CDS-THE DESIGNER'S MEDIA, THE ANALYST'S MODEL

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Abstract

Conceptual design of aerospace vehicles requires the capability to rapidly design, analyze, and iterate initial configurations. Rockwell has developed a flexible conceptual design program called the Configuration Development System (CDS) which permits rapid conceptual design and iteration in an interactive-graphics environment.

This paper presents the capabilities of CDS both as a tool for designers and a geometric model for analysts. The design philosophy using CDS is described and the data base structure is detailed. Examples of specific capabilities such as wave drag optimization and vision plotting are given. The capabilities of CDS are illustrated with a recent example in which CDS was employed to create a spacecraft concept including engines, cockpit, landing gear, and payload bay.

I. Introduction

In 1976, the initial specification was written for what developed into Rockwell's Configuration Development System (CDS). At that time, aircraft design was done solely on the drafting board, with laborious digitizing required to prepare a model for analysis. The all-to-frequent design changes each required 40 hours for redesign on the drafting board, following by redigitizing into an analysis model. This limited the number of trade studies which could be made. The only solution seemed to be a fusion between the designer's media and the analyst's model.

An evaluation of the existing tools for computer-aided design found them to be tailored towards production design rather than conceptual design. But much as the skills and equipment needed for initial layout and framing of new buildings are distinct from those of the finish carpenter and cabinet maker, so conceptual design differs from production design work. Production design deals with rigid definition of specific pieces such as frames, ribs, brackets, and stiffeners. In contrast, conceptual design requires quick definition of surfaces, rapid checks on major component clearances, and fast calculation of surface area and volume. These capabilities were either not present in existing design software, or were cumbersome in their adaption to the conceptual environment, so a decision was made to proceed with an all-new computer-aided design system.

CDS was conceived with a three-dimensional, arbitrary body geometry much like that in use for analysis, but with increased flexibility. A six-axis (roll, pitch, yaw, x, y, z) component orientation allowed positioning independent of component geometry. Also, non-geometric data was attached to each component, allowing scalar quantities to be stored.

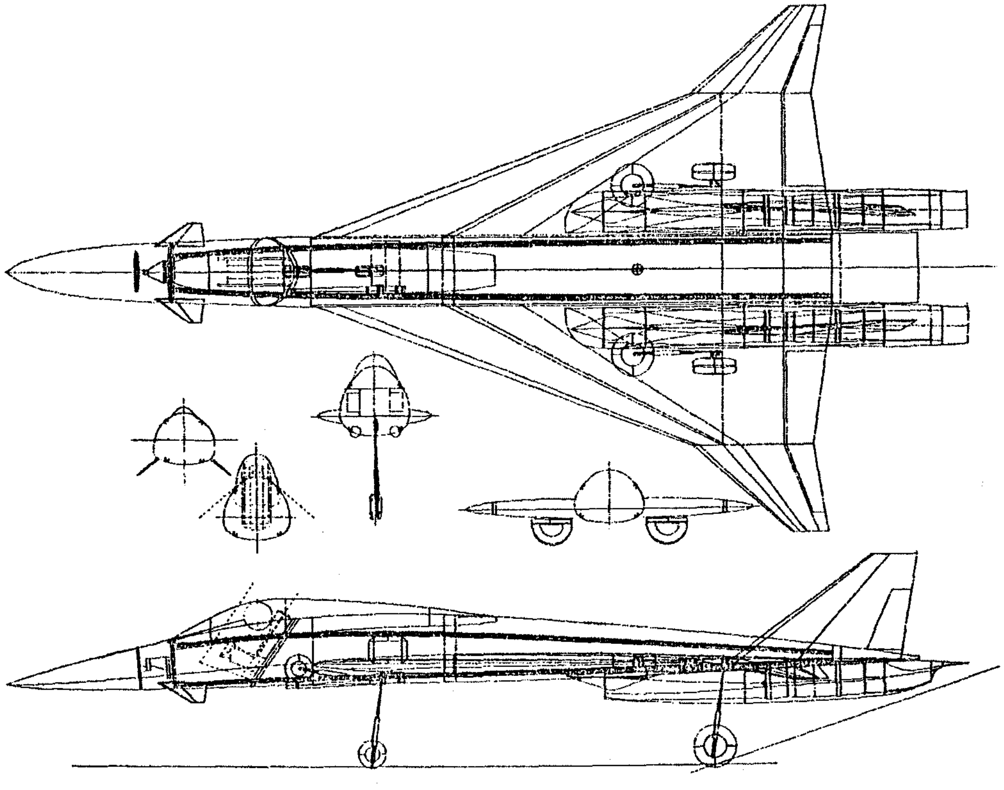


Fig. 1 Two views and Sections of a Typical Design

This flexible data structure provided a convenient common data base for analysis yet allowed creation of a wide variety of design tools, ranging from initial surface lofting to landing gear location. This paper will describe CDS as both a tool for conceptual design (see Figure 1), and as a common data base for analysis. Evolution of an advanced spacecraft concept will illustrate this dual usage of Rockwell's Configuration Development System.

II. CDS: The Designer's Media

CDS is a highly flexible "box of tools." There are no rigid procedures for designing a vehicle. The computer does not lead the user in a step-by-step fashion. Instead, there are about 75 commands, with numerous options, which allow the user to develop the concept as desired. These commands are all English words, such as DISPLAY and MOVE.

There are four major command modes within CDS. Primary Mode contains file commands, interface commands, display commands, and analysis commands. Edit Mode contains component parameter, drafting construction, section definition and modification, and scaling commands. Edit Group Mode allows interactive positioning of components by a variety of powerful commands. Data Mode allows entry and modification of component non-geometric data, including weight, center of gravity, and moment of inertia estimation.

Components are created one cross section at a time. The designer can numerically enter cross section points directly, or create cross sections via commands that develop conics, circular arcs, reflexed curves, and straight lines. Another way to create cross sections is by superposition and scaling of circles, ellipses, and squares, followed by interactive point modifications as desired. One can also develop a single cross section, then copy it into new locations and scale or reshape as desired.

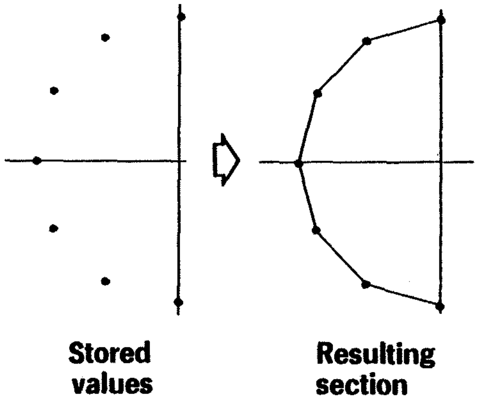


Fig. 2 Surface Point Cross Section

Irregular components are developed and stored as a string of actual cross section points (Figure 2), which are linearly connected into a surface representation. This provides a quick method of defining bodies where exact shape isn't critical, such as the engine, ejection seat, or avionics boxes. For components requiring an accurate surface definition, CDS uses biquartic patch mathematics. For biquartic surfaces, the stored cross section points are used in Bezier-fashion to create an exact mathematic surface (Figure 3). CDS allows development of biquartic patch components using conic cross section inputs, by free-fairing to obtain desired cross sections, or by fitting biquartic curves to an input set of surface points. Biquartic components are used for fuselages, wings, and other smooth surfaces.

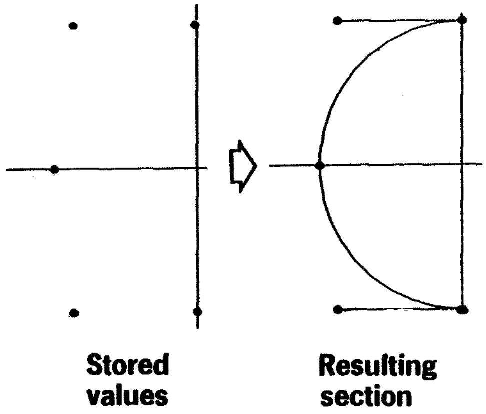


Fig. 3 Biquartic Cross Section

Fuselage development begins with an initial cross section chosen as representative of the desired final shape. This section is copied and scaled from nose to tail by a routine that generates a minimum wave drag body which matches inputs for volume and fineness ratio. This initial body is used while various internal components are arranged, then the body is reshaped to enclose the internal components and meet requirements such as overnose vision. Surface refinement is carried out with a number of commands. One command takes a cross section cut through all internal components at the requested fuselage station, then permits interactive reshaping of the fuselage at that cross section, as shown in Figure 4. Another routine provides automatic surface smoothing. Figure 5 shows automatic smoothing from a circle to a square. Still another routine permits modification of longitudinal control lines. The user selects the command appropriate to the particular problems of the design, and can try several approaches.

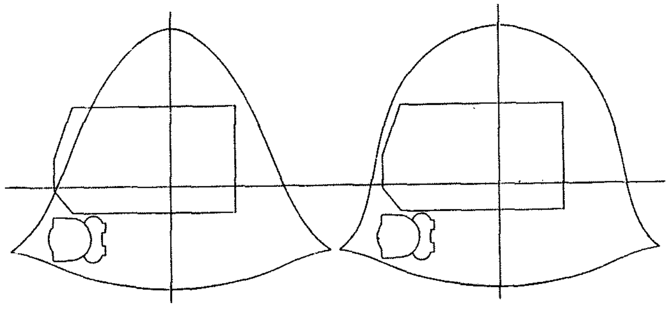


Fig. 4 Cross Section Reshaping

Wings and tail surfaces are created from a selected airfoil section. The user enters area, aspect ratio, and other parameters, from which CDS creates a three-dimensional trapezoidal wing. Then the designer cuts the wing off at the side of the fuselage and performs any required blending or planform modification. As an alternative, a wing developed by Aerodynamics can be passed to CDS for inclusion in a design. After the wing has been developed, fuel tanks, control surfaces, and leading edge devices are created by copying the wing and cutting out the desired surfaces.

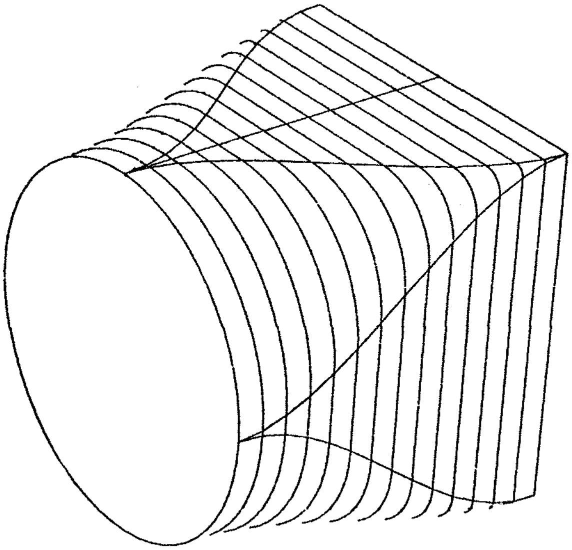


Fig. 5 Automatic Smoothing from Circle to Square

Fuselage fuel tanks are created by copying the fuselage, then cutting out the desired tank area. Fuel tank volumes and centroids can be calculated, then empty and full weights stored in the component data positions for center of gravity estimation.

Landing gear is developed with separate components for wheels and struts in the up and down position which are based upon tail down clearance and overturn angle. Wheels and struts from the component bank are scaled to the proper size, then placed appropriately. Next the strut trunion point is located. The wheel and strut are then copied and rotated into the up position. For concepts in which wheel up position is critical, a special routine allows rapid location of the required trunion axis orientation.

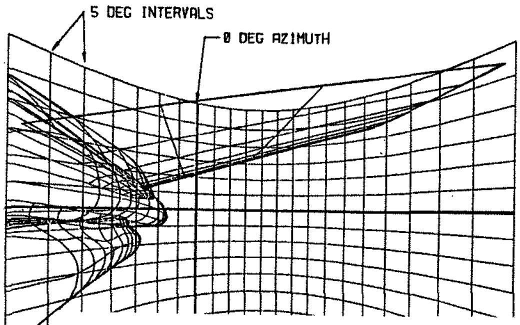


Fig. 6 Wing Root ECM Blocked by a Canard

From the three-dimensional geometry, CDS can immediately create a perspective display from any viewpoint. By selecting the pilot's eye as the viewpoint, vision plots can be created, then a grid of five degree increments can be superimposed on the resulting display. This vision plot capability can also rapidly evaluate sensor blockage, as shown in Figure 6. Here, a canard is limiting the coverage of wing root electronic countermeasures for an advanced fighter. Figure 7 shows the view seen by a pilot on final approach.

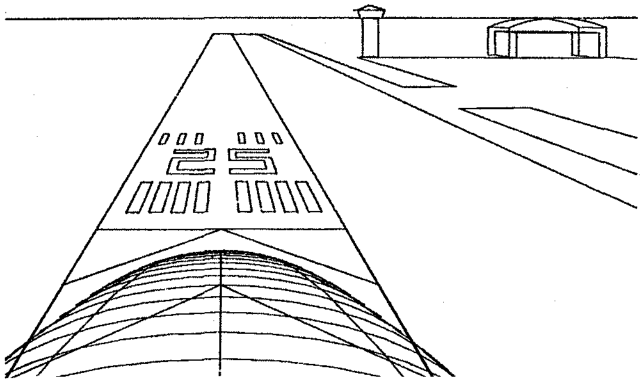


Fig. 7 Overnose View on Landing

One of the potent capabilities of CDS is that of creating command files. CDS can store all user inputs in a special Command File component. When a sequence of inputs has been completed, they can be rerun at any time with a single command. For example, a complicated three-view drawing requires the initial three-view command, commands to request cross section cuts, commands to grid the drawing, commands to letter and label, and commands to develop geometry blocks and the title block. If the user creates a command file the first time he makes the three-view, he can then reuse the commands automatically each time he must redraw the three-view due to revisions. Figure 8 shows an ejection sequence display, created by a command file which loops through a single move command given by the user. This looping capability actually allows CDS commands to be programmed like a higher-order computer language for creation of desired displays.

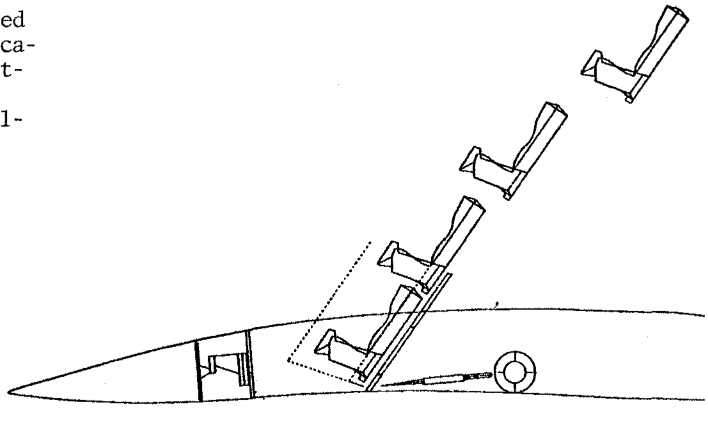


Fig. 8 Ejection Sequence Drawn from Command File

Another capability provided by Command Files is animation. A command file can be developed which sequentially moves and rotates an aircraft following some prescribed maneuver. A 16mm movie camera can be triggered when each frame is drawn via the hardcopy pin on the terminal, creating an animated movie.

III. CDS: The Analyst's Model

CDS provides a wide range of design tools permitting rapid development of new concepts. However, it also provides a complete and flexible geometric model for analysis.

Analysis requires two broad categories of geometric data. One type is actual three dimensional geometry, such as that required to calculate wave drag or for input into NASTRAN. The second type is scalar quantities extracted from geometry. A good example of this is the wing geometric parameters; area, aspect ratio, sweep, etc.

CDS provides both types of data. Obviously, the fully three dimensional component data can be directly passed to analysis models. CDS can also calculate and provide surface derivatives, normals, principle curvatures, and principle directions. Also, the components hold many of the requisite scalar quantities, including the wing data described above. CDS can measure or calculate any other scalar values, which can then be used for analysis.

CDS has both on-line analysis capabilities, and interfaces to analysis programs used by other functional groups. One of the most potent on-line analysis tools is the wave drag calculation and optimization module.

The wave drag optimizer is based upon a far-field Mach plan cut analysis which uses the actual three-dimensional geometry of the vehicle. The optimizer can be applied to any part of the design. For fuselage and nacelle components, the upper center line, lower center line, or maximum width line can be optimized. For wings and tails, either the thickness ratio variation with span or the airfoil thickness from leading to trailing edge can be optimized. After initial unconstrained optimization, the user can rerun the optimizer with selected area constraints such as at the cockpit. CDS can also generate aircraft displays showing wave drag problem areas to permit design-dependent drag optimization, such as tail relocation, which a mathematical optimization may not consider.

Aerodynamic center and lift and moment derivatives are calculated by three-dimensional panelling. Friction drag is calculated by surface strips. The user defines Mach number, transition length, form factors, and flight conditions. CDS calculates and prints drag from each component and the total drag. Methodologies for wave drag, friction drag, and aerodynamics derivatives are documented in reference two.

Weight, balance, and inertias are calculated in CDS on a component by component basis. Each component has weight, center of gravity location, and moments and products of inertia stored in data positions. Component weight can be input if known, or can be estimated by CDS statistical equations. Center of gravity and inertia values can also be input or calculated by CDS assuming uniform density. When these values have been stored for all components, the totals can be calculated. The output includes empty, payload, fuel, and total values for weight, center of gravity, and inertias. Also, the principal axis is calculated. Once component values are stored, components can be moved around and the new totals calculated instantly.

For aircraft design, CDS has on-line estimation routines for cost, mission sizing, tail sizing, and tire and strut sizing. Comparable routines will be implemented for spacecraft design in the near future.

Note that all these analysis routines are intended only to guide the designer in his task of conceptual design. The actual analysis of the resulting concept is performed outside of CDS using methods in the appropriate functional groups. For these detailed analysis, CDS creates geometric interface files which are transferred to the analyses programs. From the biquartic patch surfaces, analysts can instantly extract surface mesh points, surface normals, radii of curvature, and any desired surface derivatives. This permits nearly automatic creation of finite element models and surface paneling. Analysts can also access the CDS data for any scalar quantities normally measured on a drafting board such as lengths, angles, areas, and volumes. Analytical programs currently interfaced to CDS include NASTRAN, APAS (Aerodynamic Preliminary Analysis System Structural Weight Estimating Program), VSPEP (Vehicle Sizing and Performance Evaluation Program), and RASCAL (Rockwell Automated System for Computer-Aided Loft). In addition, CDS can pass geometry to Computervision and AD2000 for detailed part design.

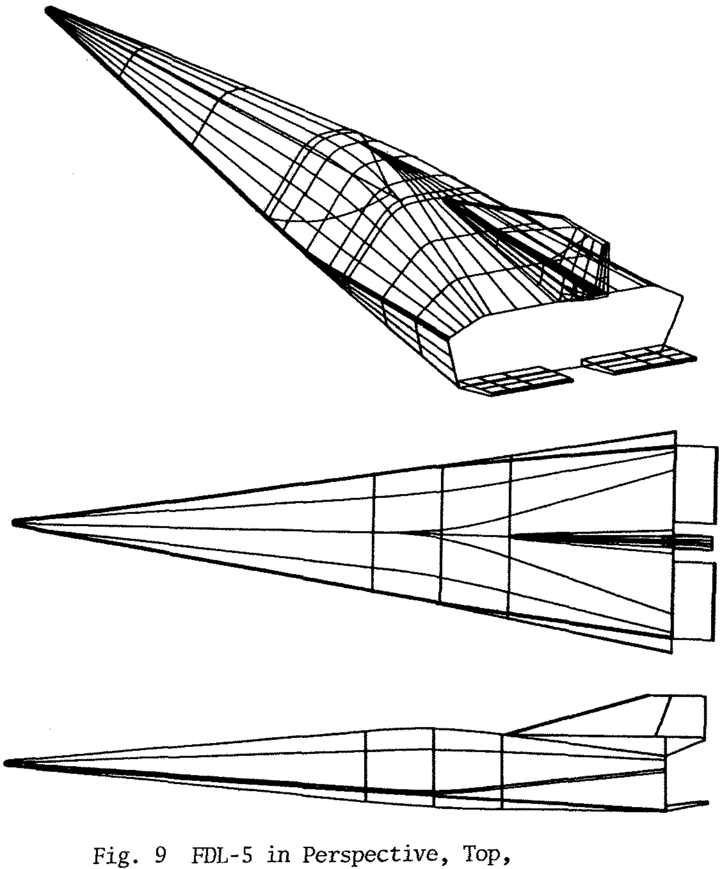


Fig. 9 FDL-5 in Perspective, Top, and Side Views

IV. CDS Example: Spacecraft Design

A recent example of intensive use of CDS was a conceptual design of an earth-to-orbit transportation system performed by Rockwell's Space Transportation and Systems Group. This study required the design and evaluation of several system concepts, each of which was evaluated for sensitivity to technology advancements, providing a technology roadmap for the future. CDS was used for the vehicle design, preliminary integration and sizing, and as an analysis data base.

The FDL-5A lifting body (Figure 9) was initially selected as the upper stage for multi-stage systems. This was modelled on CDS by numerically inputting conic, circular arc, and straight lines to form cross sections (Figure 10). It required 35 patches to model this body. Figure 11 shows cross section cuts of the resulting body. In a similar manner, a vertical tail, fairing, and the body flaps were added. Surface area and volume plots were made and used for mass properties evaluation.

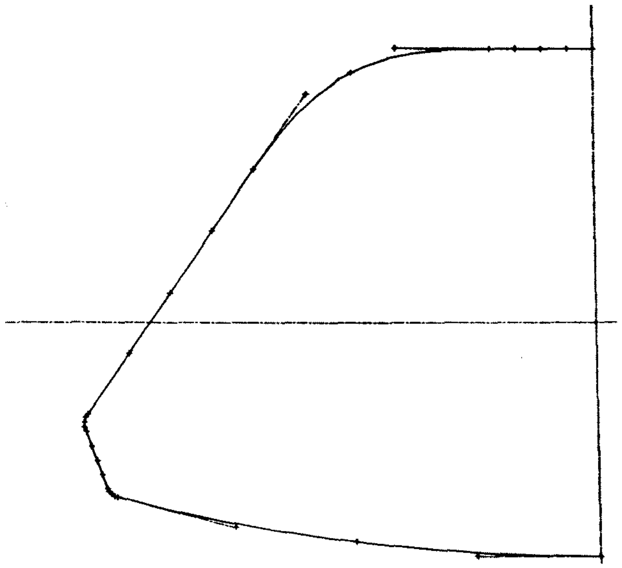


Fig. 10 Quartics Defining a Typical FDL-5 Cross Section

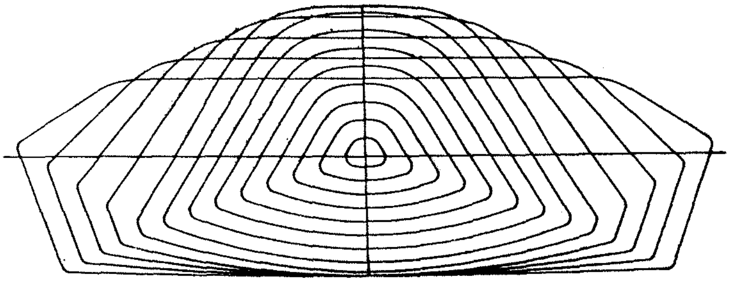


Fig. 11 Cross Section Cuts of the FDL-5

Since growth factors on spacecraft are as much as an order of magnitude higher than for aircraft, packaging of internal components was especially critical. The landing gear was copied from the component storage bank and scaled to fit within the wheel well. A payload was developed as a cylinder of specified dimensions. Crew and equipment compartments were defined to a required internal volume. Integral propellant tanks were developed to conformally fit the fuselage mold lines with a specified offset clearance (Figure 12), and were checked for required volume. The engine was modelled from geometric data supplied by the manufacturer (Figure 13).

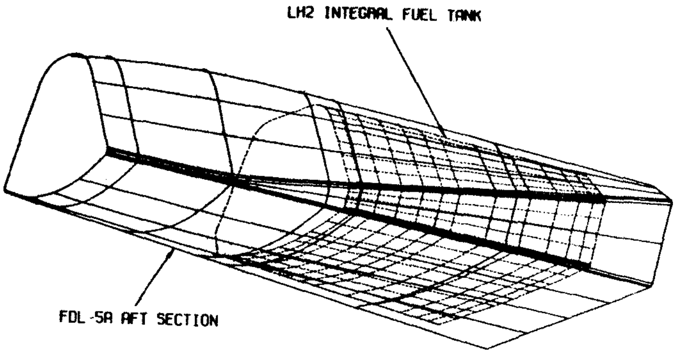


Fig. 12 Integral Propellant Tank

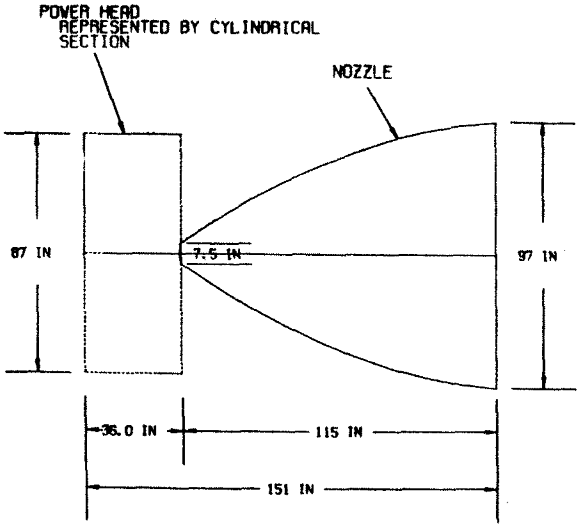


Fig. 13 Engine

Weights were input for all components, and the center of gravity was calculated. This fell outside the allowable range for the FDL-5A. Several attempts at component rearrangement were unable to resolve this problem, so a derivative vehicle, termed the FDL-8, was substituted (Figure 14). The internal components were rearranged to fit this body. The center of gravity was rechecked and found to fall within acceptable limits.

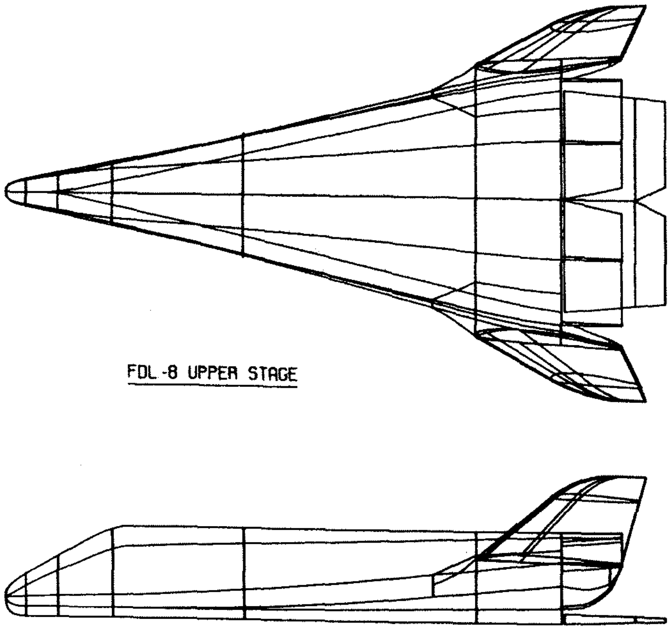


Fig. 14 FDL-8 Vehicle

A critical driver for this concept was the available propellant volume as a function of vehicle length. This was evaluated on CDS by varying fuselage length, redesigning the internal tanks, and calculating volumes for four alternate configurations (Figure 15).

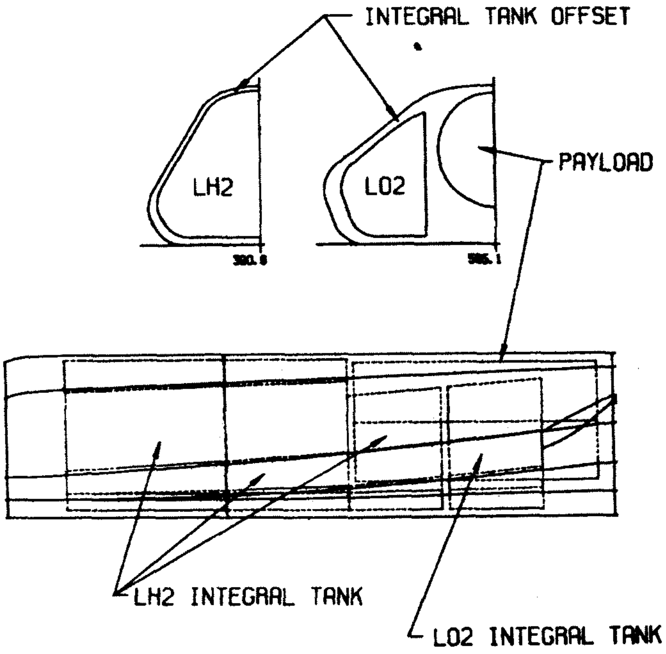


Fig. 15 Installed Propellant Tanks

A second critical driver was payload diameter. Again, CDS was used to design the alternatives, determining the required vehicle length to contain different payloads.

A third driver evaluated was the engine packaging. Alternative concepts were developed with varying numbers and sizes of engines, allowing an emperical relationship to be developed for optimization.

In essence, CDS permitted a parametric description of the orbiter based on constraints from propellant volume, engine size, and payload dimensions. These geometric functional relationships were then used by analysts to evaluate over 120 alternate concepts. 20 of these were then designed on CDS to verify the applicability and correctness of the parametric model. In each case, the parametric model predicted the integrated vehicle size. With this confidence established, analysis was able to compare concepts and select the best vehicle, shown in Figure 16.

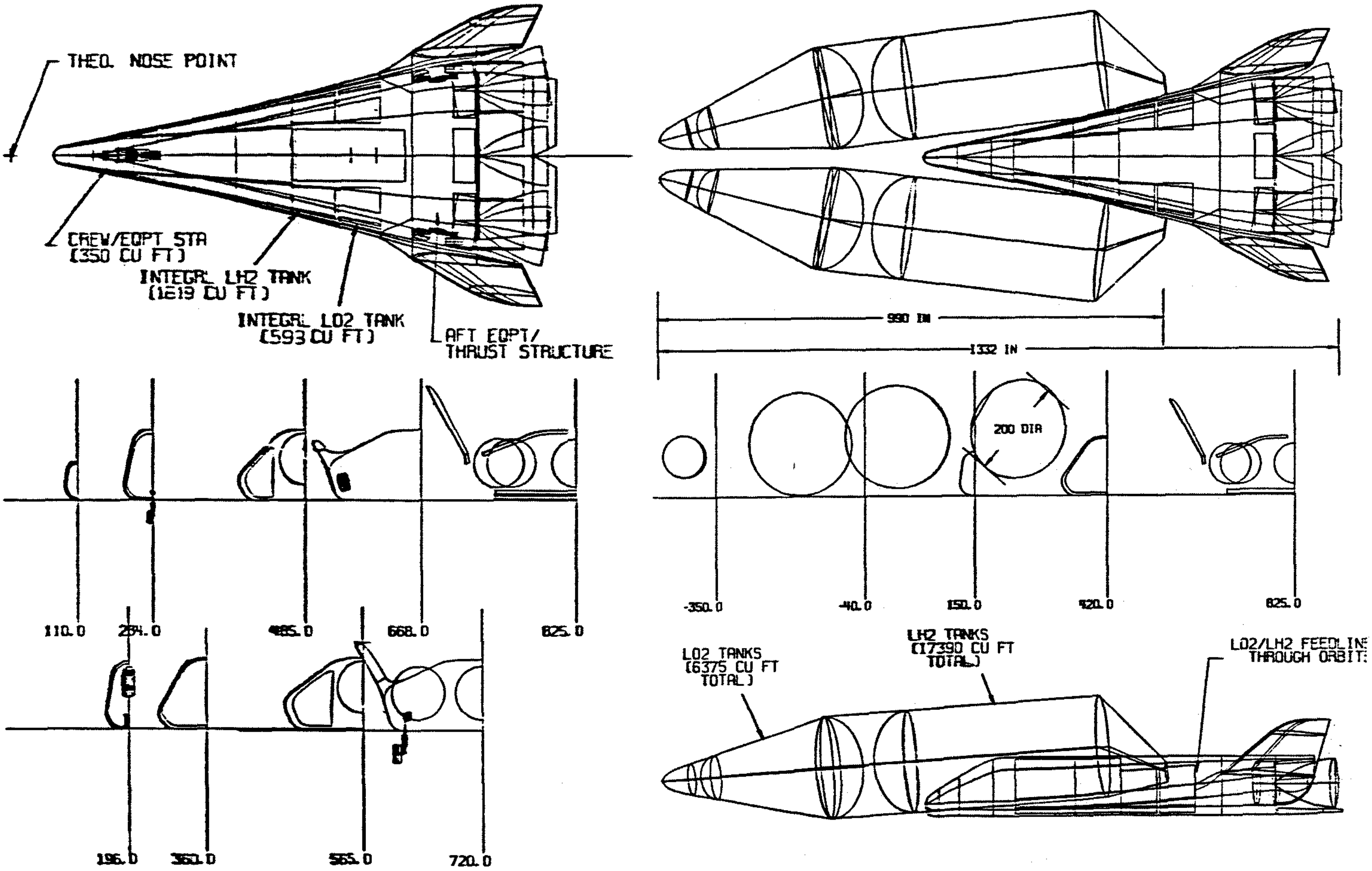
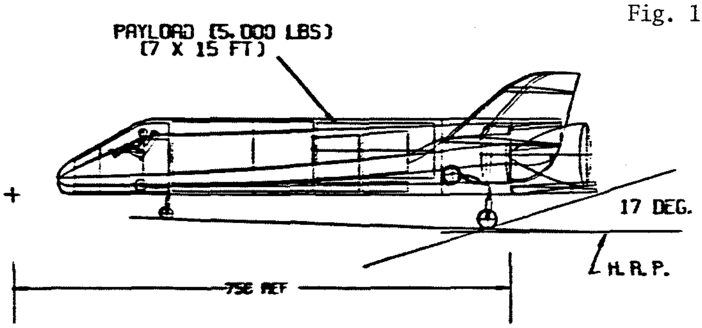


Fig. 16 Selected FDL-8 Concept



V. CDS Implementation

CDS is currently being used by Rockwell's North American Aircraft Operations (Los Angeles, California and Columbus, Ohio) and Space Transportation and Systems Group (Downey, California). It is also in regular use at Naval Air Systems Command (NAVAIR) in Crystal City, Virginia. The FIMB organization at Wright Patterson Air Force Base is running CDS over phone lines, and will receive CDS this year as the geometric design module of the IDAS (Integrated Design and Analysis) system being developed by Rockwell under contract. Satellite communications are being used to allow SAAB in Sweden to access CDS as a part of the JAS Fighter program.

It takes about one month for a new user to attain reasonable competence on CDS. This includes a one week training course and three weeks of supervised use. The training course consists of six hours of lectures and 10 hands-on tutorial sessions contained in the Users Manual (Reference 5). The tutorial sessions introduce the major CDS command options, then lead the trainee through design of a simplified aircraft. Figure 17 shows a helicopter created by a designer at Naval Air Systems Command after about three weeks of experience on CDS.

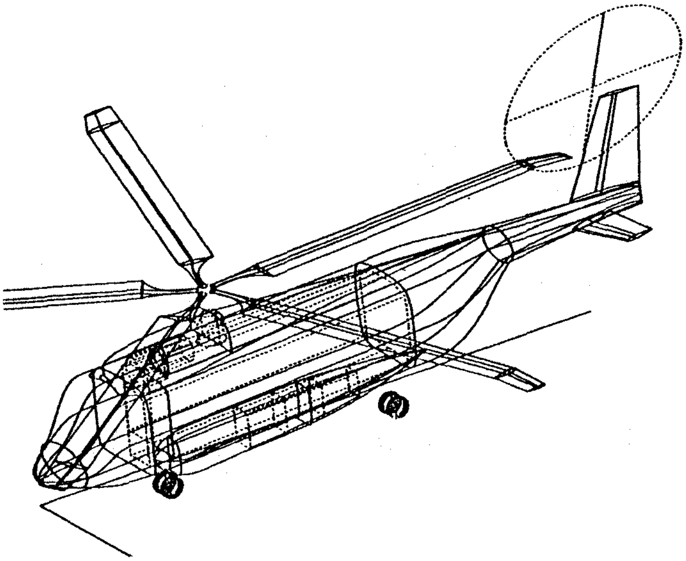


Fig. 17 Helicopter Developed by a New User

While substantial effort has been devoted to simplify the CDS command language, CDS is nevertheless a substantial and sophisticated program with over thirty thousand lines of code. Most new users go through a period where they feel like the poor fellow in Figure 18.

After four years of production use of CDS, substantial productivity improvements have been verified. For the average or occasional user, an overall productivity ratio of about four to one is attained. Experienced users can expect an average improvement approaching ten to one, and certain tasks such as redesign can experience twenty to one improvements. However, these improvements usually result in more iterations leading to a better design, instead of direct cost reductions. On a recent fighter design, wave drag was iterated and optimized over 250 times before the first conceptual layout was finished, resulting in a 40% wave drag reduction over the previous concept.

On the spacecraft design described above, several weeks were saved in the early discovery of the center of gravity problem with the FDL-5A. Development of the 20 configurations took about 10 weeks on CDS, whereas the same level of detail designed on a drafting board would have taken more than a year. Other savings were obtained by using CDS perspectives as underlays for artist's concept paintings.

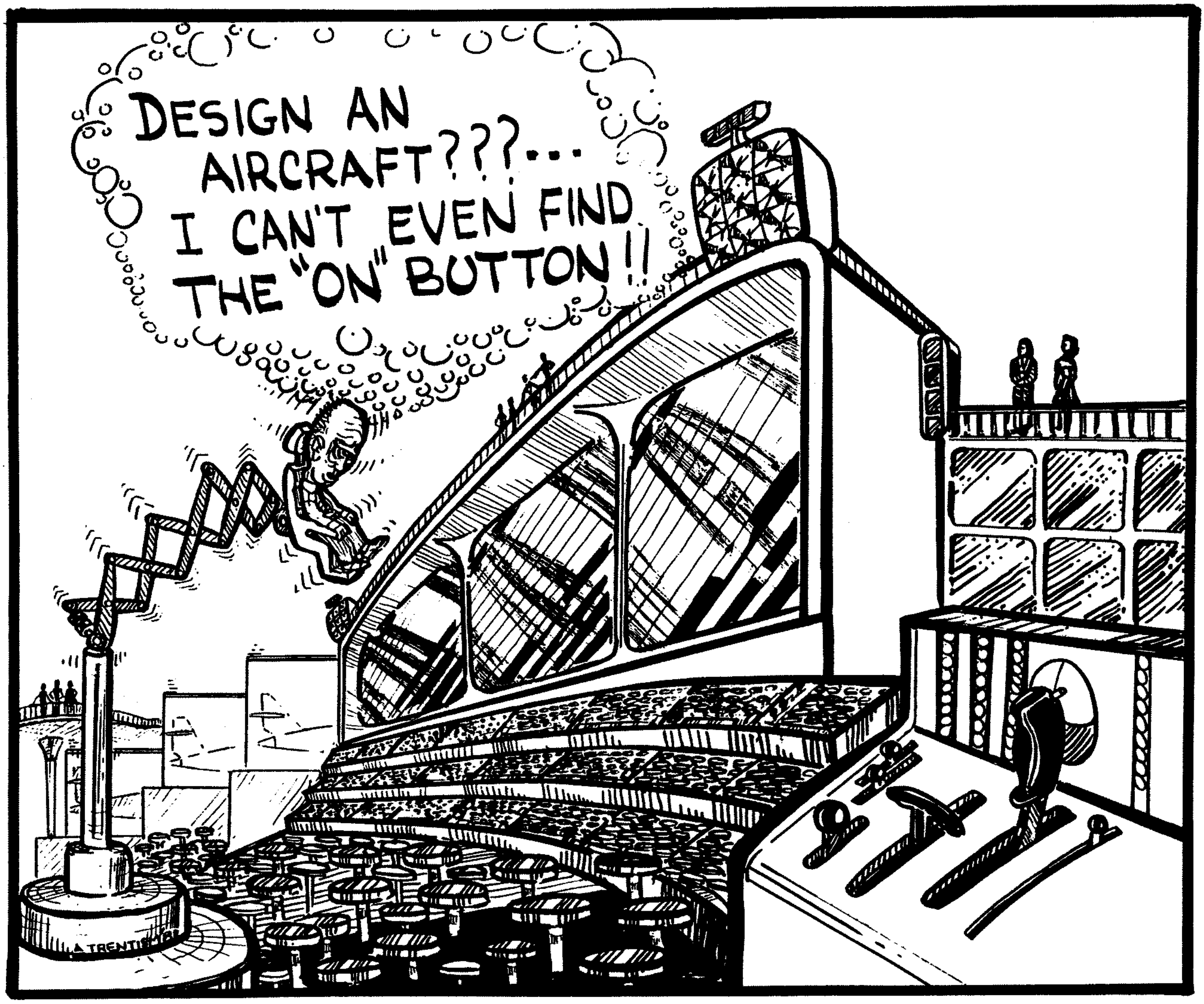


Fig. 18 The First Session on CDS

VI. Summary and Conclusions

Rockwell's Configuration Development System (CDS) is a powerful and flexible interactive graphics program for the conceptual design of aerospace vehicles. It offers as well a fully three-dimensional geometric data base suitable for use by analysis programs. Thus, it is truly both the designer's media and the analyst's model.

Experience with CDS at Rockwell's aircraft and spacecraft design organizations has verified the substantial productivity improvements attainable with such a system. However, as others have reported (reference 6), this productivity gain tends to be used for more iterations rather than for reducing throughtime. This results in more optimal designs at an earlier stage. The ultimate results of interactive conceptual design will be improved cost-effectiveness in the 1990's-generation aerospace vehicles.

Acknowledgements

The following Rockwell personnel have made signigicant contributions in the planning and development of CDS, and their effort and advice are greatly appreciated: James Kojima, James Berry, Mark Killian, Herschel Owens, Steve White, Jim Klimmek, Robert Maier, Arnold Knudson, Richard Child, Kenneth Dunn, Erick Sturcke, Ellwood Bonner, Paul Kimball, and Willard Clever.

Also, thanks is given to Marty Trent for the artwork in Figure 18, and to Steven Zalesch of NAVAIR for Figure 17.

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