APPLICATION OF SPEED IN AVIATION INDUSTRY

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Abstract

SPEED is a China project to implement the ISO STEP. STEP adopts IDEFIX and develops EXPRESS as the information modeling methodology. Part of SPEED is how to semiautomatically generate CIMS kernels with the information modeling methodology, IDEFIX and EXPRESS. Described in this paper are the structures and functions of a computer aided modeling system - BUCAMS developed under the China 863 Hi-Tech SPEED project.

The applied models in an aircraft manufacturing corporation are very big and complex. Only part of the SPEED IPIM draft has been developed. It is used to define the following applied models: product manifestation model, profile model, airframe structural model, technological equipment model, manufacturing part model and part manufacturing technology model needed by China aviation industry today and in the near future. The form-feature in SPEED IPIM draft has been enriched very much. In this paper detailed are those applied models.

II. Computer Aided Modeling System – BUCAMS

IDEFIX & EXPRESS

IDEFIX is the extension of the IDEF1 ( I–CAM Definition Method–1 ) proposed by the U.S. Air force in mid 70's. IDEFIX ( IDEF1–Extended ) is one of the techniques for information modeling based on the Entity Relationship Model developed by Peter Chen in 1975 and the Relational Model developed by E.F. Codd in early 70's.

The elementary structure of IDEFIX model is:
A. The objects in the real world are represented by boxes and called entities.
B. The relationship between objects are represented by solid or dash lines.
C. The characters of the objects are represented by the attributes in the boxes.

The IDEF1X diagram, which has not been assigned for any attributes, is called entity–level IDEF1X diagram; otherwise, called entity–attribute–level IDEF1X diagram.

EXPRESSION is a formal language to formulate a precise information specification that people can understand and computers can directly employ. EXPRESS itself is not a methodology. It provides the words, syntax, and grammar needed to describe a UoD (Universe of Discourse) in a uniform, precise, and compact manner and can be used as part of a methodology aimed at creating an information model.

The main descriptive elements of EXPRESS are:

  Schema
  Type
  Entity
  Algorithm
  Function
  Procedure
  Rule

"Schema" is a description of a UoD and is composed of declarations of types, entities, functions and the like. "Schema" is roughly similar to a description of a database.
"Type" describes the characteristics of the data used to represent entities. "Entity" describes the things of interest to a UoD. These elements are roughly similar to records

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in a database. "Rule" defines the constraints on entity attributes enforced by the information system. "Functions", "Procedure", and "Rule" are used to describe the behavior of things.

EXPRESS is still in development. The final EXPRESS will be an Object-Oriented language which can perform the functions of programming language, DDL (Data Definition Language) and DML (Data Manipulation Language) in database, and it will be used to write the CIMS system kernels directly.

**BUCAMS**

Making use of the information modeling methodology: IDEFIX and EXPRESS language of the STEP, we have developed the BUCAMS (Computer Aided Modeling System developed by Beijing University of Aeronautics and Astronautics) at APOLLO workstation in C, which can be used to produce CIMS kernels, even Object-Oriented CIMS kernels, semi-automatically. There are three modules (Fig. 1): CAIM (Computer-Aided Information Modeling) module, CATIK (Computer-Aided Translating the IDEFIX model into CIMS Kernel) module, and MEC (Module of EXPRESS Compiler) module.

![Diagram of BUCAMS](image)

**Fig. 1 The IDEF0 diagram of BUCAMS**

Entity Pool, Entity Alias Pool, ERM (Entity Relationship Matrix), Attribute Pool and EARM (Entity-Attribute Relationship Matrix) can be created, modified, managed, checked, displayed on the screen by the CAIM module. The entity-level IDEFIX diagrams and entity-attribute-level IDEFIX diagrams can also be managed, displayed on the screen, and transferred to Autocad 10.0 in PC by the CAIM module.

There are three ways to generate the CIMS kernels in STEP after the definition of IDEFIX. The first uses a programming language (e.g. C), DDL and DML to write the kernels with the Include File defined by STEP. The second uses EXPRESS as DDL and DML to define and manipulate the data in the kernels and a programming language to write the kernels. The third uses the EXPRESS to write and generate the Object-Oriented kernels directly. The CATIK module is designed to perform those functions.

We have developed a testing module of EXPRESS-like language compiler to generate the CIMS kernels\(^6\). We are trying to make it more perfect for the EXPRESS and to generate the Object-Oriented CIMS kernels automatically.

**CAIM Module**

There are four sub-modules in CAIM\(^6\): "To build Entity Pool", "To deal with the ERM", "To build Attribute Pool", and "To deal with the EARM". The Entity Pool can be created, modified, checked, managed, and displayed on the screen by the sub-module, "To build Entity Pool", and so can the ERM by the sub-module, "To deal with the ERM", the Attribute Pool by the sub-module, "To build Attribute Pool", and the EARM by the sub-module, "To deal with the EARM".

In the sub-module, "To build Entity Pool", we divide the entities of the IPIM and user protocol into two parts. User cannot define any child entity in the first part. When an entity relationship is defined or modified, CAIM will automatically check if the parent entity belongs to the first part and prohibit the user from changing anything in the first part.

In the CAIM module matrix algorithms have been developed\(^6\). The IDEF0 diagram of CAIM was described in (6). Besides those added is a function to deal with the EARM in CAIM, which is: If it is a foreign key of an entity, the attribute must at least be a key of one of the

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parent entities of the entity. Otherwise, redefine the attribute.

The final IDEF1X model generated by CAIM will be transferred to Autocad 10.0 in PC to draw the IDEF1X diagrams on a plotter or print them on a printer with the Screen File and the DXF File automatically.

**CATIK Module**

After defining information model with IDEF1X, the Object-Oriented CIMS kernels will be generated by CATIK semiautomatically based on the final IDEF1X model output from CAIM. There are six sub-modules in CATIK to generate the CIMS kernels (Fig. 2).

![Fig. 2 The IDEF0 diagram of CATIK](image)

The objects of IPIM and user protocol used here include not only the entities, the attributes, the entity relationships and the entity-attribute relationships, but also the constraints and manipulations of the entities written in C or "C and DDL--like part of EXPRESS" in the first case and in EXPRESS only in the second case.

In the first case, the objects in IPIM and user protocol used in the CIMS kernel are abstracted from the IPIM and user protocol as "C Include File". The objects not in IPIM and user protocol are defined by the user with C or "C and DDL--like part of EXPRESS", but the function names, the data declaration, the called and calling relationship between the functions and the data definition are generated by CATIK automatically. Then the kernel is translated to C by a pre--compiler. At the final stage the whole C functions will be recombined with the "C Include File" based on the IDEF1X model and recompiled into the code of the Object-Oriented CIMS system kernel. For the second case it is quite similar to the first case, and the difference is that only the EXPRESS is used.

However, the constraints and manipulations are not in CATIK.

III. Product Model in Aviation

The course of establishing aircraft product model is the process of defining and using the SPEED IPIM. Now, we have only set up the product manifestation model, profile model, airframe structural model, technological equipment model, manufacturing part model and part manufacturing technology model. The SPEED IPIM draft has been also defined and proposed. The form--feature in STEP IPIM defined on 2D manifold today is far from meeting the needs of aviation industry because there are a great variety and big number of parts and assemblies with complex shape and high accuracy in an airframe. Therefore, the SPEED IPIM has been enriched very much based on the design and manufacturing customs in China, the data access format used in the domestic aircraft design and manufacturing software systems, and the needs in China aviation industry today and in the near future. The common functions and procedures used in the domestic software are defined as the entities of SPEED IPIM as far as possible.

**Product Manifestation Model**

Product manifestation model is mainly used in MRP II, generation of BOM, optimization of assembling
sequence, and management of design changes. The model is hierarchical. The leaf nodes of the model are purchased parts, purchased assemblies, or the parts made by the corporation itself. Every assembling operation, surface treatment operation and inspection operation done after assembling at different places is a node of the model. The main part of product manifestation model is the E-R assembly model in terms of the assembling sequence. The assembling operations are divided into four classes.

In the first class, landing gears, special assemblies (e.g. actuators), and special equipment (e.g. radars) are assembled. The assembled objects (entities) in this class are highly exchangeable with assembling surfaces on the rigid machined parts in them, and are assembled directly without any correction. The tolerance system used in this class is just as the common manufacturing tolerance system.

In the second class, assembled are assemblies with some independent functions in an airframe, e.g. wings, fuselage (FWD fuselage module, center or mid fuselage module, and AFT fuselage module), vertical stabilizer, horizontal stabilizer, canard, and rudder, etc. Fig. 4 shows a structural breakdown of a fighter. The assemblies consist of subassemblies and parts.
In the third class, assembled are integral parts and subassemblies. The latter is composed of more than two parts joined by welding, riveting, adhesive bonding, bolts and screws, etc. The entities in this class include ribs, spars, frames, leading edges, panels, and longerons, etc. (Fig. 5).

![Diagram of a typical wing](image)

Fig. 5 A typical wing

In the fourth class, parts are assembled. The subassemblies include typical ribs, typical frames, combined frames, and combined panels, etc. In the other part of this paper, the word “assembly” represents both the assembly itself and the subassembly.

Profile Model

The shape model in STEP IPIM is perfect. No entity needs adding. Considering the main trend of the algorithms used in domestic software, the profile model is suggested to mainly use 3x3 nurbs representing sculptured surfaces, 1x2 or 1x3 nurbs representing ruled surfaces, and the nurbs method exactly representing analytical surfaces. The profile model is divided into six sub-models, which are:

- fuselage — high longitudinally streamline, symmetrical, with control sections consisting of segmental conic curves in many cases;
- wings (including Vee stabilizers, horizontal stabilizers and/or canards) — nonsymmetrical, with curvature constraints at the front edge and rear edge;
- vertical stabilizer (including fins) — symmetrical, with curvature constraints at the front edge and rear edge, using ruled surfaces in many cases;
- the inside and outside surfaces of inlet — with big variety of longitudinal curvatures, various shapes of the control sections;
- canopy — high longitudinally streamline, with free conditions on the boundaries of the surface;
- fairing — with complex boundaries, strict constraints on the boundaries, high streamline of the surface.

Airframe Structural Model

The constraint relationships of geometry and tolerance between the parts and assemblies of an aircraft are defined in this model. Based on the airframe structural model and the local database of airframe structural design, computer aided structural design can be realized. The model is also served as the reference model to check the consistency of geometry and manufacturing technology between the corresponding parts and assemblies.

The constraint relationships are:

- profile model to constrain skins, panels, and profiled parts;
- skins and panels to constrain spars and longerons;
- ribs constrained by skins, panels, longerons, cutouts for spars, holes for cables and actuators, holes for weight reduction, and strengthened hollows, etc.
- frames constrained by skins, panels, cutouts for spars, holes for cables and actuators, engines, special equipment, holes for weight reduction, and strengthened hollows, etc.

Almost all of the constraints can be generated by computer automatically besides the constraints related to engines and special equipment. The inner constraints of landing gears and other actuators are defined by kinematics, dynamics, mechanics and tolerance standards. The constraints related to skin rabbets, almost all of the cutouts for spars, and holes for cables and actuators can be determined by computer easily based on various China aviation industry specifications (Fig. 6).

It is a little difficult to select cutouts for spars with variable sections. The proposed algorithm to deal with it is (Fig. 7):

- To get the curve on the section of the spar where the rib or frame stands;
- To find out the vertex set A;
- To determine sub set A' from A which have minimum distance to the skin;
- To determine two vertices P1 and P2 from A' which have maximum distance;
- To define a line L through P1 and P2;
- To find out the vertex a from A which have maximum distance H to L;
- To define line L' perpendicular to L through the mid point of the two vertices;
- To define relative axes with L and L';
- To assign 14 to H and find out the outline of the cutout from the local standards database for spar cutouts, and check up if A is all included in the outline;
- To repeat the last step above until A is included in the outline completely in the following order of China aviation specifications: 142CTS5, 125CTS5, 122CTS5, 123CTS5, 124CTS5-I, 124CTS5-II, 138CTS5-I, 138CTS5-II, 127CTS5, 126CTS5-I, 126CTS5-II, 139CTS5-I, 139CTS5-II, 140CTS5, 141CTS5 (Fig. 6).
Fig. 6  Some specifications used in China aviation industry[8]
come from airframe structural model based on various design specifications.

The percentage of the machined parts in an aircraft is increasing with the development of NC, computer and machining techniques because machined parts have high accuracy and high exchangeability, need fewer TE, and can reduce the manufacturing time and the number of parts and assemblies of an aircraft. The machined parts are divided into:

2.5D parts (e.g. integral panels);
PCV parts (e.g. almost all of the frames, ribs, spars and longerons, etc.);
3D surface parts (some surface of the parts is part of the aircraft profile, e.g. canopy longerons, lips of inlet, parts requiring NC scribing the rivet position and NC riveting, etc.).

2.5D form-features, which include various kinds of pockets (e.g. rectangular pocket and triangular pocket, etc.), through holes (e.g. cylindrical hole, elliptical hole, rectangular hole, triangular hole, etc.) and their flanges, and border rebates, etc., are defined for integral panels. All of the machined surfaces on PCV part are ruled surfaces. Many 3D form-features, which include various kinds of wide-open and non-wide-open pockets (Fig. 8), upright and oblique through holes (e.g. cylindrical hole, elliptical hole, rectangular hole, triangular hole, etc.) and their flanges, and equidistance and non-equidistance rebates, etc. are defined for PCV part. Besides the working surfaces 3D surface part is mainly represented by the PCV part form-features.

Manufacturing Part Model

This model describes the form-features of geometry, tolerance and manufacturing technology and is divided into machined part model and non-machined part model. The latter supplies the part data to TE model for die design and the information of sheet-metal to blanks by unfolding algorithms and airframe structural design database. Information of sheet-metal, composite part and plexiglass part is included only in the non-machined part model. Although the percentage of the non-machined parts in an aircraft is about 40% and shapes of them are complex, the topology of them are quite simple and the basic forming method is bending, flanging, stretching or expanding. The part geometry and tolerance information of sheet-metal

Fig. 7 To select cutouts for spars with variable sections
system for Gear Reducer \(^9\). It makes us easy and correct
to define the Form–Features and build the applied models
of an aircraft. However, the CIMS kernels in an aircraft
 corporation have not generated by BUCAMS yet. What
we have done is the E–R model used in MRP II, data
structures in the CIMS kernels to be generated, and
the form–features, especially for NC machining.

The product manifestation model, profile model,
airframe structural model, technological equipment model,
manufacturing part model and part manufacturing
technology model make up a STEP / SPEED global model
in an aircraft manufacturing corporation, which is a subset
of the perfect global aircraft product model. The applied
models have partly been put into use (Fig. 9). We believe
that the models will fit the need of aircraft manufacturing
 corporations in China in this century.

There are still some programs to be improved in
BUCAMS, especially in MISC. The applied models of
aircraft and the SPEED IPIM draft are not perfect yet and
need further modification.

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