity
Supports schema evolution	Needed to support design evolution	Basically static, some structure evolution	Basically static, some structure evolution
Cont. refinement versus class instances	Needed for design refinement	Class instance	Class instance

EXPRESS/C++ design and implementation have been found that supplement those documented in reference 19. Table 3 details these findings.

Table 3. Evaluation of information models for conceptual aircraft design.

Attribute	**IDEF1X/Relational Implementation**	**EXPRESS/Object-Oriented Implementation**
Data redundancy	No data redundancy	Data redundancy
Real world representation	Data structure is unnatural. Does not replicate how data is actually collected and kept during the design phase.	Data is structured in a way that better replicates how data is actually collected and kept during the aircraft conceptual design phase.
Design tools	Limited design tools	Limited design tools
Speed		Has been demonstrated to be faster than conventional RDMSs when model-based and architecture-based issues are eliminated.
Ease of schema changes	Can be difficult to modify schema, but not impossible	A little more flexible to modify schema than IDEF1X, but still requires some work
Programming language interface	Application language and query language typically different	Can have a common application and query language
Manipulation of objects	Requires multiple queries and can be somewhat difficult	Object orientation makes it easy
Inheritance	Does not support inheritance	Supports inheritance
Many-to-many relationships	Many-to-many relationships require the introduction of a relationship table in the relational model	Many-to-many relationships can be represented directly in the object-oriented model

In nearly all applications, it is important to be able to modify a schema with minimum impact on exiting applications. This can be even more important in design applications, because the user as well as the application programmer may modify the schema (for example, to define new types of design components or design constraints). Current DBMSs do not provide good facilities to migrate data to new schemas.[14] Typically, the application language and query language are different in RDBMSs requiring pre-compilers. If the C++ programming language is chosen, then the application and query language can be common. The OODBMSs allows for an object type to have all of the attributes of an existing object whereas RDBMSs do not support inheritance.
Binary many-to-many relationships can be represented directly in the object-oriented model through two list-valued attributes, but they demand the introduction of a relationship table in the relational model (if the database is to be in first normal form).[14]

CHAPTER VII

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.

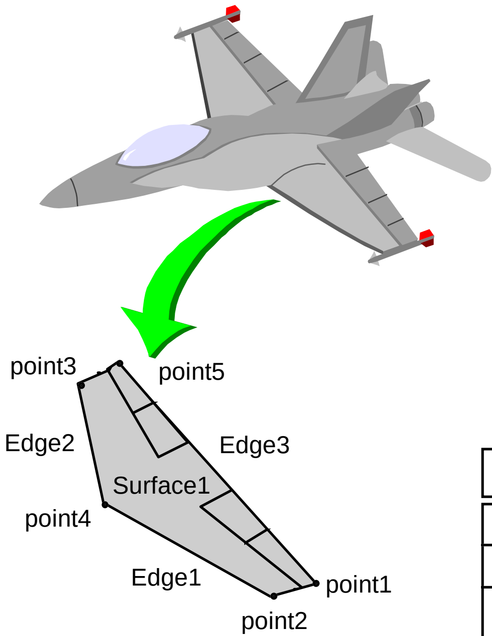
This research has focused on the impact of data modeling and database implementation methods in order to gain a better understanding of how efficient data management can optimize the aircraft design process. This research has included the development of a formal process model for the conceptual aircraft design sequence. The author has been involved in numerous conceptual studies over the last ten years with two major airframe companies. Although each company was very active in the conceptual design process, there seemed to be a lack of process formality. Part of this research has been to identify a common process in order to ascertain what the data requirements are for the process.

Two database design approaches have been taken. An IDEF1X approach with a relational implementation and an EXPRESS approach with a C++ programming language implementation. In the development of these database designs it 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.

The popularity of the relational data model is partly due to its simplicity. It is easy to understand because data is structured in tables, a concept familiar to almost everyone. The maturity level of the RDBMs also makes it quite attractive. It provides a very powerful query language and very little programming is required for implementation. However, the relational model is best suited for the data retrieval and manipulation of business application requirements and not engineering applications. In modeling the data required for conceptual design, if third normal form is strictly enforced, the organization of the data is very unnatural. Unnatural here means that the data structure is very unrepresentative of how that data exists in the physical world.

The object-oriented representation of conceptual design data does a better job at providing a more realistic or natural data structure than the relational approach. Cattell states that the context of object data management are in the three areas of software engineering, mechanical and electrical engineering, and documents.[14] Design tools such as CAD and CAE have database systems embedded inside them which are not typically accessible by the user. The problem arises when the user is faced with a variety of application all with incompatible data representations.

Consider the simplistic wing example shown in figure 44. In order to describe a single surface with relational tables would require a minimum of the three tables shown. An edge is described by two points and five edges describe the single surface denoted as *Surface 1*.



Edges		
EdgeID	Length	Attribute
Edge1	100.	. . .
Edge2	100.	. . .
Edge3	350.	. . .
. . .	. . .	. . .
. . .	. . .	. . .

Points			
PointID	X	Y	Z
Point1	132.0	75.0	100.0
Point2	125.0	75.0	100.0
Point3	125.0	-75.0	100.0
. . .	. . .	. . .	. . .
. . .	. . .	. . .	. . .

StartEnd	
EdgeID	PointID
Edge1	Point2
Edge1	Point4
Edge3	Point1
. . .	. . .
. . .	. . .

Figure 44. Relational database representation of a wing surface.

A major drawback of a relational design becomes quickly apparent in this example, that is the problem of segmentation. Kemper states that one of the most severe drawbacks of the relational model is the need to decompose logically coherent application objects over several base relations.[20] Due to the segmentation introduced in the relational design, in order to perform a simple rotation of the surface requires a query consisting of multiple joins. The query serves to reconstruct the object for rotation. The object-oriented environment provides a means for modeling the structure of the object as well as its behavior. It is this function that makes the object-oriented approach to data modeling very appealing for engineering applications.

CHAPTER VIII

RECOMMENDATIONS

Conceptually, both the IDEF1X/ORACLE and EXPRESS/Object-oriented programming language approaches fall short of providing the user with the ease of schema changes. However, less work is required when using the EXPRESS/Object-oriented programming language methodology when making schema changes. This is a very desirable feature in the domain of conceptual aircraft design. It is important for the user to be able to modify a schema with minimum impact on existing applications.[14] Of the two approaches researched, the EXPRESS/Object-oriented programming language offers the best solution at the present time. The reasons for this choice are: (1) more commonality with the physical world, (2) commonality in application and query language, (3) the increased activity and support for STEP protocols, which are developed using EXPRESS, (4) relative ease in the manipulation of objects, (5) OODBMSs currently have the best chance for providing a solution where applications and CAD models share a common database, and (6) OODBMSs are still in the infancy stage when compared to RDBMs. The power of the RDBMS is partly derived from the RDBMS's maturity level. Where RDBMS capabilities are becoming more saturated over time, the

OODBMS capabilities are just beginning to be exploited, and this will continue to increase over time.

Figure 45 is a recommended database design strategy. The ultimate goal would be to develop an application protocol within STEP. With the numerous applications that have been developed already, as well as those currently in development, there does not exist a project for developing an application protocol for core conceptual aircraft design. The author realizes that the conceptual design phase is highly dependent upon the design in question, however, a baseline standardization would definitely serve as a design optimization tool. This would be extremely helpful in the situation where there are a variety of different companies working on the same design and the need for sharing data exists. The steps proposed for database design are:

1. Development of a process model
2. Development of a data dictionary
3. Development of a data schema
4. Creation of populated objects
5. Object-oriented programming language for data manipulation
6. Development of a STEP application protocol

It is also suggested that the data schema should serve as a template to help optimize the design process early in the data management development stages. One of the impediments to successful database design implementation is overcoming the existing cultural barriers within a company. Using the data schema as a template prior to any database implementation would at least eliminate some of the data redundancy problems that are so common today. Cultural barriers are built up over time. Overcoming some of the data management problems will take time as well. This first small step could serve as the first increment toward breaking down some these cultural barriers.

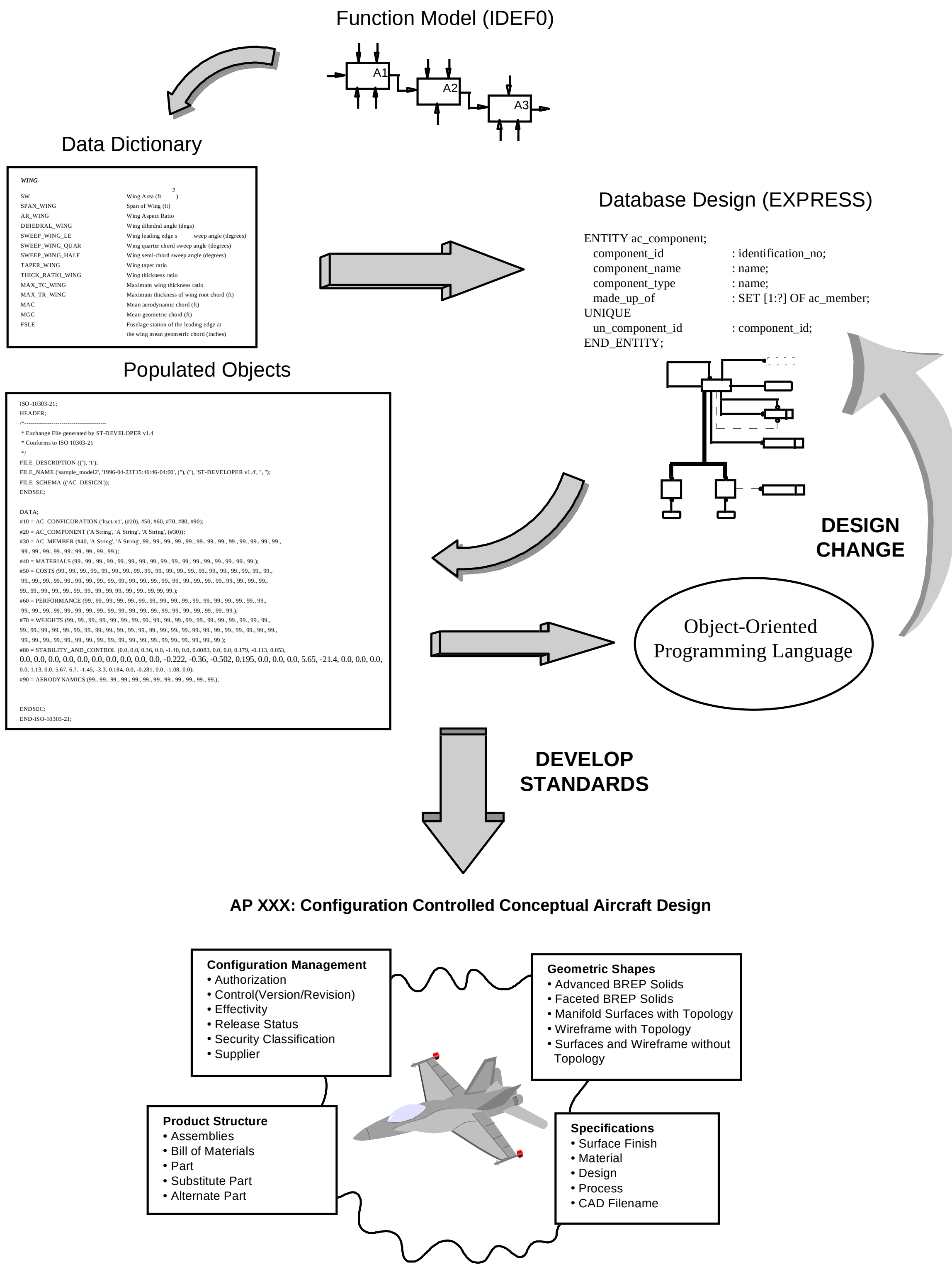


Figure 45. Recommended database design strategy and standards.

APPENDIX A

DATA SCHEMA

AC_COMPONENT (COMPONENT_ID, COMPONENT_NAME, COMPONENT_TYPE)

AC_CONFIGURATION (CONF_NO)

CONFIG_COMPONENT (CONF_NO, COMPONENT_ID)

ENGINE (COMPONENT_ID, ENG_LEN_TOT, ENG_MAIN_FRAME, ENG_MAXWT_LEN, 00 ENG_REAR_FRAME, FAN_CASE_DIA, FAN_FACE_LEN, MAX_NOZZLE_HEIGHT, MAX_NOZZLE_WIDTH, NOZZLE_HT, NOZZLE_INTERN_WIDTH, WT_ENGINES, WT_PER_ENG, WT_ENG_INSTALL, WT_START_SYS, WT_AFTERBURN, WT_THRUST_REV, KPG_TOREN, KB_TOREN, KEC_GD)

FUSELAGE (COMPONENT_ID, FUSE_HT_MAX, FUSE_LEN, FUSE_LEN_NONAC, FUSE_WIDTH_MAX, K_FUSE_TOREN, K_INLETS, PASS_CABIN_LEN, SFSG_TOREN)

GEAR (COMPONENT_ID, LGSTRUT_LEN_MG, LGSTRUT_LEN_NG)

INLET (COMPONENT_ID, APER_AR_INLET, AREA_RATIO_INLET, BLEED_AREA_INLET, BYPASS_AREA_INLET, CAP_AREA_INLET, CONTR_RATIO_INLET, CORR_AIRFLOW_INLET, CORR_ECS_AIR_INLET, DESIGN_M_INLET, FACE_RECOV_INLET, IN_LIP_ANG_INLET, LEAK_AREA_INLET, PRESS_RECOV_INLET, RAMP_ANG_FIN_INLET, RAMP_ANG_INIT_INLET, SPILL_AREA_INLET, SUBSONIC_DIF_LD, THROAT_M_INLET, WT_RAMP, WT_SPIKE, WT_AIRINDUCT_SYS, KD_GD, KM_GD, KD_TOREN, KR_GD, KS_GD)

NOZZLE (COMPONENT_ID, ACOUS_AREA_NOZ, EXH_NOZ_THR_COEFF, JET_VEL_NOZ, NOZ_EJECT_FLOWRATE, SEC_NOZ_THR_COEFF, SUPPRESS_AREA_NOZ, SUPPRESS_NOZ, V_JET_AVG_NOZ)

CANARD (COMPONENT_ID, AR_CANARD, LC, MAX_TC_CANARD, MAX_TR_CANARD, SC, SPAN_CANARD, SWEEP_CANARD_HALF, SWEEP_CANARD_LE, SWEEP_CANARD_QUAR, TAPER_CANARD, THICK_RATIO_CANARD)

HORIZONTAL (COMPONENT_ID, AR_HORIZ, KH, LH, MAX_TC_HORIZ, MAX_TR_HORIZ, SH, SPAN_HORIZ, SWEEP_HORIZ_HALF, SWEEP_HORIZ_LE, SWEEP_HORIZ_QUAR, TAPER_HORIZ, THICK_RATIO_HORIZ, VH, ZH)

VERTICAL (COMPONENT_ID, AR_VERT, KV, LV, MAX_TC_VERT, SPAN_VERT, SV, SWEEP_VERT_HALF, SWEEP_VERT_LE, SWEEP_VERT_QUAR, TAPER_VERT, THICK_RATIO_VERT)

WING (COMPONENT_ID, AR_WING, DIHEDRAL_WING, FSLE, MAC, MAX_TC_WING, MAX_TR_WING, MSG, SPAN_WING, SW, SWEEP_WING_HALF, SWEEP_WING_LE, SWEEP_WING_QUAR, TAPER_WING, THICK_RATIO_WING)

EMISSIONS (COMPONENT_ID, CO2_INDEX, CO_INDEX, H2O_INDEX, HC_INDEX, NOX_INDEX, SO2_INDEX)

MIX_PLANE (COMPONENT_ID, MIX_EFF_AREA_COLD, MIX_EFF_AREA_HOT, MIX_GAS_FLOW_COLD, MIX_GAS_FLOW_COLD, MIX_PRESS_COLD, MIX_PRESS_HOT, MIX_TEMP_TOT_COLD, MIX_TEMP_TOT_HOT)

THRUST (COMPONENT_ID, ALT, D_AFTERBODY, FG_IDLE, FG_INTERM, FG_MAX, FG_MAX_DRY, FG_MIN, FN_IDLE, FN_INTERM, FN_LESS_AFTERB, FN_MAX, FN_MAX_DRY, FN_MIN, FRAM, MACH_NO)

TURBINE (COMPONENT_ID, AVG_WORK_TURB, BLADE_CHORDLEN_TURB, BLADE_COUNT_TURB, EFF_TURB, EXIT_SPEED_TURB, HUB_TIP_RATIO_TURB, NO_STAGES_TURB, PRESS_RATIO_TURB, REL_TIP_RATIO_TURB, ROTORTIP_SPACE_TURB, ROTOR_CHORDLEN_TURB, ROTOR_TIP_DIA_TURB, STATOR_CHLEN_TURB, STATOR_COUNT_TURB, TIP_DIA_TURB, TIP_SPEED_TURB, VANE_CHORDLEN_TURB)

COMPRESSOR (COMPONENT_ID, CORR_FLOW_COMP, CORR_TIP_SPEED_COMP, EXPAN_RATIO_COMP, FAN_DIA_COMP, HUBTIP_RATIO_COMP, HUB_TIP_RATIO_IN, MACH_EXIT_COMP, NO_AIRFOILS_COMP, NO_STAGES_COMP, NO_VAR_STAGES_COMP, PRESS_RATIO_COMP, ROTOR_SPEED_COMP, VEL_MEAN_COMP, V_RIM_EXIT_COMP)

COMP_MEMBER (COMPONENT_ID, MEMBER_ID)

AC_MEMBER (MEMBER_ID, EPS_X, EPS_Y, EPS_Z, F_X, F_Y, F_Z, MEMBER_NAME, M_X, M_Y, M_Z, SIG_X, SIG_Y, SIG_Z, THETA_X, THETA_Y, THETA_Z, U_X, U_Y, U_Z, V_X, V_Y, V_Z, MEMBER_MAT, MEMBER_WT)

MATERIALS (MEMBER_MAT, COEFF_THERM_EXP, COMPRESS_YIELD, CORR_RESIST, CRACK_GROWTH, ELAS_MOD, FATIG_STREN, FRACT_TOUGH, MAT_TEMP, MOD_RIGIDITY, SHEAR_PROP_LIMIT, SHEAR_ULT_STREN, SHEAR_YIELD_PT, SHEAR_YIELD_STREN, STRESS_INTEN_COEFF, TEN_YIELD, THERM_STRAIN, UTL_TEN_STREN)

STAB_AND_CONT (CONF_NO, ZERO_COEFF_ID, WING_BODY_ID, THRUST_DERIVS_ID, P_Q_R_ID, CONT_DERIVS_ID, ALPHA_BETA_DERIVS_ID)

CONT_DERIVS (CONT_DERIVS_ID, CD_ELEV, CD_IH, CL_ELEV, CL_IH, CM_ELEV, CM_IH, CN_AIL, CR_RUD, CY_AIL, CY_RUD, CN_RUD, CR_AIL)

WING_BODY (WING_BODY_ID, CD_ALPHA_WB, CL_ALPHA_WB, CM_ALPHA_WB)

THRUST_DERIVS (THRUST_DERIVS_ID, CNT_BETA, CTM_ALPHA, CTM_U, CTX_ALPHA, CTX_U, CTZ_ALPHA, CTZ_U)

P_Q_R_DERIVS (P_Q_R_ID, CN_P, CN_R, CR_P, CR_R, CY_P, CY_R, CD_Q, CL_Q, CM_Q)

COEFF_ZERO_AOA (ZERO_COEFF_ID, CMO, CNO, CRO, CYO)

ALPHA_BETA_DERIVS (ALPHA_BETA_DERIVS_ID, CD_ALPHA, CD_ALPHA_DOT, CL_ALPHA, CL_ALPHA_DOT, CM_ALPHA, CM_ALPHA_DOT, CN_BETA, CN_BETA_DOT, CR_BETA, CR_BETA_DOT, CY_BETA, CY_BETA_DOT)

COST (CONF_NO, STD_COST_ID, OPER_COSTS_ID, HRS_RATES_ID, COST_PARAMS_ID, AC_PROP_COST_ID)

STD_COSTS (STD_COST_ID, ACQUIS_COST, DEV_SUP_COST, DTE_COST, FLTTEST_OPER_COST, LIFE_CYCLE_COST, MFGMAT_EQUIP_COST, OPER_COST, PROD_ENG_COST, RED_ENER_CONSUM, RED_ENVIR_CONTAM, RED_LC_COST)

OPER_COSTS (OPER_COSTS_ID, AC_INIT_PRICE, AC_SPARES_RATIO, AIRFRAME_COST, AIRFRAME_MAIN_COST, AIR_MAINMAT_COST, ANN_INSUR_RATE, ANN_UTIL, BLOCK_FUEL, BLOCK_TIME, COST_ENG, COST_SCALE_FAC, DEPREC_COST, DEPREC_PERIOD, ENG_MAIN_COST, ENG_SCALE_FAC, FLT_CREW_COST, FLT_TIME, FUEL_FLT_COST, FUEL_PRICE, INSUR_COST, LABOR_RATE, LAB_BURDEN_FAC, MAN_HOURS, MATCOST_PER_FLTCYC, MATCOST_PER_FLTHR, MAT_COST, MH_PER_FLTCYCLE, OPER_WT_MINUS_ENG, PROP_SPARES_RATIO, RESID_RATIO)

HRS_RATES (HRS_RATES_ID, MFG_LABOR_HRS, PROD_RATE, QUAL_CONT_HRS, TOOL_HRS, TOT_ENG_HRS)

AC_PROP_COST (AC_PROP_COST_ID, AC_PRICE_PER_LB, AC_UNIT_PRICE, AVIONICS_PRICE, ENG_PRICE)

COST_PARAMS (COST_PARAMS_ID, AMPR, AMPR_WT, CUM_QUAN_AC, KTHRUST_NIC, MAX_THRUST_SL, MMH_PER_FH, NO_FLTTEST_AC, NO_PROD_AC, VMAXBEST)

PERFORMANCE (CONF_NO, SPEED_ID, PERF_MEAS_ID, LIMITS_ID, DISTANCES_ID)

LIMITS (LIMITS_ID, BUFFET_LIMIT, CROSS_LIMIT_LND, CROSS_LIMIT_TO, FLAP_PLACARD)

DISTANCES (DISTANCES_ID, DIST_AIR, DIST_BRAKE, DIST_CLIMB, DIST_GROUND, DIST_LAND_TOTAL, DIST_ROLL, DIST_ROTATE, DIST_SEQD, DIST_TOFF_TOTAL)

SPEEDS (SPEED_ID, V_APP, V_CLIMBOUT, V_CRUISE, V_DECISION, V_DIVE, V_GROUND, V_GUST, V_LIFTOFF, V_ROTATE, V_STALL, V_TDOWN, VMCA, VMCG)

PERF_MEASURES (PERF_MEAS_ID, ALT_ABSOLUTE, ALT_SERVICE, ENDURANCE, MAX_ENDUR, MAX_RANGE, RANGE, RATE_CLIMB, SPEC_RANGE, TURN_RADIUS, TURN_RATE, V_MIN_DRAG)

AERODYNAMICS (CONF_NO, AERO_LIFT_ID, AERO_DRAG_ID)

AERO_LIFT (AERO_LIFT_ID, CL_CANARD, CL_HORIZ, CL_WB, CL_WBT, ALPHA, FLAP)

AERO_DRAG (AERO_DRAG_ID, CD_COMPRESS, CD_INDUCED, CD_INTERFERENCE, CD_PROTUB, CD_SKIN_FRIC, CD_TRIM)

WEIGHTS (CONF_NO, CG_INERTIA_ID, MISSION_WT_ID, FIX_EQUIP_WT_ID, FUEL_SYS_WT_ID)

CG_INERTIA (CG_INERTIA_ID, AC_MASS_DENS, BLCG, CG, FSCG, IXX, IXZ, IYY, IZZ, MASS_PT, WLCG, XCG, X_PT, YCG, Y_PT, ZCG, Z_PT)

MISSION_WTS (MISSION_WT_ID, DESIGN_GWT, MAX_FUEL, MAX_PAYLOAD, MAX_ZERO_FUEL, MISSION_FUEL_FRAC, MISSION_FUEL_USED, MISSION_FUEL_WT, MISSION_PAYLOAD, MISSION_RESERVES, OPER_WT_EMPTY, TRAPPED_WT, WT_CREW, WT_EMPTY, WT_TOFF)

FIXED_EQUIP_WT (FIX_EQUIP_WT_ID, AIR_COND_SYS, ANTI_ICING_SYS, APU, AUX_GEAR,AVIONIC_SYS, BAGGAGE_EQUIP, BAGGAGE_WT, BALLAST, CARGO_WT, ELECTRICAL_SYS, ELECTRONICS, FURNISHINGS, HYDRAULIC_SYS, KBUF_GD, KLAV_GD, MISC_WT, OPER_ITEMS, OXYGEN_SYS, PAINT, PASSENGER_WT, PC, PNEUMATIC_SYS, SURFACE_CONTROLS, WT_FIXED_EQUIP, WT_FLT_CONT, WT_ENG_CONTROLS)

FUEL_SYSTEM_WT (FUEL_SYS_WT_ID, NO_TANKS, KFSP, INT_FUEL_FRAC, WT_BLADDER, WT_FUEL_SYSTEM, FFR_TOFF)

APPENDIX B

DATA DICTIONARY

Attribute	**Definition**
AC_CONFIGURATION	
CONF_NO	Aircraft configuration number
AC_COMPONENT	
COMPONENT_ID	Aircraft component ID
COMPONENT_NAME	Aircraft component name
COMPONENT_TYPE	Type of aircraft component
WING	
SW	Wing Area (ft^2)
SPAN_WING	Span of Wing (ft)
AR_WING	Wing Aspect Ratio
DIHEDRAL_WING	Wing dihedral angle (degs)
SWEEP_WING_LE	Wing leading edge sweep angle (degrees)
SWEEP_WING_QUAR	Wing quarter chord sweep angle (degrees)
SWEEP_WING_HALF	Wing semi-chord sweep angle (degrees)
TAPER_WING	Wing taper ratio
THICK_RATIO_WING	Wing thickness ratio
MAX_TC_WING	Maximum wing thickness ratio
MAX_TR_WING	Maximum thickness of wing root chord (ft)
MAC	Mean aerodynamic chord (ft)
MGC	Mean geometric chord (ft)
FSLE	Fuselage station of the leading edge at the wing mean geometric chord (inches)
HORIZONTAL	
SH	Horizontal Area (ft^2)
SPAN_HORIZ	Span of Horizontal (ft)
AR_HORIZ	Horizontal Aspect Ratio
SWEEP_HORIZ_LE	Horizontal leading edge sweep angle (degrees)
SWEEP_HORIZ_QUAR	Horizontal quarter chord sweep angle (degrees)

SWEEP_HORIZ_HALF	Horizontal semi-chord sweep angle (degrees)
TAPER_HORIZ	Horizontal taper ratio
THICK_RATIO_HORIZ	Horizontal thickness ratio
MAX_TC_HORIZ	Maximum horizontal thickness ratio
MAX_TR_HORIZ	Maximum thickness of horizontal root chord (ft)
LH	Distance from the wing quarter chord to the horizontal tail quarter chord (ft)
ZH	Distance from the vertical tail root to where the horizontal tail is mounted on the vertical tail (for fuselage mounted horizontal tails, set ZH = 0.0) (ft)
KH	Horizontal stabilizer factor (Torenbeek Method) = 1.0 for fixed incidence stabilizers = 1.1 for variable incidence stabilizers
VH	Horizontal tail volume

VERTICAL

SV	Vertical Area (ft^2)
SPAN_VERT	Span of Vertical (ft)
AR_VERT	Vertical Aspect Ratio
SWEEP_VERT_LE	Vertical leading edge sweep angle (degrees)
SWEEP_VERT_QUAR	Vertical quarter chord sweep angle (degrees)
SWEEP_VERT_HALF	Vertical semi-chord sweep angle (degrees)
TAPER_VERT	Vertical taper ratio
THICK_RATIO_VERT	Vertical thickness ratio
MAX_TC_VERT	Maximum vertical thickness ratio
MAX_TR_VERT	Maximum thickness of vertical root chord
LV	Distance from the wing quarter chord to the vertical tail quarter chord (ft)
KV	Vertical factor (Torenbeek Method) = 1.0 for fuselage mounted horizontal tails = [1 + 0.15*(SPAN_HORIZ*ZH)/(SPAN_VERT* SPAN_VERT)]

CANARD

SC	Canard Area (ft^2)
SPAN_CANARD	Span of Canard (ft)
AR_CANARD	Canard Aspect Ratio
SWEEP_CANARD_LE	Canard leading edge sweep angle (degrees)
SWEEP_CANARD_QUAR	Canard quarter chord sweep angle (degrees)
SWEEP_CANARD_HALF	Canard semi-chord sweep angle (degrees)

TAPER_CANARD	Canard taper ratio
THICK_RATIO_CANARD	Canard thickness ratio
MAX_TC_CANARD	Maximum vertical thickness ratio
MAX_TR_CANARD	Maximum thickness of vertical root chord (ft)
LC	Distance from the wing quarter chord to the canard quarter chord (ft)

FUSELAGE

FUSE_LEN_NONAC	Fuselage length, not including nose mounted nacelle length (ft)
FUSE_LEN	Fuselage length (ft)
PASS_CABIN_LEN	Length of the passenger cabin (ft)
FUSE_WIDTH_MAX	Maximum fuselage width (ft)
FUSE_HT_MAX	Maximum fueslage height (ft)
K_INLETS	Inlet factor (General Dynamics Method) = 1.25 for airplanes with inlets in or on the fuselage for a buried engine installation = 1.0 for inlets located elsewhere
K_FUSE_TOREN	Fuselage factor (Torenbeek Method) = 1.08 for a pressurized fuselage = 1.07 for a main gear attached to the fuselage = 1.10 for a cargo airplane with a cargo floor
SFGS_TOREN	Fuselage gross shell area (Torenbeek Method) (ft^2)

GEAR

LGSTRUT_LEN_MG	Shock strut length for main gear (ft)
LGSTRUT_LEN_NG	Shock strut length for nose gear (ft)

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)
WT_RAMP	Weight of a variable geometry ramp (lbs)
WT_SPIKE	Weight of an inlet spike (lbs)
WT_AIRINDUCT_SYS	Weight of air induction system (lbs) (includes inlet ducts, ramps, spikes, and associated controls)

Air Induction Weight Estimation

KD_GD	Air induction factor for buried engine installation for a commercial transport (General Dynamics Method) = 1.33 for ducts with flat cross sections = 1.00 for ducts with curved cross sections
KM_GD	Air induction factor for buried engine installation for a commercial transport (General Dynamics Method) = 1.0 for M_D below 1.4 = 1.5 for M_D above 1.4
KD_TOREN	Air induction factor for buried engine installations (Torenbeek Method) = 1.00 for ducts with curved cross sections = 1.33 for ducts with flat cross sections
KR_GD	Ramp factor (General Dynamics Method) = 1.0 for M_D below 3.0 = $(M_D + 2)/5$ for M_D above 3.0
KS_GD	Inlet spike constant (General Dynamics Method) = 12.53 for half round fixed spikes = 15.65 for full round translating spikes = 51.80 for translating and expanding spikes

NOZZLE

JET_VEL_NOZ	Jet velocity (ft/sec)
SUPRESS_NOZ	Nozzle noise suppression (dB)
SUPPRESS_AREA_NOZ	Suppresser Area (ft^2)
NOZ_EJECT_FLOWRATE	Ejector flow rate (lbm/sec)
ACOUS_AREA_NOZ	Acoustic treatment area (ft^2)
EXH_NOZ_THR_COEFF	Exhaust nozzle gross thrust coefficient

SEC_NOZ_THR_COEFF	Secondary nozzle gross thrust coefficient
V_JET_AVG_NOZ	Average exhaust jet velocity (ft/sec)

ENGINE

ENG_LEN_TOT	Overall engine length (ft)
FAN_FACE_LEN	Length from fan face to nozzle throat (ft)
ENG_MAXWT_LEN	x - distance of engine maximum weight location (ft)
ENG_REAR_FRAME	x - distance of engine rear frame
ENG_MAIN_FRAME	x - distance of engine main frame
FAN_CASE_DIA	Fan case diameter (inches)
NOZZLE_HT	Nozzle exit height (inches)
MAX_NOZZLE_WIDTH	Maximum nozzle width (inches)
NOZZLE_INTERN_WIDTH	Nozzle internal width (inches)
MAX_NOZZLE_HEIGHT	Maximum nozzle height (inches)
WT_ENGINES	Weight of all engines (lbs) (includes engine, exhaust, cooling, and lubrication system)
WT_PER_ENG	Weight of each engine(s) (lbs)
WT_ENG_INSTALL	Engine(s) installation weight (lbs)
WT_START_SYS	Weight of engine(s) starting system (lbs)
WT_AFTERBURN	Weight of afterburner system (lbs)
WT_THRUST_REV	Weight of thrust reverser system (lbs)

Engine Weight Estimation

KPG_TOREN	Powerplant weight constant for jet airplanes (Torenbeek Method) = 1.40 for airplanes with buried engines = 1.00 for other

Propulsion System Weight Estimation

KEC_GD	Engine control factor for commercial transport airplanes (General Dynamics Method) = 0.686 for non-afterburning engines = 1.080 for afterburing engines

KB_TOREN	Weight factor for accessory drives, powerplant controls, starting, and ignition systems (Torenbeek Method) = 1.0 without beta controls = 1.3 with beta controls

COMPRESSOR

NO_STAGES_COMP	Number of compressor stages
FAN_DIA_COMP	Fan diameter (inches)
PRESS_RATIO_COMP	Overall pressure ratio
CORR_FLOW_COMP	Corrected mass flow (lbm/sec)
ROTOR_SPEED_COMP	Rotor speed (ft/sec)
CORR_TIP_SPEED_COMP	Corrected tip speed (ft/sec)
HUB_TIP_RATIO_IN	Inlet hub/tip ratio
MACH_EXIT_COMP	Compressor exit Mach number
HUBTIP_RATIO_COMP	Exit hub/tip ratio
V_RIM_EXIT_COMP	Maximum exit rim speed (ft/sec)
NO_VAR_STAGES_COMP	Number of variable stages
NO_AIRFOILS_COMP	Number of airfoils
EXPAN_RATIO_COMP	Expansion ratio
VEL_MEAN_COMP	Mean velocity ratio

TURBINE

NO_STAGES_TURB	Number of turbine stages
PRESS_RATIO_TURB_TOT	Total turbine pressure ratio
AVG_WORK_TURB	Average turbine work (BTU/lb)
TIP_DIA_TURB	Blade tip diameter (inches)
TIP_SPEED_TURB	Blade tip speed (ft/sec)
EXIT_SPEED_TURB	Blade exit relative speed (ft/sec)
BLADE_CHORDLEN_TURB	Blade chord length (inches)
VANE_CHORDLEN_TURB	Vane chord length (inches)
HUB_TIP_RATIO_TURB	Hub to tip ratio
REL_TIP_M_TURB	Relative tip Mach number
PRESS_RATIO_TURB	1^{st} to 2^{nd} stage pressure ratio
EFF_TURB	1^{st} to 2^{nd} stage efficiency
ROTOR_CHORDLEN_TURB	Rotor chord length (inches)
BLADE_COUNT_TURB	Blade count
STATOR_CHLEN_TURB	Stator chord length (inches)
STATOR_COUNT_TURB	Stator count
ROTOR_TIP_DIA_TURB	Rotor tip diameter (inches)
ROTORTIP_SPACE_TURB	Rotor to stator tip spacing (inches)

EMISSIONS

NOX_INDEX	NOX emissions index (grams/kilogram fuel)
CO_INDEX	CO emissions index (grams/kilogram fuel)
HC_INDEX	HC emissions index (grams/kilogram fuel)
SO2_INDEX	SO_2 emissions index (grams/kilogram fuel)
H2O_INDEX	H_2O emissions index (grams/kilogram fuel)
CO2_INDEX	CO_2 emissions index (grams/kilogram fuel)

MIX_PLANE

MIX_EFF_AREA_COLD	Mixing plane cold stream effective area (sq in)
MIX_TEMP_TOT_COLD	Mixing plane cold stream total temperature (deg R)
MIX_GAS_FLOW_COLD	Mixing plane cold stream total gas flow (lbm/sec)
MIX_PRESS_COLD	Mixing plane cold stream total pressure (psia)
MIX_EFF_AREA_HOT	Mixing plane hot stream effective area (sq in)
MIX_TEMP_TOT_HOT	Mixing plane hot stream total temperature (deg R)
MIX_GAS_FLOW_HOT	Mixing plane hot stream total gas flow (lbm/sec)
MIX_PRESS_HOT	Mixing plane hot stream total pressure (psia)

THRUST

ALT	Pressure altitude (ft)
MACH_NO	Mach Number
FRAM	Total ram drag (lbf)
D_AFTERBODY	Afterbody drag (lbf)
FN_LESS_AFTERB	Net thrust less afterbody drag (lbf)
FN_MAX	Total net thrust - max power (lbf)
FN_MIN	Total net thrust - min power (lbf)
FN_MAX_DRY	Total net thrust - dry power (lbf)
FN_INTERM	Total net thrust - intermediate power (lbf)
FN_IDLE	Total net thrust - idle power (lbf)
FG_MAX	Total gross thrust - max power (lbf)
FG_MIN	Total gross thrust - min power (lbf)
FG_MAX_DRY	Total gross thrust - dry power (lbf)
FG_INTERM	Total gross thrust - intermediate power (lbf)
FG_IDLE	Total gross thrust - idle power (lbf)

AC_MEMBER

MEMBER_ID	Aircraft component member ID
MEMBER_NAME	Name of aircraft member
MEMBER_MAT	Member material
MEMBER_WT	Weight of member (lbs)
EPS_X	Member strain in the x - direction
EPS_Y	Member strain in the y - direction

EPS_Z	Member strain in the z - direction
F_X	Member force in the x - direction
F_Y	Member force in the y - direction
F_Z	Member force in the z - direction
M_X	Member bending about the x - axis
M_Y	Member bending about the y - axis
M_Z	Member bending about the z - axis
SIG_X	Member stress in the x - direction
SIG_Y	Member stress in the y - direction
SIG_Z	Member stress in the z - direction
THETA_X	Member rotation about the x - axis
THETA_Y	Member rotation about the y - axis
THETA_Z	Member rotation about the z - axis
U_X	Displacement in the x - direction
U_Y	Displacement in the y - direction
U_Z	Displacement in the z - direction
V_X	Shear force in the x - direction
V_Y	Shear force in the y - direction
V_Z	Shear force in the z - direction

MATERIALS

ULT_TEN_STREN	Ultimate tensile strength (ksi)
COMPRESS_YIELD	Compressive yield strength (ksi)
TEN_YIELD	Tensile yield strength (ksi)
SHEAR_PROP_LIMIT	Shearing proportional limit
SHEAR_YIELD_STREN	Shearing yield strength (ksi)
SHEAR_YIELD_PT	Shearing yield point
SHEAR_ULT_STREN	Shearing ultimate strength (ksi)
ELAS_MOD	Elastic Modulus (psi)
MOD_RIGIDITY	Modulus of rigidity (psi)
FATIG_STRENGTH	Fatigue strength
CORR_RESIST	Corrosion resistance
FRACT_TOUGH	Fracture toughness
STRESS_INTEN_COEFF	Stress intensity coefficient
CRACK_GROWTH	Crack growth rate
MAT_TEMP	Material temperature (degs F)
COEFF_THERM_EXP	Coefficient of thermal expansion (1/F)
THERM_STRAIN	Thermal strain coefficient

CG_INERTIA

CG_INERTIA_ID	Identification number of cg_inertia instance
IXX	Rolling moment of inertia (slugs-ft^2)
IYY	Pitching moment of inertia (slugs-ft^2)
IZZ	Yawing moment of inertia (slugs-ft^2)
IXZ	Product of inertia (slugs_ft^2)
AC_MASS_DENS	Aircraft mass density (slugs)
MASS_PT	Mass particle on the aircraft (slugs)
X_PT	X-distance of a mass particle on the aircraft (ft)
Y_PT	Y-distance of a mass particle on the aircraft (ft)
Z_PT	Z-distance of a mass particle on the aircraft (ft)
CG	Center of gravity (%mac)
XCG	Center of gravity location along the x-axis (ft)
YCG	Center of gravity location along the y-axis (ft)
ZCG	Center of gravity location along the z-axis (ft)
FSCG	Fuselage station of cg (inches)
WLCG	Waterline of cg location (inches)
BLCG	Buttline of cg location (inches)

MISSION_WTS

MISSION_WT_ID	Identification number of mission weight instance
WT_CREW	Crew Weight (lbs)
TRAPPED_WT	Trapped fuel and oil weight (lbs)
OPER_WT_EMPTY	Operating Weight Empty (lbs) WT_EMPTY + TRAPPED_WT + WT_CREW
WT_EMPTY	Aircraft empty weight (lbs) WT_STRUCTURES + WT_POWERPLANT + WT_FIXED_EQUIP
MISSON_FUEL_USED	Fuel that is actually used during a mission (lbs)
MISSON_RESERVES	Fuel reserves required for the mission (lbs)
MISSION_FUEL_FRAC	Mission fuel fraction
MISSION_FUEL_WT	Mission fuel weight (lbs) (1. - MFF)*TOFF_GWT + MISSION_RESERVES
MISSON_PAYLOAD	Mission payload weight (lbs)
WT_TOFF	Take-off weight (lbs) WT_EMPTY + MISSION_FUEL_WT + MISSION_PAYLOAD_WT + TRAPPED_WT + WT_CREW
DESIGN_GWT	Aircraft flight design gross weight (lbs)
MAX_PAYLOAD	Maximum payload (lbs)
MAX_FUEL	Maximum fuel capacity (lbs)
MAX_ZERO_FUEL	Maximum zero fuel weight (lbs)

WT_TOFF - MISSION_FUEL_WT

FIXED_EQUIP_WT

FIX_EQUIP_WT_ID	Identification number of fixed equipment weight instance
WT_FLT_CONT	Weight of flight control system (lbs)
SURFACE_CONTROLS	Weight of aircraft control surfaces (lbs)
HYDRAULIC_SYS	Weight of hydraulic system (lbs)
PNEUMATIC_SYS	Weight of pneumatic system (lbs)
ELECTRICAL_SYS	Total weight of aircraft electrical systems (lbs)
AVIONIC_INSTR	Avionics and instrumentation weight (lbs)
ELECTRONICS	Total weight of aircraft electronics
AIR_COND_SYS	Weight of aircraft air conditioning system (lbs)
ANTI_ICING_SYS	Weight of aircraft anti-icing system
OXYGEN_SYS	Aircraft Oxygen system weight (lbs)
APU	Auxiliary power unit weight (lbs)
FURNISHINGS	Total weight of aircraft furnishings (seats, overhead, galley, etc.) (lbs)
BAGGAGE_EQUP	Weight of baggage and cargo handling equipment (lbs)
OPER_ITEMS	Weight of operating items (lbs)
AUX_GEAR	Weight of auxiliary gear (lbs)
BALLAST	Aircraft ballast weight
PAINT	Weight of aircraft paint (lbs)
MISC_WT	Miscellaneous weight (lbs)
WT_FIXED_EQUIP	Total fixed equipment weight (lbs)
PC	Design ultimate cabin pressure (psi)
KLAV_GD	Laboratory factor for commercial transport aircraft (General Dynamics Method) = 1.11 for long range airplanes
KBUF_GD	Food provisions factor for commercial transport ircraft (General Dynamics Method) = 1.02 for short ranges = 5.68 for long ranges
WT_ENG_CONTROLS	Weight of engine(s) controls (lbs)
PASSENGER_WT	Passenger weight (includes flight attendants) (lbs)
NO_CREW	Number of crew
NO_PASS_MAX	Maximum number of passengers
NO_FLT_ATTENDS	Number of flight attendants
BAGGAGE_WT	Baggage weight (lbs)
CARGO_WT	Cargo weight (lbs)

FUEL_SYSTEM_WT

FUEL_SYS_WT_ID	Identification number of fuel system weight instance

Fuel System Weight Estimation

NO_TANKS	Number of separate fuel tanks
INT_FUEL_FRAC	Fraction of fuel tanks which are integral
KFSP	Fuel factor (lbs/gal) = 5.87 for aviation gasoline = 6.55 for JP-4

Propulsion System Weight Estimation

FFR_TOFF	Fuel flow rate at take-off (lbs/sec)
WT_BLADDER	Weight of the bladder support structure (lbs)
WT_FUEL_SYSTEM	Weight of fuel system (lbs)

AERODYNAMICS

AERO_LIFT_ID	Identification number of an aerodynamic lift instance
AERO_DRAG_ID	Identification number of an aerodynamic drag instance

AERO_DRAG

CD_SKIN_FRIC	Skin fricition drag coefficient
CD_PROTUB	Protuberance drag coefficient
CD_INTERFERENCE	Interference drag coefficient
CD_TRIM	Trim drag coefficient
CD_INDUCED	Induced drag coefficient
CD_COMPRESS	Compressibility drag coefficient

AERO_LIFT

ALPHA	Angle-of-attack (degs)
FLAP	Flap angle (degs)
CL_CANARD	Lift coefficient of the canard
CL_HORIZ	Lift coefficient of the horizontal
CL_WB	Wing-body lift coefficient
CL_WBT	Wing-body-tail lift coefficient

PERFORMANCE

SPEED_ID	Identification number of a speed instance
PERF_MEAS_ID	Identification number of a performance measure instance
LIMITS_ID	Identification number of a limits instance
DISTANCES_ID	Identification number of a distances instance

LIMITS

FLAP_PLACARD	Flap placard speed (knots)
BUFFET_LIMIT	Buffet limit speed (knots)
CROSS_LIMIT_TO	Take-off crosswind limit speed (knots)
CROSS_LIMIT_LND	Landing crosswind limit speed (knots)

DISTANCES

DIST_AIR	Air distance (ft)
DIST_BRAKE	Braking distance (ft)
DIST_SEGD	Distance in segment D in landing (ft)
DIST_CLIMB	Climb distance (ft)
DIST_ROLL	Free roll distance (ft)
DIST_GROUND	Ground distance (ft)
DIST_ROTATE	Rotation distance (ft)
DIST_TOFF_TOTAL	Total take-off distance (ft)
DIST_LAND_TOTAL	Total landing distance (ft)

SPEEDS

V_CRUISE	Cruise speed (knots)
V_DECISION	Decision speed (knots)
V_CLIMBOUT	Climbout speed (knots)
V_GROUND	Ground speed (knots)
V_APP	Approach speed (knots)
V_GUST	Design speed for maximum gust intensity (knots)
V_DIVE	Dive speed (knots)
V_LIFTOFF	Lift-off speed (knots)
V_ROTATE	Rotation speed (knots)
V_TDOWN	Touchdown speed (knots)
V_STALL	Stall speed (knots)
VMCA	Air minimum control speed (knots)
VMCG	Ground minimum control speed (knots)

PERF_MEASURES

RANGE	Aircraft range (n miles)
SPEC_RANGE	Aircraft specific range (nau miles/lb)
RATE_CLIMB	Rate of climb (ft/min)

V_MIN_DRAG	Speed for which drag is a minimum
ALT_SERVICE	Service ceiling (ft)
ALT_ABSOLUTE	Absolute ceiling (ft)
ENDURANCE	Aircraft endurance (hours)
MAX_RANGE	Maximum range (miles)
MAX_ENDUR	Maximum endurance (hours)
TURN_RATE	Aircraft turn rate (degs/sec)
TURN_RADIUS	Aircraft turn radius (ft)

STABILITY AND CONTROL

ZERO_COEFF_ID	Identification number of a zero coefficient instance
WING_BODY_ID	Identification number of wing-body derivative instance
THRUST_DERIVS_ID	Identification of thrust derivative instance
P_Q_R_DERIVS_ID	Identification of a rate derivative instance
CONT_DERIVS_ID	Identification of a control derivative instance
ALPHA_BETA_DERIVS_ID	Identification of an alpha or beta derivative instance

COEFF_ZERO_AOA

CMO	Pitching moment coefficient for zero angle of attack, zero elevator angle, and zero stabilizer
CRO	Rolling moment coefficient for zero sideslip, aileron, and rudder angles
CNO	Yawing moment coefficient for zero sideslip, aileron, and rudder angles
CYO	Side force coefficient for zero sideslip, aileron, and rudder angles

WING_BODY

CL_ALPHA_WB	Variation of wing-body lift coefficient with angle of attack (rad^{-1}, deg^{-1})
CD_ALPHA_WB	Variation of wing-body drag coefficient with angle of attack (rad^{-1}, deg^{-1})
CM_ALPHA_WB	Variation of wing-body pitching moment coefficient with angle of attack (rad^{-1}, deg^{-1})

CONT_DERIVS

CL_IH	Change in total airplane lift coefficient for unit change of horizontal stabilizer (rad^{-1}, deg^{-1})
CL_ELEV	Change in total airplane lift coefficient for unit change of elevator angle (rad^{-1}, deg^{-1})
CD_IH	Total airplane drag change with horizontal stabilizer at zero angle of attack (rad^{-1}, deg^{-1})
CD_ELEV	Total airplane drag change with elevator at zero angle of attack (rad^{-1}, deg^{-1})
CM_IH	Variation of pitching moment coefficient with stabilizer angle (rad^{-1}, deg^{-1})
CM_ELEV	Variation of pitching moment coefficient with elevator angle (rad^{-1}, deg^{-1})
CR_AIL	Variation of rolling moment coefficient with aileron angle (rad^{-1}, deg^{-1})
CR_RUD	Variation of rolling moment coefficient with rudder angle (rad^{-1}, deg^{-1})
CN_AIL	Variation of yawing moment coefficient with aileron
CN_RUD	Variation of yawing moment coefficient with rudder angle (rad^{-1}, deg^{-1})
CY_AIL	Variation of side force coefficient with aileron angle (rad^{-1}, deg^{-1})
CY_RUD	Variation of side force coefficient with rudder angle (rad^{-1}, deg^{-1})

ALPHA_BETA_DERIVS

α–Derivatives

CL_ALPHA	Variation of lift coefficient with angle of attack (rad^{-1}, deg^{-1})
CD_ALPHA	Variation of drag coefficient with angle of attack (rad^{-1}, deg^{-1})
CM_ALPHA	Variation of pitching moment coefficient with angle of attack (rad^{-1}, deg^{-1})

$\dot{\alpha}$-Derivatives

CL_ALPHA_DOT	Variation of lift coefficient with rate of change of angle of attack
CD_ALPHA_DOT	Variation of drag coefficient with rate of change of angle of attack
CM_ALPHA_DOT	Variation of pitching moment coefficient with rate of change of angle of attack

β-Derivatives

CY_BETA	Variation of side force coefficient with sideslip angle (rad^{-1}, deg^{-1})
CR_BETA	Variation of rolling moment coefficient with sideslip angle (rad^{-1}, deg^{-1})
CN_BETA	Variation of yawing moment coefficient with sideslip angle (rad^{-1}, deg^{-1})

β-Derivatives

CY_BETA_DOT	Variation of side force coefficient with rate of change of sideslip angle
CR_BETA_DOT	Variation of rolling moment coefficient with rate of change of sideslip angle
CN_BETA_DOT	Variation of yawing moment coefficient with rate of change of sideslip angle

P_Q_R_DERIVS

p-Derivatives

CY_P	Variation of side force coefficient with roll rate
CR_P	Variation of rolling moment coefficient with roll rate
CN_P	Variation of yawing moment coefficient with roll rate

q-Derivatives

CL_Q	Variation of lift coefficient with pitch rate
CD_Q	Variation of drag coefficient with pitch rate
CM_Q	Variation of pitching moment coefficient with pitch rate

r-Derivatives

CY_R	Variation of side force coefficient with yaw rate
CR_R	Variation of rolling moment coefficient with yaw rate
CN_R	Variation of yawing moment coefficient with yaw rate

THRUST_DERIVS

u-Thrust Derivatives

CTX_U	Variation of x-thrust coefficient with speed
CTZ_U	Variation of z-thrust coefficient with speed
CTM_U	Variation of thrust pitching moment coefficient with speed

α-Thrust Derivatives

CTX_ALPHA	Variation of x-thrust coefficient with angle of attack
CTZ_ALPHA	Variation of z-thrust coefficient with angle of attack
CTM_ALPHA	Variation of thrust pitching moment coefficient with angle of attack

β-Thrust Derivatives

CNT_BETA	Variation of thrust induced yawing moment coefficient with sideslip angle

COST

STD_COST_ID	Identifcation number of a standard cost instance
OPER_COSTS_ID	Identification number of an operating cost instance
HRS_RATES_ID	Identifcation number of an hours-rates instance
COST_PARAMS_ID	Identification number of a cost parameter instance
AC_PROP_COST_ID	Identification number of an aircraft-propulsion cost instance

COST_PARAMS

NO_FLTTEST_AC	Number of flight test aircraft
NO_PROD_AC	Number of production aircraft
CUM_QUAN_AC	Cumulative aircraft quantity produced
AMPR_WT	The AMPR weight (lbs)
VMAXBEST	The maximum speed at the best altitude (knots)

	NO_FLTTEST_AC + NO_PROD_AC
MAX_THRUST_SL	Sea level maximum thrust (lbs)
MMH_PER_FH	Maintenance man hours per flying hours
KTHRUST_NIC	Thrust cost factor (Nicloai) = 109 for turbojets = 130 for turbofans

HRS_RATES

TOOL_HRS	Cumulative tooling hours $4.0127*AMPR\_WT^{0.764}*VMAXBEST^{0.899}$ $*CUM\_QUAN\_PROD^{0.178}*PROD\_RATE^{0.066}$
PROD_RATE	Production rate (deliveries/month)
MFG_LABOR_HRS	Cumulative manufacturing labor hours $28.984*AMPR\_WT^{0.740}*VMAXBEST^{0.543}$ $*CUM\_QUAN\_PROD^{0.524}$
QUAL_CONT_HRS	Quality control hours 0.13*LABOR_HRS
TOT_ENG_HOURS	Cumlative total airframe engineering hours $0.0396*AMPR\_WT^{0.791}*VMAXBEST^{1.526}$ $*CUM\_QUAN\_PROD^{0.183}$

STD_COSTS

RED_LC_COST	Reduced life cycle cost (dollars)
RED_ENER_CONSUM	Reduced energy consumption
RED_ENVIR_CONTAM	Reduced environmental contamination
DTE_COST	Development, test, and evaluation cost (dollars). Cost required to engineer, develop, fabricate, and flight test the number of flight test aircraft prior to committing to production
ACQUIS_COST	Acquisition cost (dollars). The cost of the cumulative number of production aircraft, associated ground equipment, initial spares, and training aids.
OPER_COST	Operations cost (dollars). The cost of the fuel and oil including storage and delivery, salaries of operating and support personnel, day-to-day maintenance, depot and overhaul, spares, depreciation of equipment, and indirect costs.
LIFE_CYCLE_COST	Life cycle cost (dollars) DTE_COST + ACQUIS_COST + OPER_COST

DEV_SUP_COST	The nonrecurring manufacturing effort undertaken in support of engineering during the DT&E phase of an aircraft program (dollars) $0.008325 * AMPR\_WT^{0.873} * VMAXBEST^{1.890} * NO\_FLTTEST\_AC^{0.346}$
FLTTEST_OPER_COST	Flight test operations cost (dollars) $0.001244 * AMPR\_WT^{1.160} * VMAXBEST^{1.371} * NO\_FLTTEST\_AC^{1.281}$
MFGMAT_EQUIP_COST	Total manufacturing material and equipment costs (dollars) $25.672 * AMPR\_WT^{0.689} * VMAXBEST^{0.624} * CUM\_QUAN\_PROD^{0.792}$
PROD_ENG_COST	Production engine unit cost (dollars) $KTHRUST * MAX\_THRUST^{0.8356}$

OPER_COSTS

Flight Crew

BLOCK_TIME	Block time (hrs)
FLT_CREW_COST	Flight crew costs (dollars/flight)

Insurance

ANN_INSUR_RATE	Annual insurance rate (percentage/100)
AC_INIT_PRICE	Total aircraft initial price (dollars)
ANN_UTIL	Annual utilization (hrs/year)
INSUR_COST	Insurance costs (dollars/flight)

Depreciation

DEPREC_PERIOD	Depreciation period (yrs)
PROP_SPARES_RATIO	Propulsion system spares ratio
AC_SPARES_RATIO	Airframe spares ratio
RESID_RATIO	Residual value ratio
COST_ENG	Cost of engine (dollars)
AIRFRAME_COST	Airframe cost (dollars) AC_INIT_PRICE - COST_ENG
DEPREC_COST	Depreciation costs (dollars/flight)

Maintenance

FLT_TIME	Fight time (hrs)
MH_PER_FLTCYCLE	Manhours per flight cycle
OPER_WT_MINUS_ENG	Operator's empty weight less engines (lbs)
LABOR_RATE	Labor rate (dollars/hour)
LAB_BURDEN_FAC	Labor burden factor
AIRFRAME_MAIN_COST	Airframe maintenance labor costs (dollars/flight)

Airframe Material

MATCOST_PER_FLTHR	Material cost per flight hour (dollars/hr)
MATCOST_PER_FLTCYC	Material cost per flight cycle
AIR_MAINMAT_COST	Airframe maintenance material costs (dollar/flight)

Engines

MAN_HOURS	Man hours
MAT_COST	Material cost (dollars)
ENG_SCALE_FAC	Engine scale factor
COST_SCALE_FAC	Cost scale factor
ENG_MAIN_COST	Engine maintenance cost (dollars)

Fuel

FUEL_FLT_COST	Fuel cost per flight (dollars/flight)
FUEL_PRICE	Price of fuel (dollars/gallon)
BLOCK_FUEL	Block fuel (lbs)

AC_PROP_COST

Aircraft and Propulsion System Pricing

AC_UNIT_PRICE	Total aircraft unit price (dollars)
AC_PRICE_PER_LB	Airframe price per pound (dollars/lb)
AVIONICS_PRICE	Avionics price (dollars)
ENG_PRICE	Price of engines (dollars)

APPENDIX C

LEXICAL EXPRESS MODEL

```
SCHEMA ac_design;

TYPE positive_length = REAL;
WHERE
  non_neg  : SELF = 0;
END_TYPE;

TYPE weight = REAL;
WHERE
  non_neg  : SELF = 0;
END_TYPE;

TYPE area = REAL;
WHERE
  non_neg : SELF = 0;
END_TYPE;

TYPE non_dimensional_ratio = REAL;
WHERE
  non_neg : SELF = 0;
END_TYPE;

TYPE percentage_capture_area = REAL;
WHERE
  range:
    {0.0 <= SELF <= 1.0};
END_TYPE;

TYPE rate_airflow = REAL;
WHERE
  non_neg : SELF = 0;
END_TYPE;
```

```
TYPE non_dimensional_factor = REAL;
WHERE
  non_neg : SELF = 0;
END_TYPE;

TYPE dimensional_factor = REAL;
WHERE
  non_neg : SELF = 0;
END_TYPE;

TYPE pressure = REAL;
WHERE
  non_neg : SELF = 0;
END_TYPE;

TYPE positive_angle = REAL;
WHERE
  range :
    { 0.0 <= SELF <= 360.0 };
END_TYPE;

TYPE mach_number = REAL;
WHERE
  non_neg: SELF = 0;
END_TYPE;

TYPE non_dimensional_coeff = REAL;
END_TYPE;

TYPE speed_fps = REAL;
WHERE
  non_neg : SELF = 0;
END_TYPE;

TYPE speed_knots = REAL;
WHERE
  non_neg : SELF = 0;
END_TYPE;
```

```
TYPE noise = REAL;
WHERE
  non_neg : SELF = 0;
END_TYPE;

TYPE measured_work = REAL;
WHERE
  non_neg : SELF = 0;
END_TYPE;

TYPE positive_integer = INTEGER;
WHERE
  non_neg: SELF = 0;
END_TYPE;

TYPE efficiency = REAL;
WHERE
  non_neg :  SELF = 0;
END_TYPE;

TYPE strength = REAL;
WHERE
  non_neg : SELF = 0;
END_TYPE;

TYPE temperature = REAL;
WHERE
   non_neg : SELF = 0;
END_TYPE;

TYPE name = STRING;
END_TYPE;

TYPE material_name = STRING;
END_TYPE;

TYPE material_type = STRING;
END_TYPE;

TYPE deflection = REAL;
END_TYPE;

TYPE force = REAL;
```

```
WHERE
  non_neg : SELF = 0;
END_TYPE;

TYPE moment = REAL;
END_TYPE;

TYPE stress = REAL;
END_TYPE;

TYPE force = REAL;
WHERE
   non_neg : SELF = 0;
END_TYPE;

TYPE rotation = REAL;
WHERE
  range :
     { 0.0 <= SELF <= 360.0 };
END_TYPE;

TYPE strain = REAL;
END_TYPE;

TYPE shear = REAL;
END_TYPE;

TYPE length = REAL;
END_TYPE;

TYPE mass = REAL;
WHERE
  non_neg : SELF = 0;
END_TYPE;

TYPE percentage_mac = REAL;
WHERE
  range:
     {0.0 <= SELF <= 1.0};
END_TYPE;

TYPE inertia = REAL;
WHERE
```

```
  non_neg : SELF = 0;
END_TYPE;

TYPE derivative_per_degree = REAL;
END_TYPE;

TYPE annual_utilization = REAL;
WHERE
  non_neg : SELF = 0;
END_TYPE;

TYPE time_hours = REAL;
WHERE
  non_neg : SELF = 0;
END_TYPE;

TYPE time_years = REAL;
WHERE
  non_neg : SELF = 0;
END_TYPE;

TYPE dollars = REAL;
WHERE
  non_neg : SELF = 0;
END_TYPE;

TYPE dollars_per_flight = REAL;
WHERE
  non_neg : SELF = 0;
END_TYPE;

TYPE dollars_per_gallon = REAL;
WHERE
  non_neg : SELF = 0;
END_TYPE;

TYPE dollars_per_hour = REAL;
WHERE
  non_neg : SELF = 0;
END_TYPE;

TYPE dollars_per_flight_cycle = REAL;
WHERE
```

```
  non_neg: SELF = 0;
END_TYPE;

TYPE dollars_per_month = REAL;
WHERE
  non_neg : SELF = 0;
END_TYPE;

TYPE dollars_per_pound = REAL;
WHERE
  non_neg : SELF = 0;
END_TYPE;

TYPE deliveries_per_month = REAL;
WHERE
  non_neg : SELF = 0;
END_TYPE;

TYPE emission = REAL;
WHERE
  non_neg : SELF = 0;
END_TYPE;

TYPE altitude = REAL;
WHERE
  non_neg : SELF = 0;
END_TYPE;

TYPE distance_ft = REAL;
WHERE
  non_neg : SELF = 0;
END_TYPE;

TYPE distance_nau_miles = REAL;
WHERE
  non_neg : SELF = 0;
END_TYPE;
```

```
TYPE rate_fpm = REAL;
WHERE
   non_neg : SELF = 0;
END_TYPE;

TYPE rate_hpfc = REAL;
WHERE
  non_neg : SELF = 0;
END_TYPE;

TYPE range_per_pound = REAL;
WHERE
  non_neg : SELF = 0;
END_TYPE;

TYPE rate_dps = REAL;
WHERE
  non_neg : SELF = 0;
END_TYPE;

TYPE identification_no = STRING;
END_TYPE;

TYPE force_per_area = REAL;
WHERE
  non_neg : SELF = 0;
END_TYPE;

TYPE energy_per_vol = REAL;
WHERE
  non_neg : SELF = 0;
END_TYPE;

TYPE per_temperature = REAL;
WHERE
  non_neg : SELF = 0;
END_TYPE;

TYPE percentage_of_hundred = REAL;
WHERE
  non_neg : SELF = 0;
END_TYPE;
```

```
ENTITY ac_configuration;
  conf_no                        : identification_no;
  consists_of                    : SET [1:?] OF ac_component;
  has_specific                   : costs;
  demonstrates                   : performance;
  has_defined                    : weights;
  characterized_by               : stability_and_control;
  has_inherent                   : aerodynamics;
UNIQUE
  un_conf_no                     : conf_no;
END_ENTITY;

ENTITY ac_component;
  component_id                   : identification_no;
  component_name                 : name;
  component_type                 : name;
  made_up_of                     : SET [1:?] OF ac_member;
UNIQUE
  un_component_id                : component_id;
END_ENTITY;

ENTITY ac_member;
   made_of                       : materials;
   member_name                   : name;
   member_mat                    : material_type;
   member_wt                     : weight;
  eps_x                          : strain;
  eps_y                          : strain;
  eps_z                          : strain;
  f_x                            : force;
  f_y                            : force;
  f_z                            : force;
  m_x                            : moment;
  m_y                            : moment;
  m_z                            : moment;
  sig_x                          : stress;
  sig_y                          : stress;
  sig_z                          : stress;
  theta_x                        : rotation;
  theta_y                        : rotation;
  theta_z                        : rotation;
  u_x                            : deflection;
```

```
  u_y                                   : deflection;
  u_z                                   : deflection;
  v_x                                   : shear;
  v_y                                   : shear;
  v_z                                   : shear;
END_ENTITY;

ENTITY engine
  SUBTYPE OF (ac_component);
  eng_len_tot                           : positive_length;
  eng_main_frame                        : positive_length;
  eng_maxwt_len                         : positive_length;
  eng_rear_frame                        : positive_length;
  fan_case_dia                          : positive_length;
  fan_face_len                          : positive_length;
  max_nozzle_height                     : positive_length;
  max_nozzle_width                      : positive_length;
  nozzle_ht                             : positive_length;
  nozzle_intern_width                   : positive_length;
  wt_engines                            : weight;
  wt_per_eng                            : weight;
  wt_eng_install                        : weight;
   wt_start_sys                         : weight;
   wt_afterburn                         : weight;
   wt_thrust_rev                        : weight;
   kpg_toren                            : non_dimensional_factor;
   kb_toren                             : non_dimensional_factor;
   kec_gd                               : non_dimensional_factor;
   co2_index                            : emission;
  co_index                              : emission;
  h2o_index                             : emission;
  hc_index                              : emission;
  nox_index                             : emission;
  xo2_index                             : emission;
  mix_eff_area_cold                     : area;
  mix_eff_area_hot                      : area;
  mix_gas_flow_cold                     : rate_airflow;
  mix_gas_flow_hot                      : rate_airflow;
  mix_press_cold                        : pressure;
  mix_press_hot                         : pressure;
  mix_temp_tot_cold                     : temperature;
  mix_temp_tot_hor                      : temperature;
  alt                                   : altitude;
```

```
  d_afterbody                    : force;
  fg_idle                        : force;
  fg_interm                      : force;
  fg_max                         : force;
  fg_max_dry                     : force;
  fg_min                         : force;
  fn_idle                        : force;
  fn_interm                      : force;
  fn_less_afterb                 : force;
  fn_max                         : force;
  fn_max_dry                     : force;
  fn_min                         : force;
  fram                           : force;
  mach_no                        : mach_number;
END_ENTITY;

ENTITY fuselage
  SUBTYPE OF  (ac_component);
  fuse_ht_max                    : positive_length;
  fuse_len                       : positive_length;
  fuse_len_nonac                 : positive_length;
  fuse_width_max                 : positive_length;
  k_fuse_toren                   : non_dimensional_factor;
  k_inlets                       : non_dimensional_factor;
  pass_cabin_len                 : positive_length;
  sfsg_toren                     : area;
END_ENTITY;

ENTITY gear
  SUBTYPE OF (ac_component);
  lgstrut_len_mg                 : positive_length;
  lgstrut_len_ng                 : positive_length;
END_ENTITY;

ENTITY inlet
  SUBTYPE OF (ac_component);
  aper_ar_inlet                  : non_dimensional_ratio;
  area_ratio_inlet               : non_dimensional_ratio;
  bleed_area_inlet               : percentage_capture_area;
  bypass_area_inlet              : percentage_capture_area;
  cap_area_inlet                 : area;
  contr_ratio_inlet              : non_dimensional_ratio;
  corr_rate_airflow_inlet        : rate_airflow;
```

```
  corr_ecs_air_inlet            : rate_airflow;
  design_m_inlet                : mach_number;
  face_recov_inlet              : pressure;
  in_lip_ang_inlet              : positive_angle;
  leak_area_inlet               : percentage_capture_area;
  press_recov_inlet             : pressure;
  ramp_ang_fin_inlet            : positive_angle;
  ramp_ang_init_inlet           : positive_angle;
  spill_area_inlet              : percentage_capture_area;
  subsonic_dif_ld               : non_dimensional_ratio;
  throat_m_inlet                : mach_number;
  wt_ramp                       : weight;
  wt_spike                      : weight;
  wt_airinduct_sys              : weight;
  kd_gd                         : non_dimensional_factor;
  km_gd                         : non_dimensional_factor;
  kd_toren                      : non_dimensional_factor;
  kr_gd                         : non_dimensional_factor;
  ks_gd                         : non_dimensional_factor;
END_ENTITY

ENTITY nozzle
  SUBTYPE OF (ac_component);
   acous_area_noz               : area;
   exh_noz_thr_coeff            : non_dimensional_coeff;
   jet_vel_noz                  : speed_fps;
   noz_eject_flowrate           : rate_airflow;
   sec_noz_thr_coeff            : non_dimensional_coeff;
   suppress_area_noz            : area;
   suppress_noz                 : noise;
   v_jet_avg_noz                : speed_fps;
END_ENTITY;

ENTITY canard
  SUBTYPE OF (ac_component);
  ar_canard                     : non_dimensional_ratio;
  lc                            : positive_length;
  max_tc_canard                 : non_dimensional_ratio;
  max_tr_canard                 : non_dimensional_ratio;
  sc                            : area;
  span_canard                   : positive_length;
  sweep_canard_half             : positive_angle;
  sweep_canard_le               : positive_angle;
```

```
  sweep_canard_quar              : positive_angle;
  taper_canard                   : non_dimensional_ratio;
  thick_ratio_canard             : non_dimensional_ratio;
END_ENTITY;

ENTITY horizontal
  SUBTYPE OF (ac_component);
  ar_horiz                       : non_dimensional_ratio;
  kh                             : non_dimensional_factor;
  lh                             : positive_length;
  max_tc_horiz                   : non_dimensional_ratio;
  max_tr_horiz                   : non_dimensional_ratio;
  sh                             : area;
  span_horiz                     : positive_length;
  sweep_horiz_half               : positive_angle;
  sweep_horiz_le                 : positive_angle;
  sweep_horiz_quar               : positive_angle;
  taper_horiz                    : non_dimensional_ratio;
  thick_ratio_horiz              : non_dimensional_ratio;
  vh                             : non_dimensional_ratio;
  zh                             : positive_length;
END_ENTITY;

ENTITY vertical
  SUBTYPE OF (ac_component);
  ar_vert                        : non_dimensional_ratio;
  kv                             : non_dimensional_factor;
  lv                             : positive_length;
  max_tc_vert                    : non_dimensional_ratio;
  max_tr_vert                    : non_dimensional_ratio;
  span_vert                      : positive_length;
  sv                             : area;
  sweep_vert_half                : positive_angle;
  sweep_vert_le                  : positive_angle;
  sweep_vert_quar                : positive_angle;
```

```
  taper_vert                    : non_dimensional_ratio;
  thick_ratio_vert              : non_dimensional_ratio;
 END_ENTITY;

ENTITY wing
  SUBTYPE OF (ac_component);
  ar_wing                       : non_dimensional_ratio;
  dihedral_wing                 : positive_angle;
  fsle                          : length;
  mac                           : positive_length;
  max_tc_wing                   : non_dimensional_ratio;
  max_tr_wing                   : non_dimensional_ratio;
  msg                           : positive_length;
  span_wing                     : positive_length;
  sw                            : area;
  sweep_wing_half               : positive_angle;
  sweep_wing_le                 : positive_angle;
  taper_wing                    : non_dimensional_ratio;
  thick_ratio_wing              : non_dimensional_ratio;
 END_ENTITY;

ENTITY turbine
  SUBTYPE OF (engine);
  avg_work_turb                 : measured_work;
  blade_chordlen_turb           : positive_length;
  blade_count_turb              : positive_integer;
  eff_turb                      : efficiency;
  exit_speed_turb               : speed_fps;
  hub_tip_ratio_turb            : non_dimensional_ratio;
  no_stages_turb                : positive_integer;
  press_ratio_turb              : non_dimensional_ratio;
  rel_tip_m_turb                : mach_number;
  rotortip_space_turb           : positive_length;
  rotor_chordlen_turb           : positive_length;
  rotor_tip_dia_turb            : positive_length;
  stator_chlen_turb             : positive_length;
  stator_count_turb             : positive_integer;
  tip_dia_turb                  : positive_length;
  tip_speed_turb                : speed_fps;
```

```
  vane_chordlen_turb              : positive_length;
  press_ratio_turb_tot            : non_dimensional_ratio;
END_ENTITY;

ENTITY compressor
  SUBTYPE OF (engine);
  corr_flow_comp                  : rate_airflow;
  corr_tip_speed_comp             : speed_fps;
  expan_ratio_comp                : non_dimensional_ratio;
  fan_dia_comp                    : positive_length;
  hubtip_ratio_comp               : non_dimensional_ratio;
  hub_tip_ratio_in                : non_dimensional_ratio;
  mach_exit_comp                  : mach_number;
  no_airfoils_comp                : positive_integer;
  no_stages_comp                  : positive_integer;
  no_var_stages_comp              : positive_integer;
  press_ratio_comp                : non_dimensional_ratio;
  rotor_speed_comp                : speed_fps;
  vel_mean_comp                   : non_dimensional_ratio;
  v_rim_exit_comp                 : speed_fps;
END_ENTITY;

ENTITY materials;
  coeff_therm_exp                 : per_temperature;
  compress_yield                  : strength;
  corr_resist                     : strength;
  crack_growth                    : strength;
  elas_mod                        : strength;
  fatig_stren                     : strength;
  fract_tough                     : energy_per_vol;
  mat_temp                        : temperature;
  mod_rigidity                    : strength;
  shear_prop_limit                : strength;
  shear_ult_stren                 : strength;
  shear_yield_pt                  : strength;
  shear_yield_stren               : strength;
  stress_inten_coeff              : non_dimensional_coeff;
  ten_yield                       : strength;
  therm_strain                    : non_dimensional_coeff;
  ult_ten_stren                   : strength;
END_ENTITY;
```

```
ENTITY costs;
  acquis_cost                 : dollars;
  dev_sup_cost                : dollars;
  dte_cost                    : dollars;
  flttest_oper_cost           : dollars;
  life_cycle_cost             : dollars;
  mfgmat_equip_cost           : dollars;
  oper_cost                   : dollars;
  prod_eng_cost               : dollars;
  red_ener_consum             : dollars;
  red_envir_contam            : dollars;
  red_lc_cost                 : dollars;
  ac_init_price               : dollars;
  ac_spares_ratio             : non_dimensional_ratio;
  airframe_cost               : dollars;
  airframe_main_cost          : dollars;
  air_mainmat_cost            : dollars;
  ann_insur_rate              : percentage_of_hundred;
  ann_util                    : annual_utilization;
  block_fuel                  : weight;
  block_time                  : time_hours;
  cost_eng                    : dollars;
  cost_scale_fac              : non_dimensional_factor;
  deprec_cost                 : dollars_per_flight;
  deprec_period               : time_years;
  eng_main_cost               : dollars;
  eng_scale_fac               : non_dimensional_factor;
  flt_crew_cost               : dollars_per_flight;
  flt_time                    : time_hours;
  fuel_flt_cost               : dollars_per_flight;
  fuel_price                  : dollars_per_gallon;
  insur_cost                  : dollars_per_flight;
  labor_rate                  : dollars_per_hour;
  lab_burden_fac              : non_dimensional_factor;
  man_hours                   : time_hours;
  matcost_per_fltcyc          : dollars_per_flight_cycle;
  matcost_per_flthr           : dollars_per_hour;
  mat_cost                    : dollars;
  mh_per_fltcycle             : rate_hpfc;
  oper_wt_minus_eng           : weight;
  prop_spares_ratio           : non_dimensional_ratio;
  resid_ratio                 : non_dimensional_ratio;
  mfg_labor_hrs               : time_hours;
```

```
   prod_rate                        : deliveries_per_month;
   qual_cont_hrs                    : time_hours;
   tool_hrs                         : time_hours;
   tot_eng_hrs                      : time_hours;
   ac_price_per_lb                  : dollars_per_pound;
   ac_unit_price                    : dollars;
   avionics_price                   : dollars;
   eng_price                        : dollars;
   ampr_wt                          : weight;
   cum_quan_ac                      : positive_integer;
   kthrust_nic                      : non_dimensional_factor;
   max_thrust_sl                    : force;
   mmh_per_fh                       : non_dimensional_ratio;
   no_fltest_ac                     : positive_integer;
   no_prod_ac                       : positve_integer;
   vmaxbest                         : speed_knots;
END_ENTITY;


ENTITY performance;
   buffet_limit                     : speed_knots;
   cross_limit_lnd                  : speed_knots;
   cross_limit_to                   : speed_knots;
   flap_placard                     : speed_knots;
   dist_air                         : distance_ft;
   dist_brake                       : distance_ft;
   dist_climb                       : distance_ft;
   dist_ground                      : distance_ft;
   dist_land_total                  : distance_ft;
   dist_roll                        : distance_ft;
   dist_rotate                      : distance_ft;
   dist_segd                        : distance_ft;
   dist_toff_total                  : distance_ft;
   v_app                            : speed_knots;
   v_climbout                       : speed_knots;
   v_cruise                         : speed_knots;
   v_decision                       : speed_knots;
   v_dive                           : speed_knots;
   v_ground                         : speed_knots;
   v_gust                           : speed_knots;
   v_liftoff                        : speed_knots;
   v_rotate                         : speed_knots;
   v_stall                          : speed_knots;
```

```
  v_tdown                    : speed_knots;
  vmca                       : speed_knots;
  vmcg                       : speed_knots;
  alt_absolute               : altitude;
  alt_service                : altitude;
  endurance                  : time_hours;
  max_endur                  : time_hours;
  max_range                  : distance_nau_miles;
  range                      : distance_nau_miles;
  rate_climb                 : rate_fpm;
  spec_range                 : range_per_pound;
  turn_radius                : distance_ft;
  turn_rate                  : rate_dps;
  v_min_drag                 : speed_knots;
END_ENTITY;


ENTITY weights;
  ac_mass_dens               : mass;
  blcg                       : length;
  cg                         : percentage_mac;
  fscg                       : length;
  ixx                        : inertia;
  ixz                        : inertia;
  iyy                        : inertia;
  izz                        : inertia;
  mass_pt                    : mass;
  wlcg                       : length;
  xcg                        : positive_length;
  x_pt                       : positive_length;
  ycg                        : positive_length;
  y_pt                       : positive_length;
  zcg                        : positive_length;
  z_pt                       : positive_length;
  design_gwt                 : weight;
  max_fuel                   : weight;
  max_payload                : weight;
  max_zero_fuel              : weight;
  mission_fuel_frac          : non_dimensional_ratio;
  mission_fuel_used          : weight;
  mission_fuel_wt            : weight;
  mission_payload            : weight;
  mission_reserves           : weight;
```

```
  oper_wt_empty                     : weight;
  trapped_wt                        : weight;
  wt_crew                           : weight;
  wt_empty                          : weight;
  wt_toff                           : weight;
  air_cond_sys                      : weight;
  anti_icing_sys                    : weight;
  apu                               : weight;
  aux_gear                          : weight;
  avionic_instr                     : weight;
  baggage_equip                     : weight;
  baggage_wt                        : weight;
  ballast                           : weight;
  cargo_wt                          : weight;
  electrical_sys                    : weight;
  electronics                       : weight;
  furnishings                       : weight;
  hydraulic_sys                     : weight;
  kbuf_gd                           : non_dimensional_factor;
  klav_gd                           : non_dimensional_factor;
  misc_wt                           : weight;
  oper_items                        : weight;
  oxygen_sys                        : weight;
  paint                             : weight;
  passenger_wt                      : weight;
  pc                                : pressure;
  pneumatic_sys                     : weight;
  surface_controls                  : weight;
  wt_fixed_equip                    : weight;
  wt_flt_cont                       : weight;
  wt_eng_controls                   : weight;
  no_tanks                          : positive_integer;
  kfsp                              : non_dimensional_factor;
  int_fuel_frac                     : non_dimensional_ratio;
  wt_bladder                        : weight;
  wt_fuel_system                    : weight;
  ffr_toff                          : dimensional_factor;
END_ENTITY;


ENTITY stability_and_control;
  cd_elev                           : derivative_per_degree;
  cd_ih                             : derivative_per_degree;
```

```
cl_elev          : derivative_per_degree;
cl_ih            : derivative_per_degree;
cm_elev          : derivative_per_degree;
cm_ih            : derivative_per_degree;
cn_ail           : derivative_per_degree;
cr_rud           : derivative_per_degree;
cy_ail           : derivative_per_degree;
cy_rud           : derivative_per_degree;
cn_rud           : derivative_per_degree;
cr_ail           : derivative_per_degree;
cd_alpha_wb      : derivative_per_degree;
cl_alpha_wb      : derivative_per_degree;
cm_alpha_wb      : derivative_per_degree;
cnt_beta         : non_dimensional_coeff;
ctm_alpha        : non_dimensional_coeff;
ctm_u            : non_dimensional_coeff;
ctx_alpha        : non_dimensional_coeff;
ctx_u            : non_dimensional_coeff;
ctz_alpha        : non_dimensional_coeff;
ctz_u            : non_dimensional_coeff;
cn_p             : non_dimensional_coeff;
cn_r             : non_dimensional_coeff;
cr_p             : non_dimensional_coeff;
cr_r             : non_dimensional_coeff;
cy_p             : non_dimensional_coeff;
cy_r             : non_dimensional_coeff;
cd_q             : non_dimensional_coeff;
cl_q             : non_dimensional_coeff;
cm_q             : non_dimensional_coeff;
cmo              : non_dimensional_coeff;
cno              : non_dimensional_coeff;
cro              : non_dimensional_coeff;
cyo              : non_dimensional_coeff;
cd_alpha         : derivative_per_degree;
cd_alpha_dot     : non_dimensional_coeff;
cl_alpha         : derivative_per_degree;
cl_alpha_dot     : non_dimensional_coeff;
cm_alpha         : derivative_per_degree;
cm_alpha_dot     :  non_dimensional_coeff;
cn_beta          : derivative_per_degree;
cn_beta_dot      : non_dimensional_coeff;
cr_beta          : derivative_per_degree;
cr_beta_dot      : non_dimensional_coeff;
```

```
  cy_beta                    : derivative_per_degree;
  cy_beta_dot                : non_dimensional_coeff;
END_ENTITY;


ENTITY aerodynamics;
  cl_canard                  : non_dimensional_coeff;
  cl_horiz                   : non_dimensional_coeff;
  cl_wb                      : non_dimensional_coeff;
  cl_wbt                     : non_dimensional_coeff;
  alpha                      : positive_angle;
  flap                       : positive_angle;
  cd_compress                : non_dimensional_coeff;
  cd_induced                 : non_dimensional_coeff;
  cd_interference            : non_dimensional_coeff;
  cd_protub                  : non_dimensional_coeff;
  cd_skin_fric               : non_dimensional_coeff;
  cd_trim                    : non_dimensional_coeff;
END_ENTITY;

END_SCHEMA;
```

APPENDIX D

EXPRESS MODEL DATA TYPES

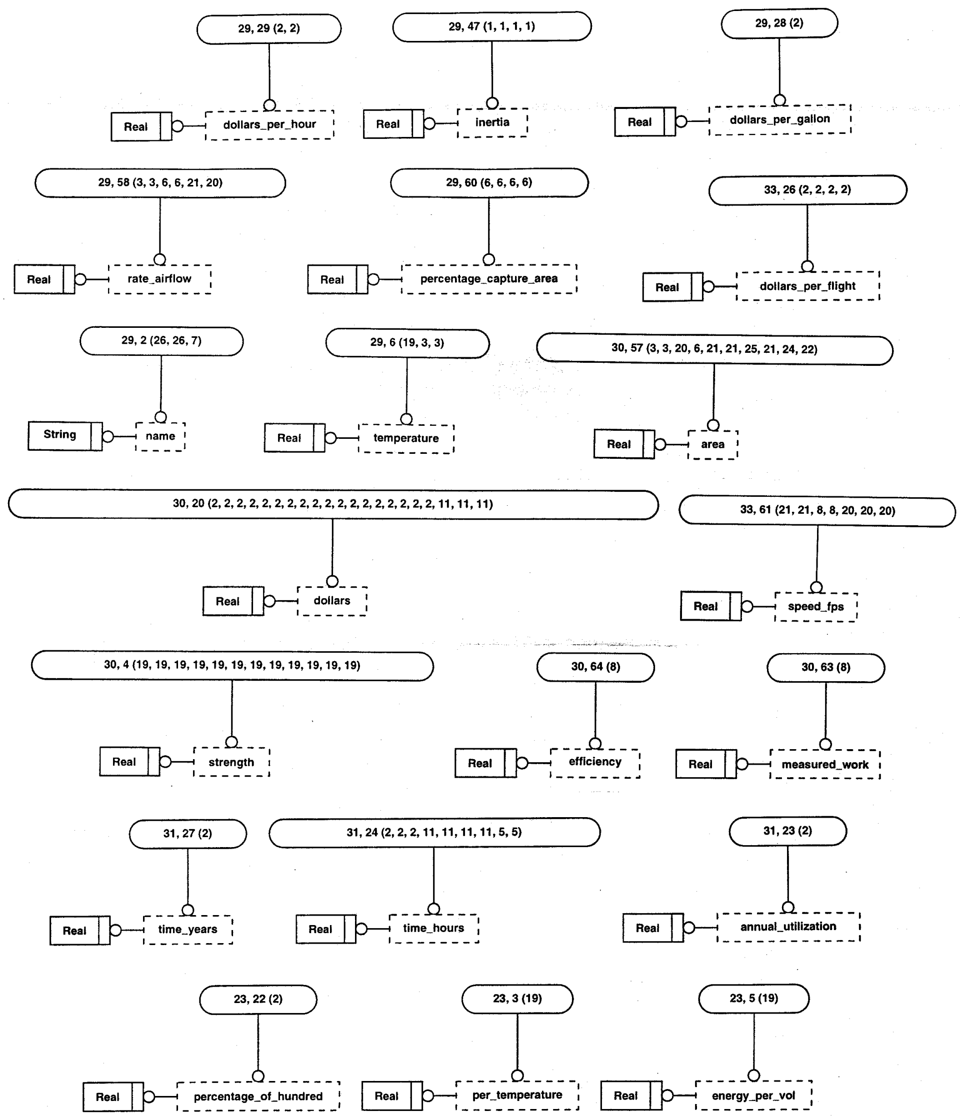


Figure 46. EXPRESS model data types (page 1 of 4)

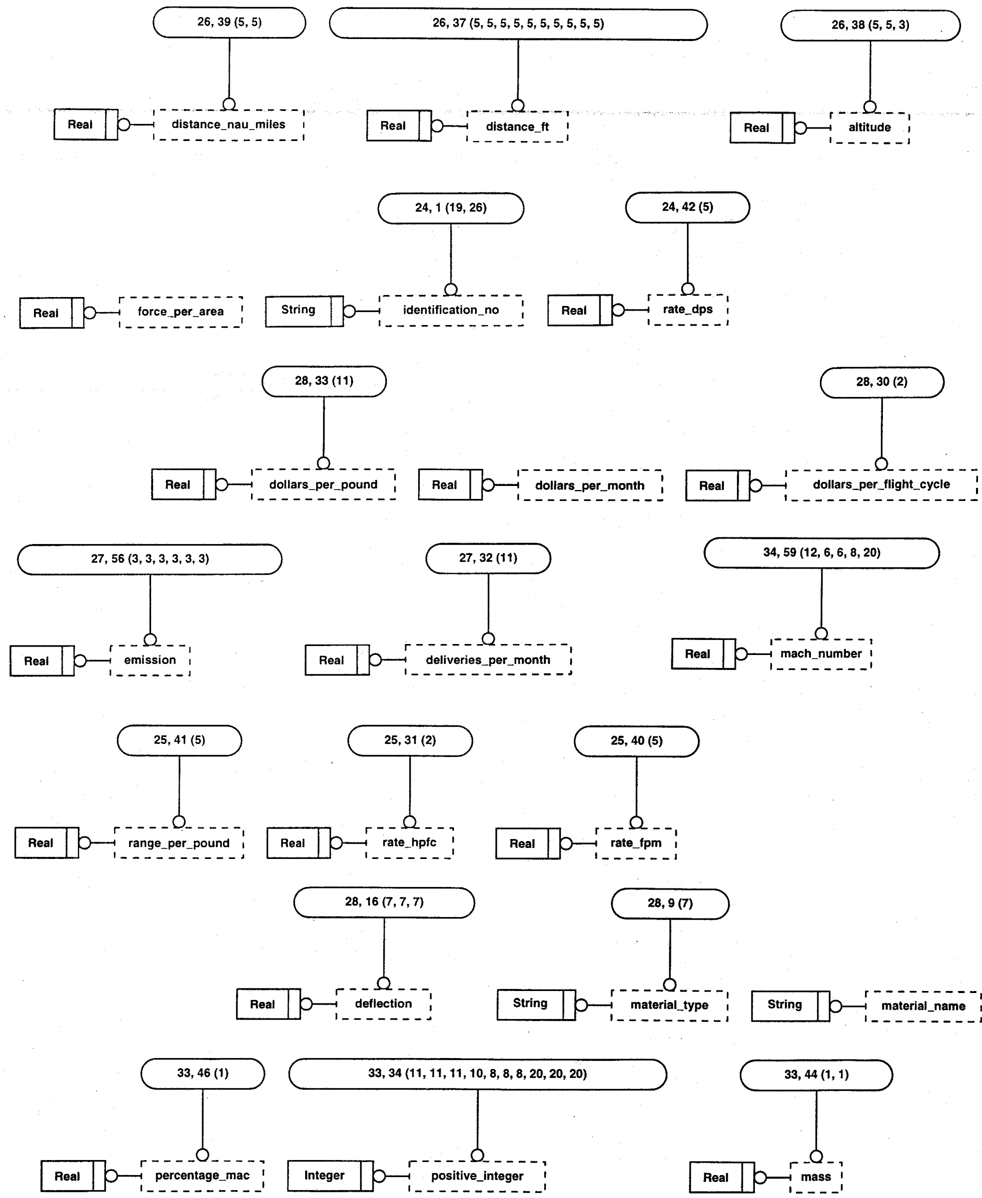


Figure 46. EXPRESS model data types (page 2 of 4)

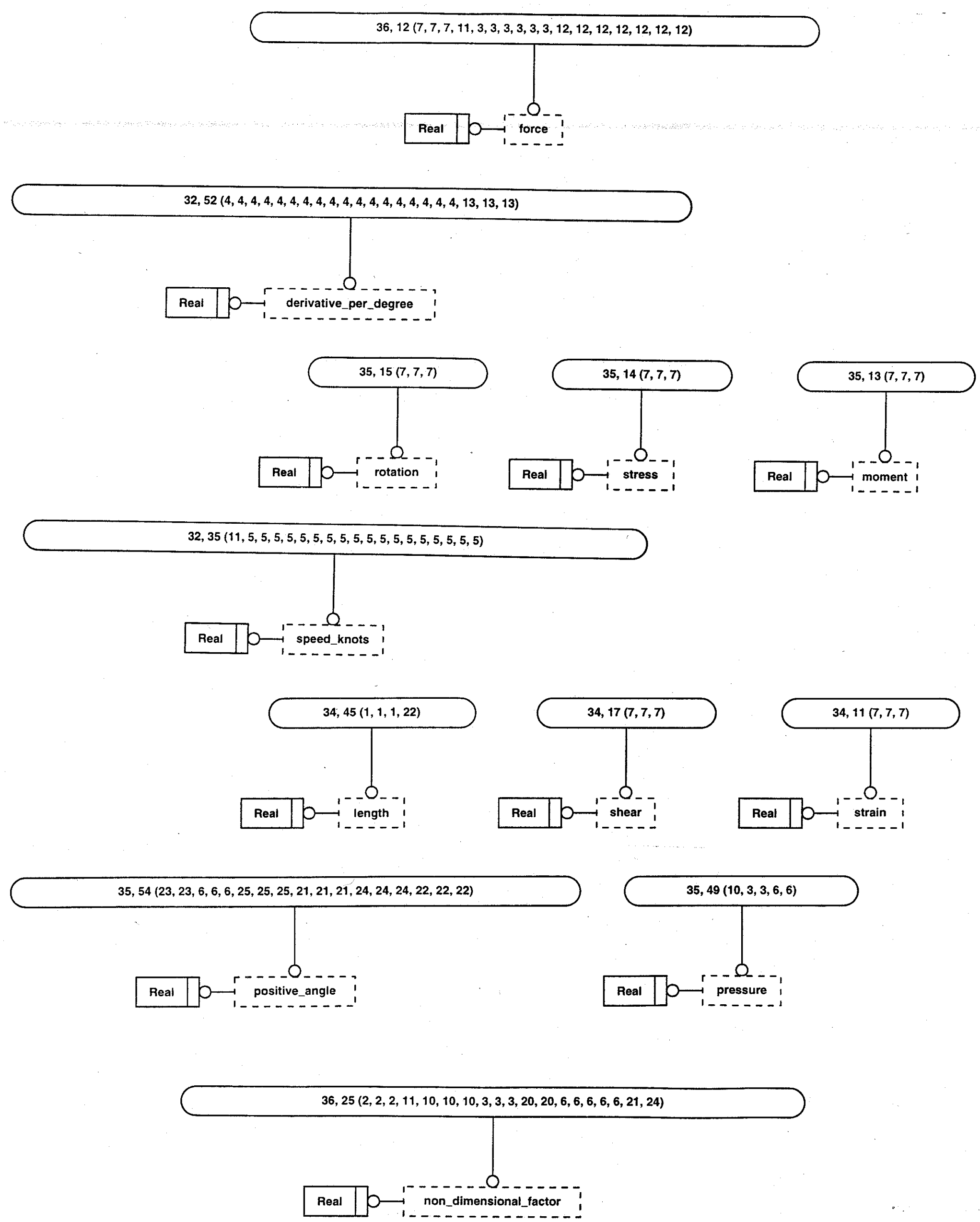


Figure 46. EXPRESS model data types (page 3 of 4)

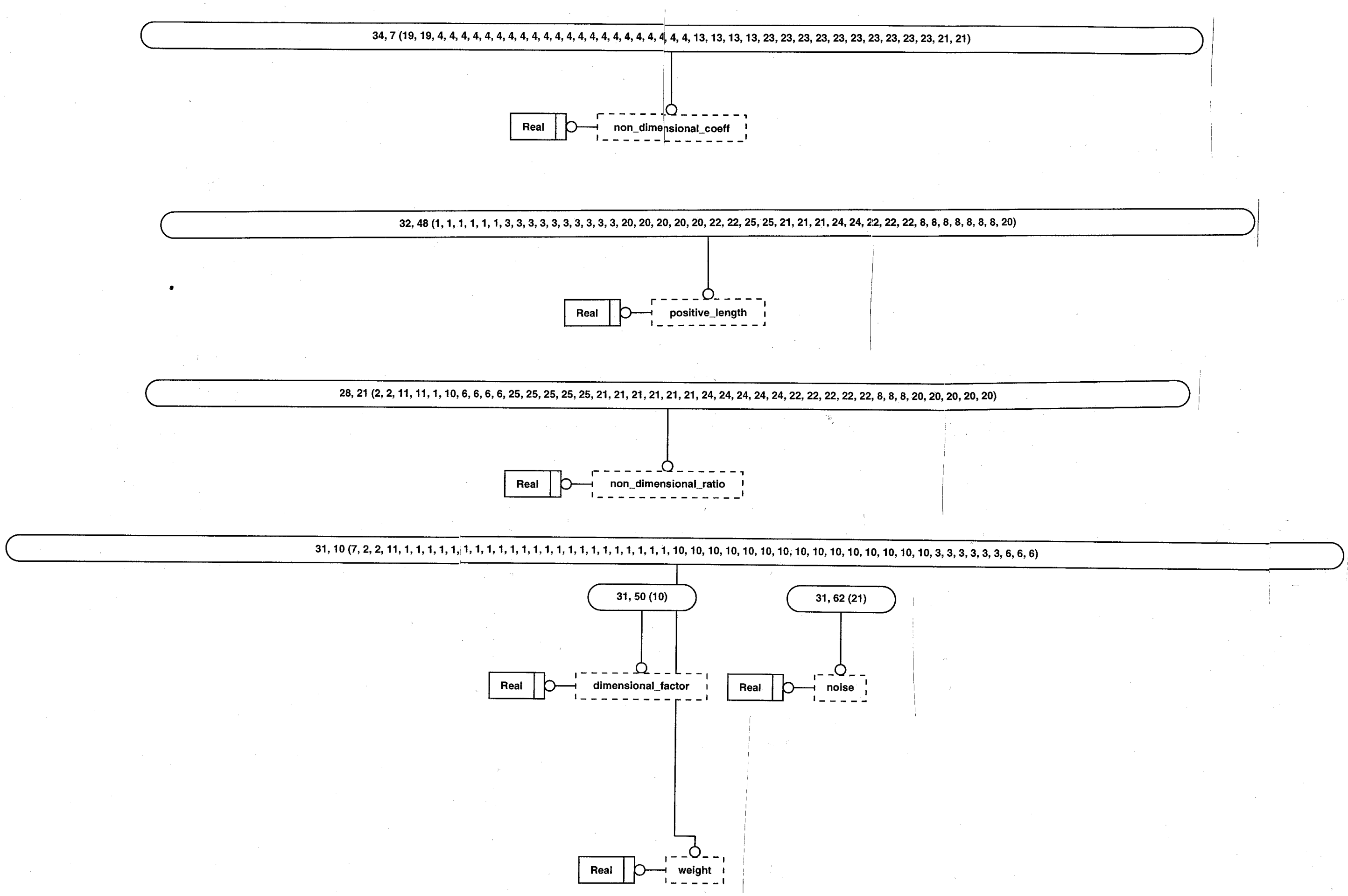


Figure 46. EXPRESS model data types (page 4 of 4)

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