APPLICATION OF SPEED IN AVIATION INDUSTRY®

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Zhao Xinli and Zhu Xinxiong
Institute of Manufacturing Systems
Department of Manufacturing Engineering
Beijing University of Aeronautics and Astronautics
Beijing, 100083, P.R.China

Abstract

SPEED is a China project to implement the ISO STEP. STEP adopts IDEF1X and develops EXPRESS as the information modeling methodology. Part of SPEED is how to semiautomatically generate CIMS kernels with the information modeling methodology, IDEF1X 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. They are required by the China aviation industry today and in the near future. Introduced in this paper are those applied models.

I. Introduction

In June 1985, ISO (International Standard Organization) decided to realize STEP (Standard for the Transfer and Exchange of Product model data) project. It will provide a software development platform for CIMS (Computer Integrated Manufacturing System) in late 90's or next century. It is not only to draw up the standard itself, but also to provide the technique for it's development.

SPEED [1](SPecification for Exchange of Engineering Data) project is set up to implement the STEP by China 863 Hi–Tech project. It adopts the whole IPIM (Integrated Product Information Model) of STEP and the information modeling methodology – IDEF1X and EXPRESS to establish the applied models for machine tools, air–blower, textile machinery and aircraft. The information modeling technique and the use of IPIM are also investigated under SPEED project. In order to establish the applied models rapidly and exactly a kind of information modeling software has been developed.

Only part of the SPEED IPIM draft has been developed. Several applied models have been built up. They are the 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

IDEF1X & EXPRESS

IDEF1X is the extension of the IDEF1 (I–CAM Definition Method–1) proposed by the U.S. Air force in mid 70's. IDEF1X (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[2].

The elementary structure of IDEF1X model is[3]:

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.

EXPRESS is a formal language to formulate a precise information specification that people can understand and computers can directly employ[4]. 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" define the constraints on entity and 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: IDEF1X 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, semiautomatically. There are three modules (Fig. 1) : CAIM (Computer-Aided Information Modeling) module, CATIK (Computer-Aided Translating the IDEF1X model into CIMS Kernel) module, and MEC (Module of EXPRESS Compiler) module.

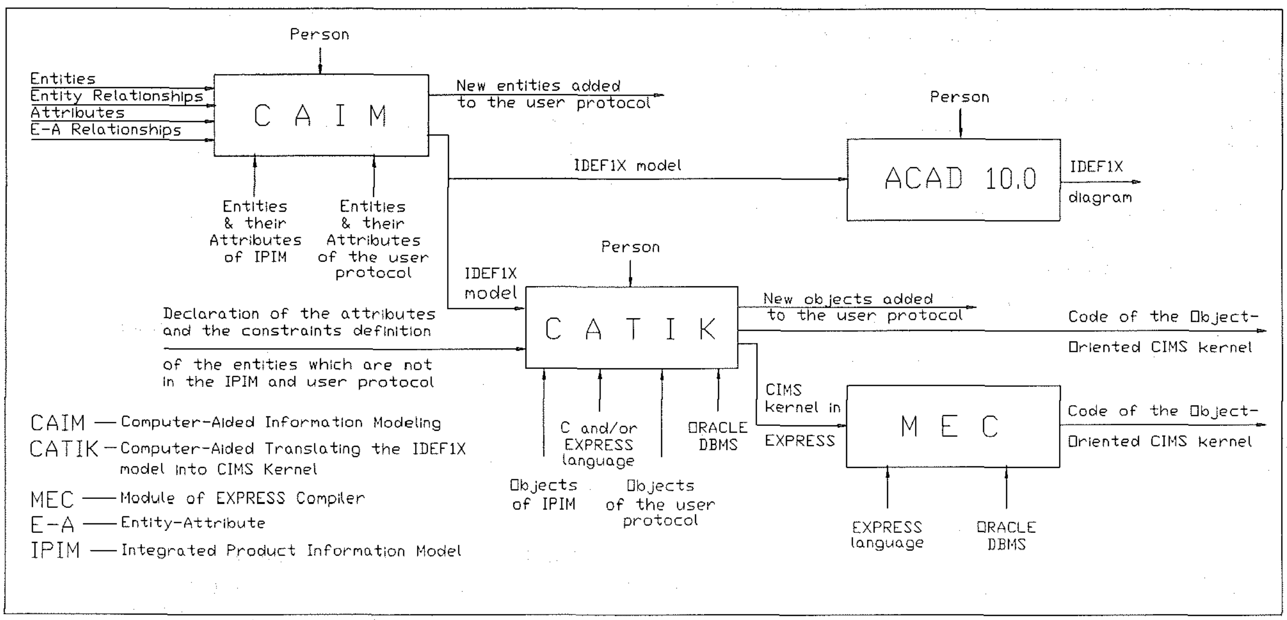


Fig. 1 The IDEF0 diagram of BUCAMS

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 IDEF1X diagrams and entity-attribute-level IDEF1X 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 IDEF1X. 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[5]. We are tying 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 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).

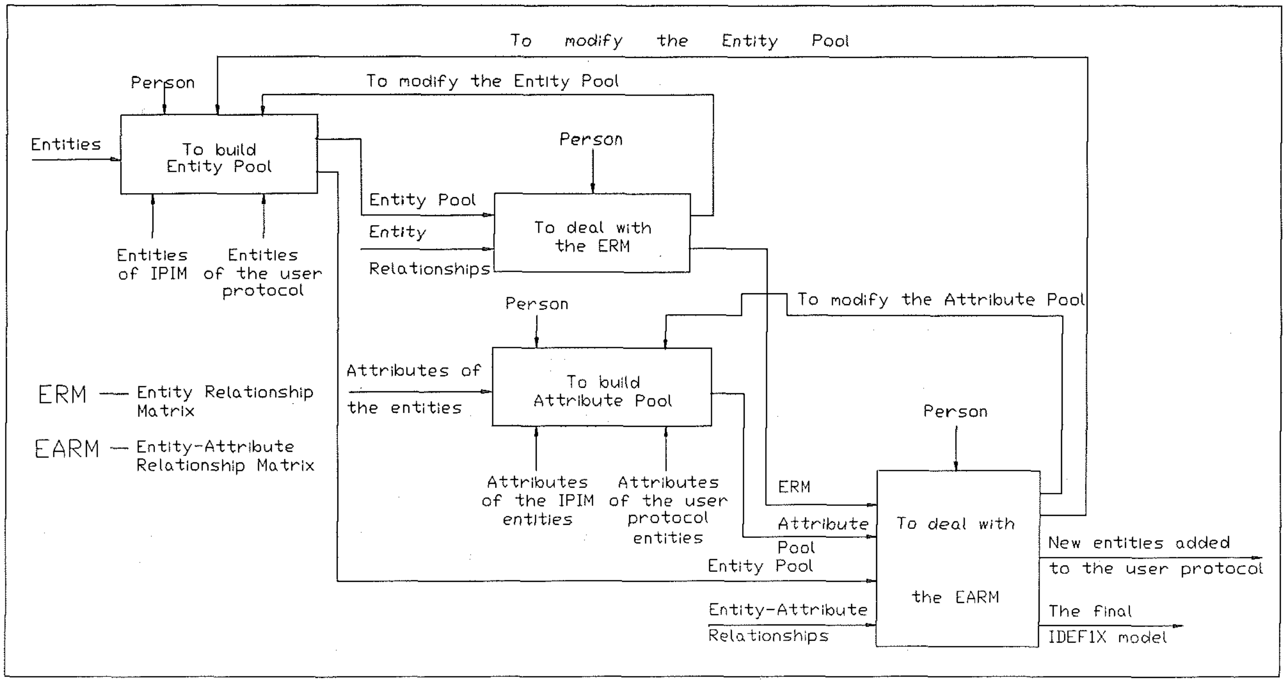


Fig. 2 The IDEF0 diagram of CATIK

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.

Fig. 3 shows the mapping from IDEF1X to C and Date Definition Language for the first case, and EXPRESS for the second case in CATIK. Here the Data Definition Language represents the DDL–like part of EXPRESS and / or the DDL in DBMS. The entity, attribute and relationships between entities are mapped automatically. 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 MRPII , generation of BOM, optimization of assembling

IDEF1X	C / DBMS	EXPRESS
entity	function	SCHEMA
attribute	external variable and / or Data Definition Language	declaring the data type in TYPE; defining whether the attribute is a key or an alternative key in ENTITY.
child entity	function called by parent function	SCHEMA used by parent SCHEMA
constraints	if (exp.! = condition ||exp. !> condition2 || exp. !< condition3) output (message); and / or Data Definition Language	defining in RULE
manipulations	C language and / or Data Manipulation Language in function	if the manipulation can be used by another SCHEMA, defining it in FUNCTION; otherwise, in PROCEDURE.

Fig. 3 Mapping IDEF1X to C+DDL and EXPRESS

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.

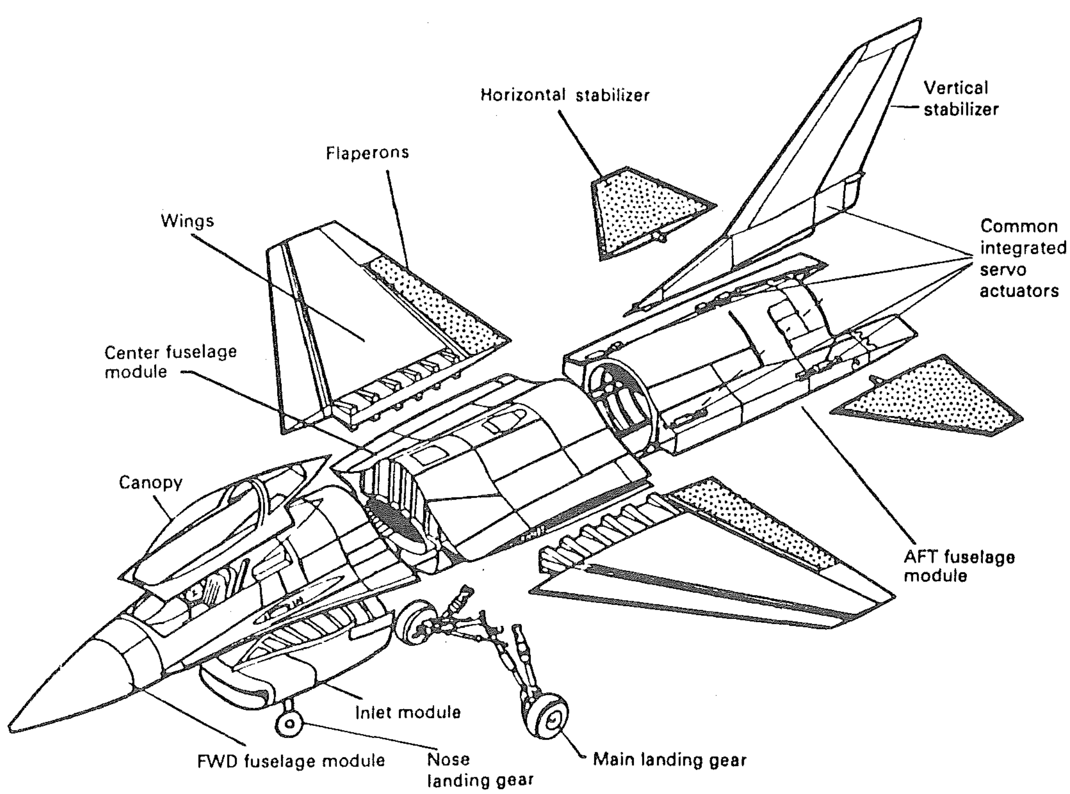


Fig. 4 An aircraft structural breakdown[7]

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).

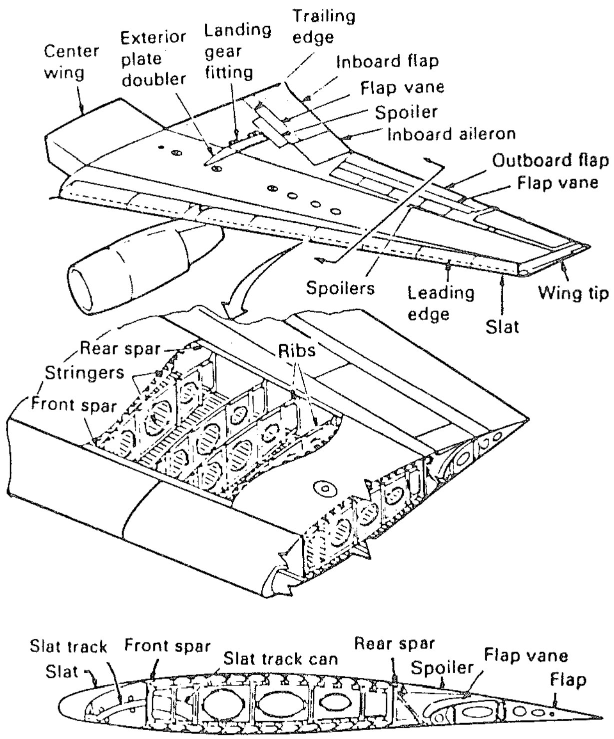


Fig. 5 A typical wing[7]

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 $P_1$and $P_2$from A′ which have maximum distance;

To define a line L through $P_1$and P_2;

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: 142CT55, 125CT55, 122CT55, 123CT55, 124CT55– I , 124CT55–II , 138CT55– I , 138CT55–II , 127CT55, 126CT55– I , 126CT55–II , 139CT55– I , 139CT55–II , 140CT55, 141CT55 (Fig. 6).

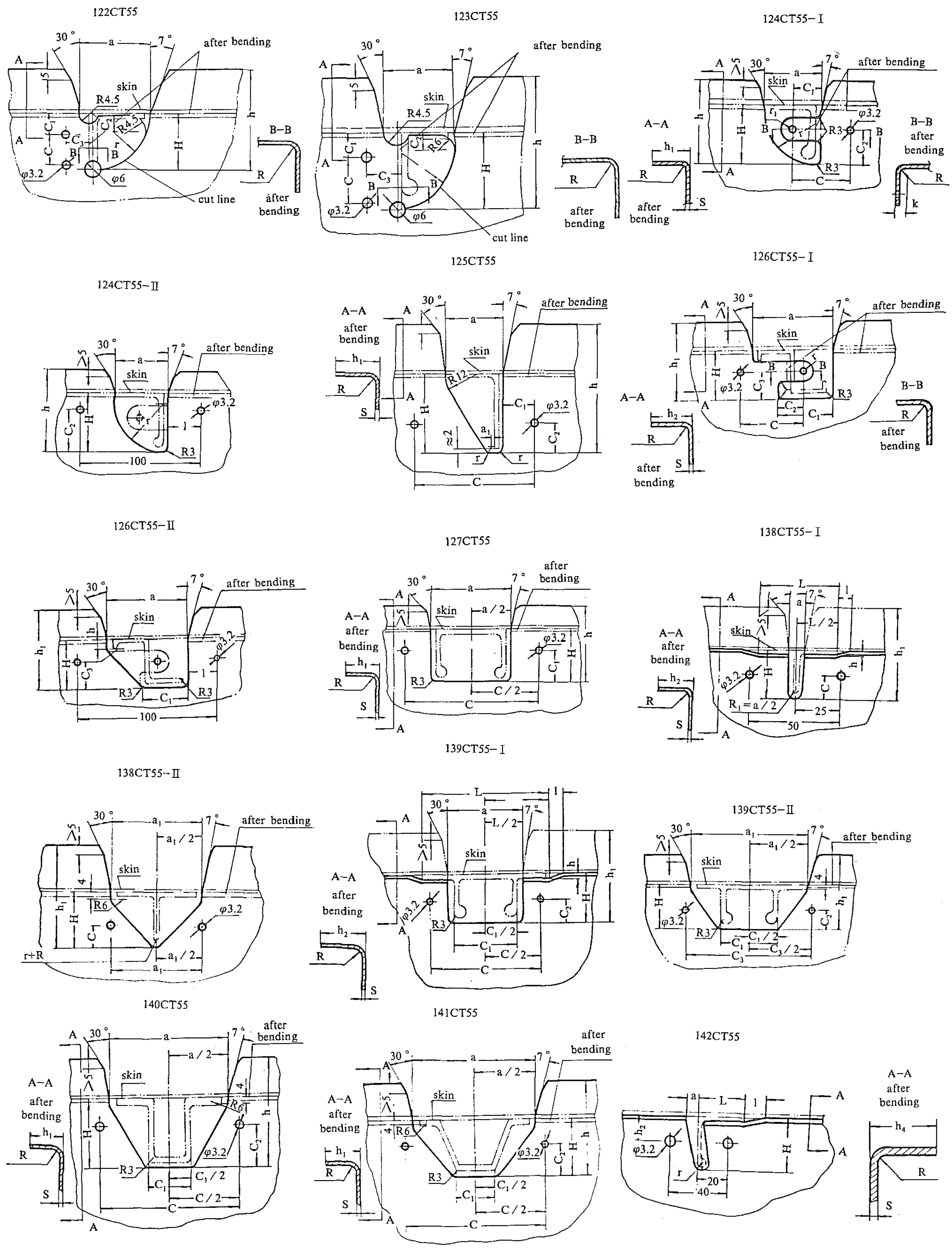


Fig. 6 Some specifications used in China aviation industry[8]

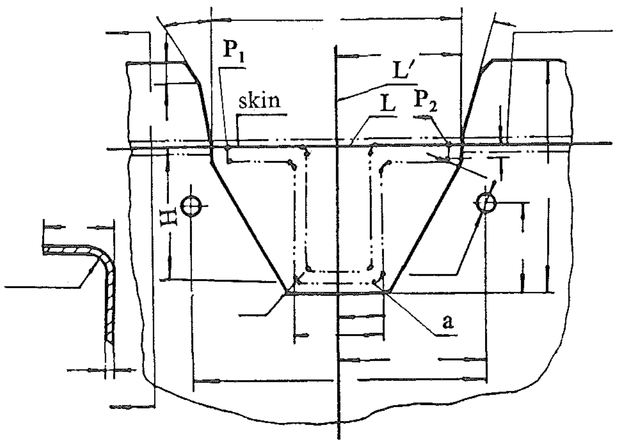


Fig. 7 To select cutouts for spars with variable sections

To increase H and repeat the last two steps above if A is not included in the outline of any China aviation specifications listed above.

Technological Equipment Model

The TE (Technological Equipment) is classified as special one and combined one. The special TE is further classified as 2D TE (e.g. templates, theoretic diagrams and airframe structural diagrams, etc.) , 3D surface TE (e.g. master pieces, sheet–metal forming dies, composite forming dies, various setting dies, casting molds and forging dies, etc.) , PCV (Plane Curve with Varied bevel angles) TE (e.g. assembling jigs, etc.) .

Almost all of 2D TE and master pieces are machined directly based on profile model. Part of the templates and airframe structural diagrams are generated in terms of the equidistance curves, non–equidistance curves, rabbets, flanges and strengthened hollows, etc. based on the profile model and airframe structural model. Various forming dies, setting dies, casting molds and forging dies are designed and manufactured based on the profile model, manufacturing part model and the engineering characteristics of the manufactured parts. 3D surface TE is mainly machined on 3 axis or 5 axis NC milling machines. The machined surfaces are spacial bounded sculptured surfaces. The machined surfaces of PCV TE are equidistance surfaces of the ruled surfaces formed by curves on two parallel sections of profile model.

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 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 rabbets, 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 rabbets, etc. are defined for PCV part. Besides the working surfaces 3D surface part is mainly represented by the PCV part form–features.

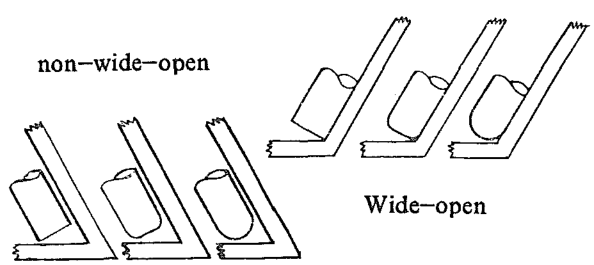


Fig. 8 Wide–open and non–wide–open pockets

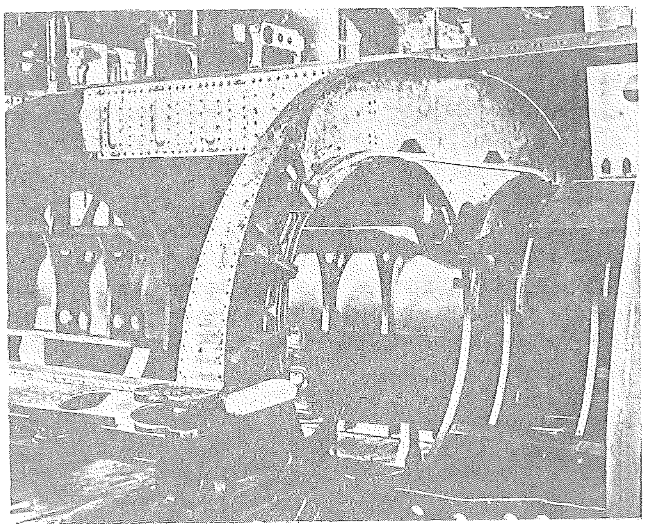
Part Manufacturing Technology Model

Every part machining operation or every inspection operation done at other place is an entity of the part manufacturing technology model. The E–R model used in MRPⅡ is based on this model and product manifestation model, and the process plans and NC instructions of machined parts are also based on this model and manufacturing part model. Actually, the part manufacturing technology model is simply the description of the process plans used now in China aviation industry with EXPRESS. The detail of the model is not discussed here.

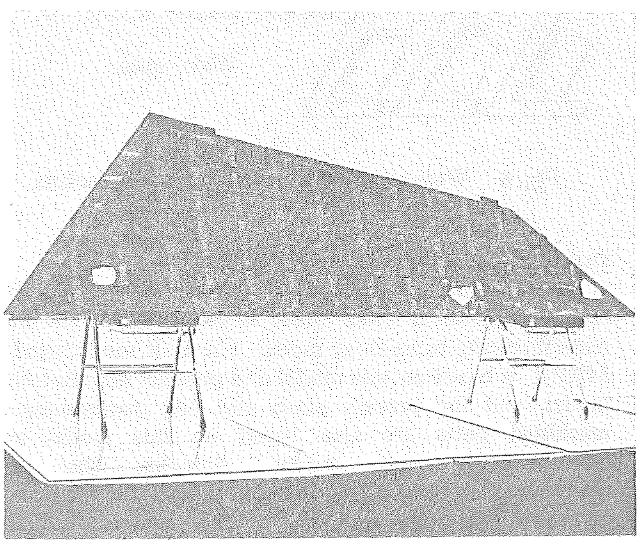
Ⅳ. Conclusions

The BUCAMS has been justified in developing a testing system GR–CAD (Computer–Aided Design 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 MRPⅡ, 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.



(a) A subassembly of an airframe



(b) An integral panel

Fig. 9 Photos of some results

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

Ⅴ. Acknowledgement

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