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SHORT COMMUNICATION

CAD/CAM Design of Trunnion Mount

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ABSTRACT

The computer-aided design (CAD), computer-aided manufacturing (CAM) of a 3-D trunnion mount located on the intercasing housing of a gas turbine engine is described. The mount carries load and thrust, hence stress-concentrating locations, like sharp edges and corners must be avoided. A program involving CAD, CAM and post-processing CAD surfaces for tool paths has been developed. Preliminary machining of a scrap aluminum piece that verified the program is described. This method is applicable to a wide variety of proprietary packages.

Keywords: Trunnion mount, CAD, CAM, gas turbine engine, fillets, CAD/CAM, software development, engine casing, filleting, 3-D modelling, intermediate tool path, numerical control technology

1. INTRODUCTION

The Gas Turbine Research Establishment (GTRE), Bangalore, has embarked on an ambitious time-bound programme of manufacturing several prototypes of aero and marine engines. Efficiency and accuracy are of utmost importance. CAD/CAM and numerical control technology (NCT) for complex features minimise operator's error. Another fabrication method is superplastic deformation forming and diffusion bonding–either separately or simultaneously. However, gas turbine structures more than a few millimeter thick are difficult to process in superplastic deformation. Present-day limitations for superplastic deformation using IN718 are around 2-3 mm, whereas the typical casing thickness is about 6 mm.

The trunnion mount on the engine casing was chosen for this project. The engine is supported on two such mounts located on the intercasing ring. The blueprint for the trunnion mount reveals certain interesting features: (i) mount sits on an intercasing cylinder with two beveled steps, (ii) surfaces of the trunnion mount are of various curvatures and these meet the top surface at different angles. The surfaces should blend smoothly at the corners, apparently the feature is difficult to render and machine properly.

The blueprint consists of various sectional drawings, and the present CAD project consists of forming a 3-D design from the 2-D sections and unifying these sections to form an acceptable rendering of the original drawings. Accuracy in machining is essential since specific radii of curvatures occur.

2. CAD/CAM PROGRAMS

CAD/CAM programs can blend surfaces by

(a) Forming an intermediate patch using only intersecting adjacent boundaries
(b) Forming generators for a lofted surface
(c) Forming fillets, which adjust automatically to the boundary conditions.

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The last option is available in some commercial packages like CAMAND and IDEAS. Others include ANSYS and AUTOCAD. The advantage of CAMAND is that both CAD and CAM modules are accessible on the same screen. Additionally, many CAD programs like ANSYS, IDEAS, and AUTOCAD can form basic surfaces like patches, lofted surfaces with generating curves in u direction, and ruled surfaces with mesh generators in u-v directions. However, automatic creation of 3-D fillets (in contrast to 2-D fillets) with adjustment for varying curvatures at the extreme boundaries was not available on some commercial programs at the time of this project. Subsequently, the CAMAND program has been acquired by IDEAS with options to do CAD with IDEAS and simulation and machine tool programming on CAMAND. For automatic filleting of two surfaces, certain systematic steps must be followed in the 3-D modelling. These are:

(a) Selection of local origin

(b) Generation of primary planes

(c) Forming suitable control curves and fillets

(d) Generating the base beveled ring

(e) Editing fillets and forming patches and lofted surfaces. (Warping and cross-over convolutions may occur and must be avoided).

Available RAM memory may be limited. For this, the number of U-V generators can be selected to optimise time and accuracy of the simulation*.

It is to be emphasised that the design involved is not initial design–rather the rendering of 2-D line drawings to a 3-D CAD rendition. In this sense, it is a 2-D to 3-D extension of the design and unification of sectional drawings to a 3-D design. During this process, some changes occur, eg, in the corner joints as discussed since the shape functions obtained during automatic filleting may be different from those envisaged by the original rendition.

3. CAD MODELLING & RENDERING

3.1 Formation of Primary Surfaces

(i) Sections GA [Fig. 1(a)], KK [Fig. 2(a)] and KD [Fig. 2(b)] give overhead, side and frontal views, respectively. The front surface forms at a radius of curvature of 25 mm., while the curvature of the side surfaces is 30 mm after initially meeting the top plane at 10° from the vertical.

(ii) The view at drawing section SS (J16) in Fig. 1(b) gives the profile for the cylindrical surface. The origin is selected to accommodate the diameter (669.8 mm to 669.9 mm). The primary cylindrical surface then forms by rotating the profile about an axis through the origin. Subsequently, a number of secondary origins and axes are required; the software must keep track of these. The profile has bevels of 5° and 7° 45′, [Fig 1(b)].

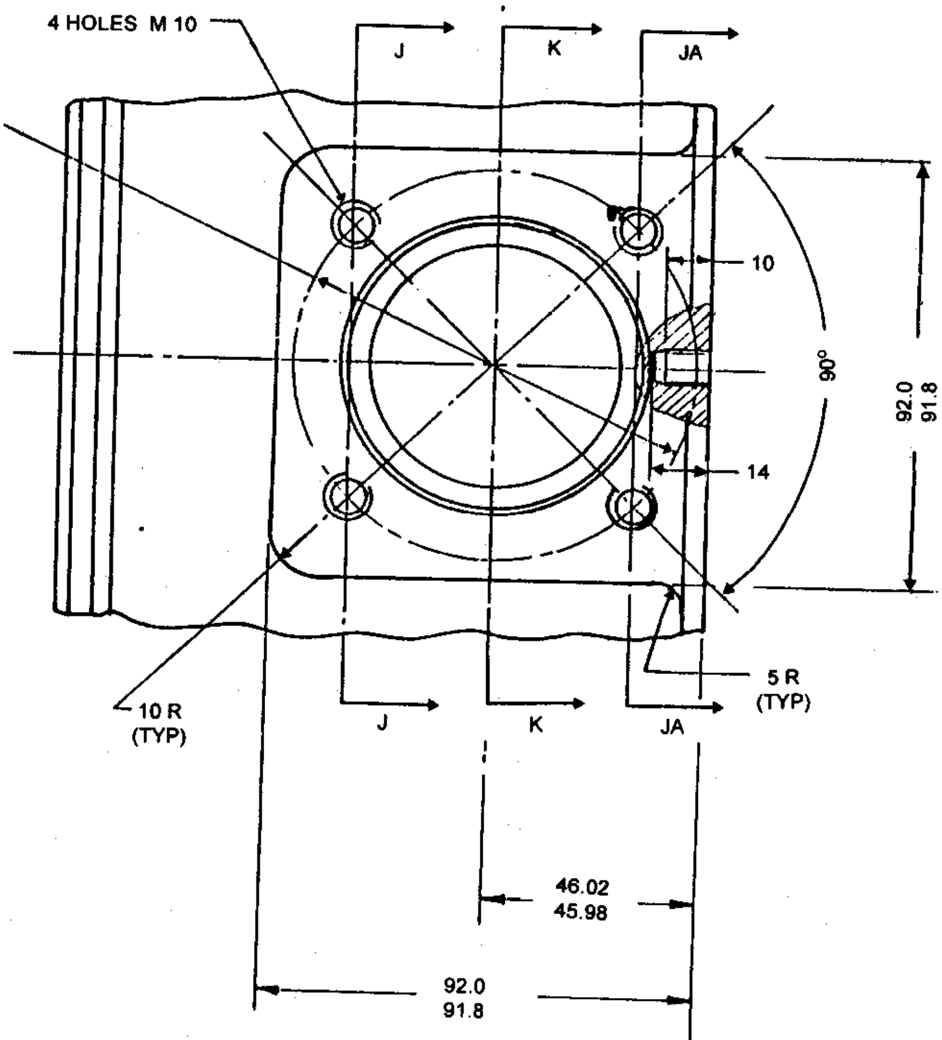
(iii) The overhead curve forms as a 2-D curve. The corners are then filleted as 10 mm radii curves automatically (2-D fillets).

(iv) Primary planes along the sides are then easily constructed by dropping lines at required angles to meet the base cylinder The primary plane which forms then intersects the base cylinder, and the line thus formed is marked (Fig. 3). These intersection lines must be smooth and made continuous by attachment and trimming whenever formed via separate CAD constructions. They are the control lines. The same procedure applies to the front and sides, except the corners where a 10 ° slope decreases to 0 ° and the radii of curvatures change from 30 mm to 25 mm.

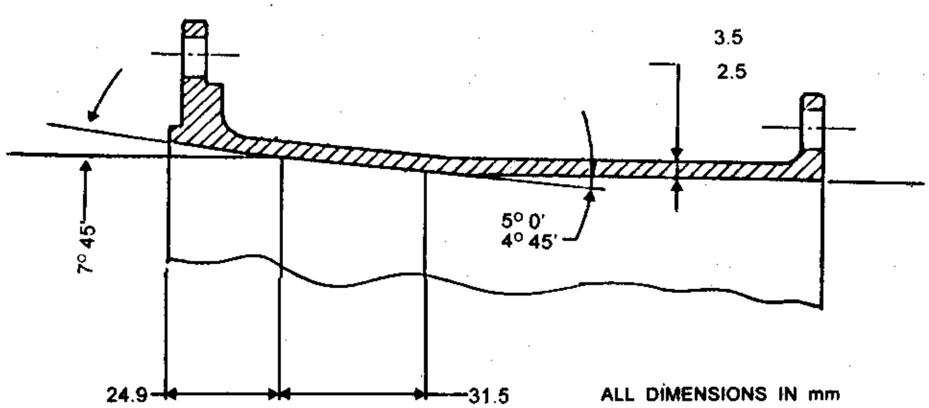
4. CAD OF CORNER SURFACES

The corner surfaces require automatic filleting with skill and forethought. All software packages do not have the capability to form a surface given merely the radii of curvatures at the outermost generators. The curves are restricted to the 10 R corners on the overhead cross-section planes. Along the corners, equally spaced points

* The project used is an IRIS machine with 16 Mbyte RAM, 12.5 MHz processor, and 170 Mbyte hard disk. The architecture of the IRIS and its processor was specially designed for graphics and performed very well at that time.



(a)



(b)

Figure 1. Formation of primary surfaces: (a) trunnion overhead view (GA), and (b) intercasing base ring profile (SS J16)

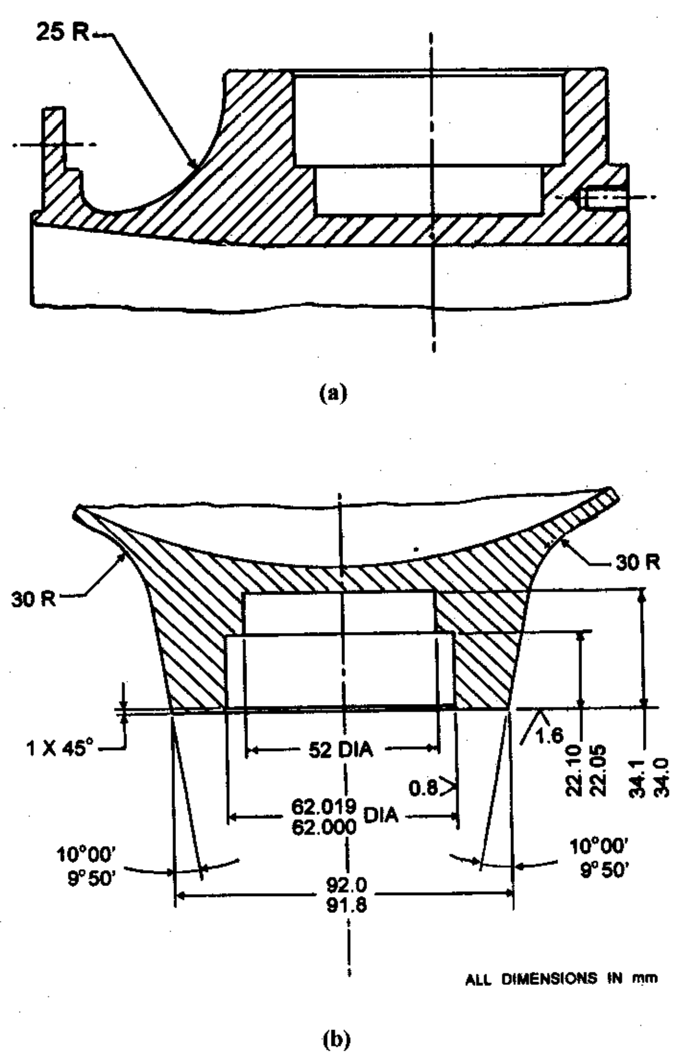


Figure 2. Side and front views illustrating varying curvatures (views KK, KD).

at 15° are selected. At each point, a local coordinate system is formed and a generating ray dropped to the base at varying angles. The projecting angle is varied from 0° to 10° depending on the position of the ray along the curve at the top.

5. FILLETING OF CORNERS

Now, a lofted surface is constructed from the dropped generators. The intersecting curve between the new surface and the beveled base cylinder can be formed. The line of intersections of all the new primary surfaces is smooth if the design is error-free, and forms the control curve after suitable trimming. Filleting is necessary to form the corners with different radii of curvatures at various sections. The trunnion mount's front face, and sides are also formed by the fillet operation (where the radii of curvatures were constant). Filleting occurs in the following three stages:

(a) Side surfaces of constant radius 30 mm

(b) Front surface of constant radius 25 mm

(c) Corners with variable radii and intersection angles.

The filleting option is available in some software** packages, including CAMAND 3, and CAMAND 5 with enhancements. The parameters used by the program may vary. In CAMAND, the control curve, orientation of normal, number of fillets, and selection of secondary origins are required. Additionally, the filleting operation is not always successful, depending on the smoothness of the primary surfaces, control curve and location of primary and secondary origins. Variable filleting is an intricate and difficult task. Programmers may prefer to design fillets manually and then form lofted surfaces. Also, after formation of automatic fillets, some near the corner junctions must be edited to avoid crossover and warping of the resultant lofted surface[1,2].

After forming the corner surfaces, some patches remain on the top due to fillets forming at different heights. Patches on these locations are created using edge curves as basic curves. Patch options usually require four-edge curves that intersect in respective corners (Fig. 4).

5.1 Specific Issues Addressed with CAMAND 3 versus CAMAND 5

Earlier, the same exercise with CAMAND 5 was attempted prior to the present exercise at the Electronics Research & Development Establishment (LRDE) without success. The main difficulty seems to have been the formation of the filleted surface at the corners, in the final CAD rendering. Specific issues addressed here were:

- Filleting
- Formation of surfaces
- Joining with attach options and patch forming
- Ability to simulate entire surface machining in one go.

** CAMAND 5 and later versions have additional features specific to filleting and surface formation.

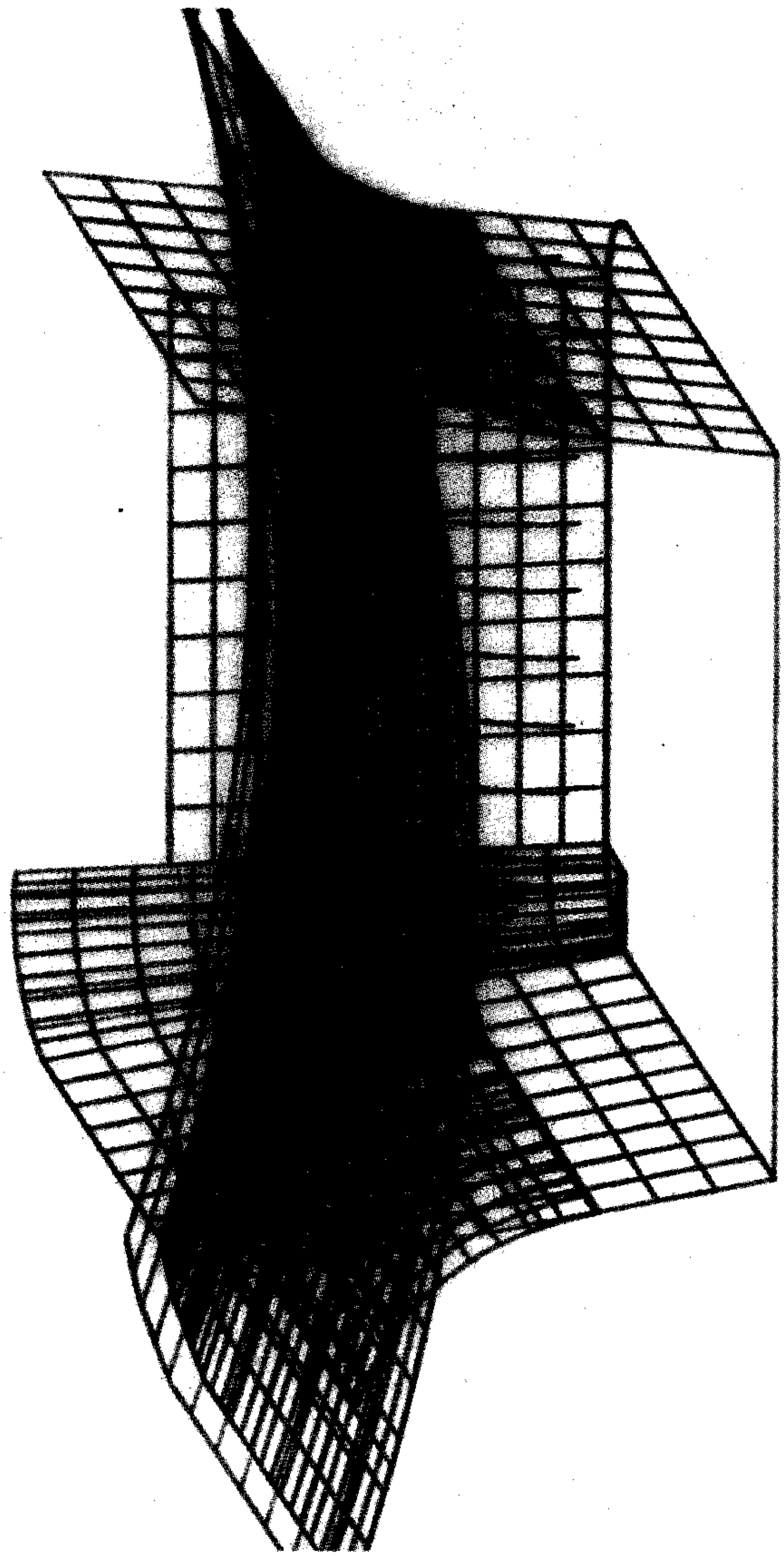


Figure 3. Primary generating planes (prior to trimming) illustrating generator lines and fillets

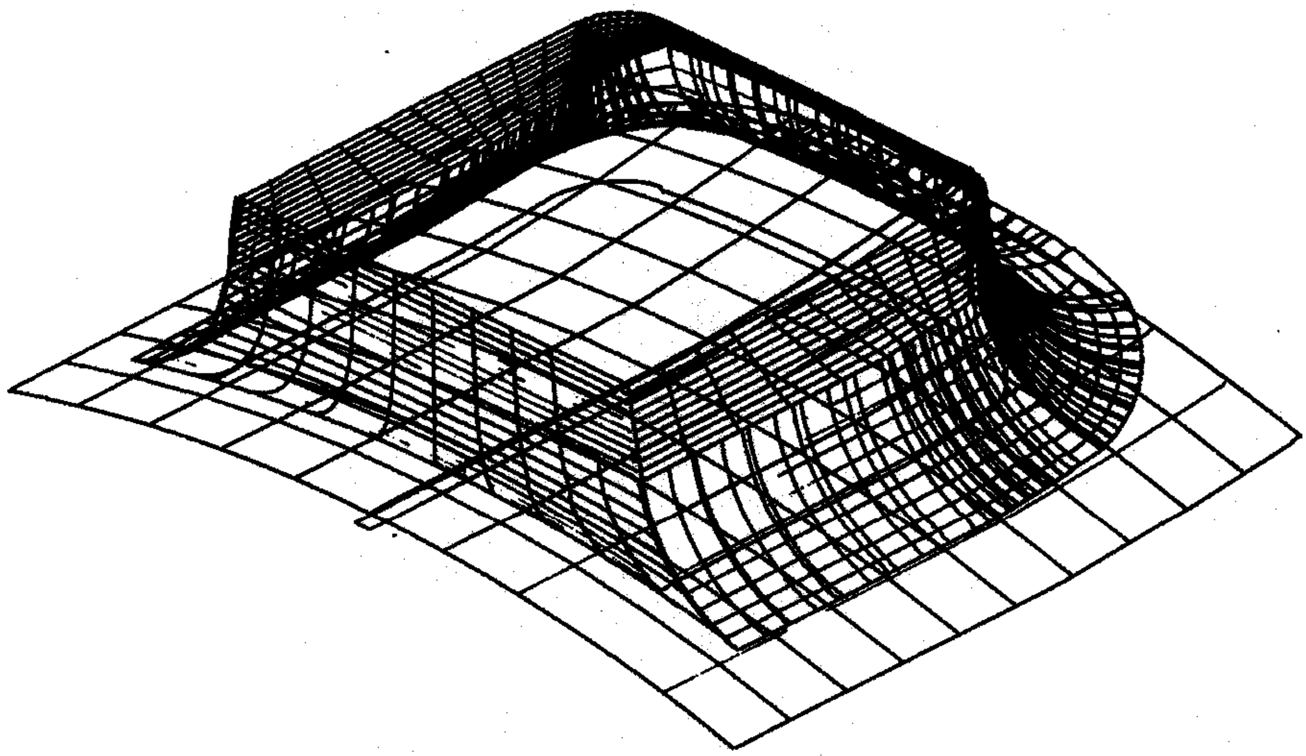


Figure 4. Trunnion mount model after trimming of planes (patches and corner construction visible)

Filleting

- CAMAND 5 has a number of advanced options for the fillet surface design. Some of these are the use of shape functions and blend surface options (for shaping the corner fillet surface). However, these attempts were not successful to the best of our knowledge – whereas the control curve method described here worked in generating fillets. The fillets needed to be edited at the junctions of the surfaces since some formed irregularly at the extreme ends. Trimming and extending the fillet surface was not automatic in CAMAND 3, whereas CAMAND 5 had trimming features and provision for shape functions in fillet generation and surface formation.
- Other features of CAMAND 5
  - Advances in the numerical control (NC) machining simulation–actual machining simulation on screen– is possible, whereas earlier, the intermediate tool path (ITP) file had to be converted and ported to the NC machine and then viewed on the console there.
  - ITP machining features, linear interpolation modes, and interference checking recalculations are made possible. Five-axis post-processing is also optionally available. Several menus are available in addition, for example curvature calculation, slopes and angular deviation. The NC module of CAMAND 5 has additional menus for cutters, shanks and holders.

Formation of Surfaces

- With regard to CAD, CAMAND 5 has the following additional features over CAMAND 3:
  - The drafting part of CAD in CAMAND 5 has ellipse and conic section creation among others. The solid modelling part includes shape functions to form the blend surface, i.e., between two existing separate surfaces, or between the edge of an existing surface and a curve, or the edges of two existing surfaces that pass through a curve.
  - Provision exists for splitting a surface and soft attaching surfaces, trimming and

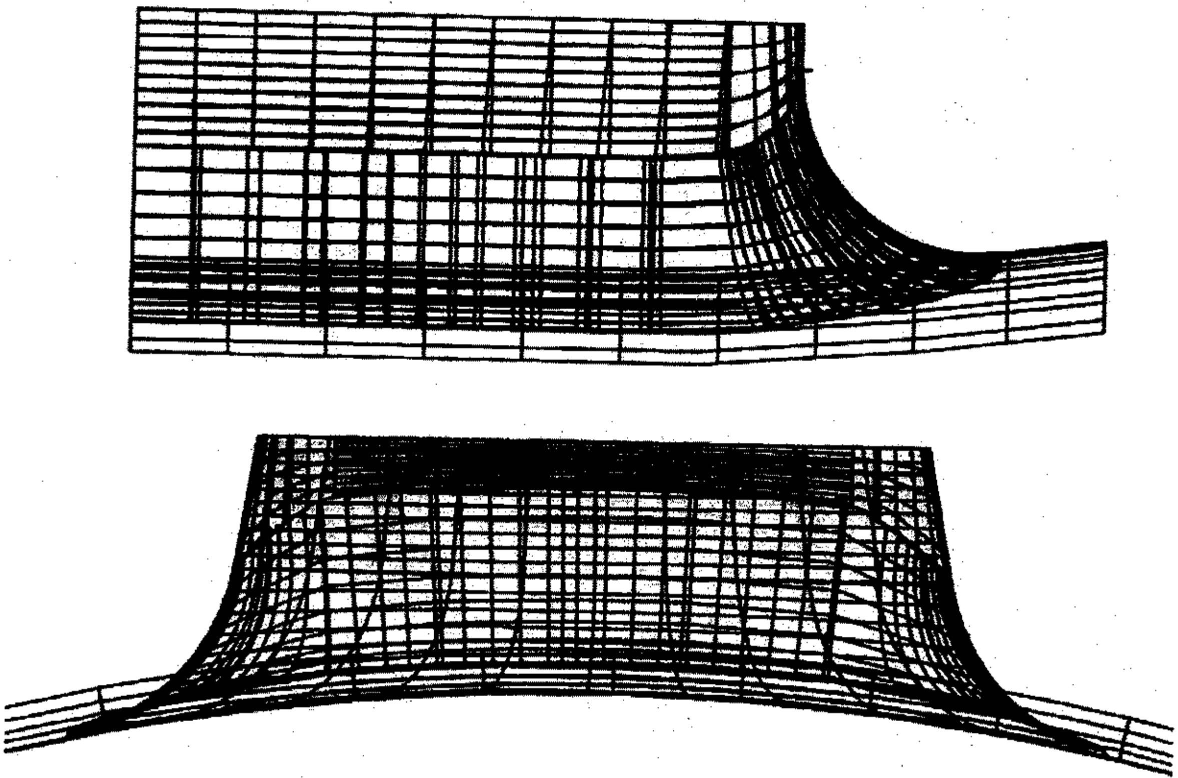


Figure 5. CAD/CAM model views for the side, front as input to the NC module

extending and forming three-sided patches. The trim surface option in the fillet operation is added in CAMAND 5, whereas in CAMAND 3, manual editing of the fillets and then formation of a lofted surface was done.

Numerical Control Programming

- Preparation of machinable surfaces
- The advantage of a program, such as CAMAND lies in the integration of CAD module and NC module (the CAM part) (Fig 5) so that

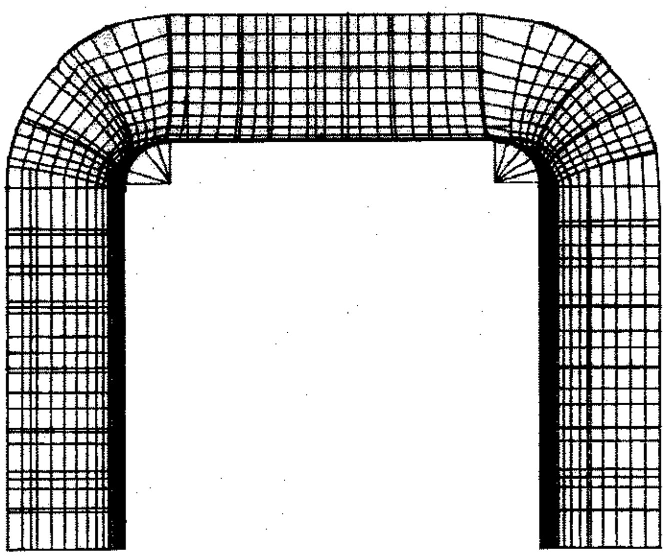


Figure 6. CAD/CAM model view for the overhead model

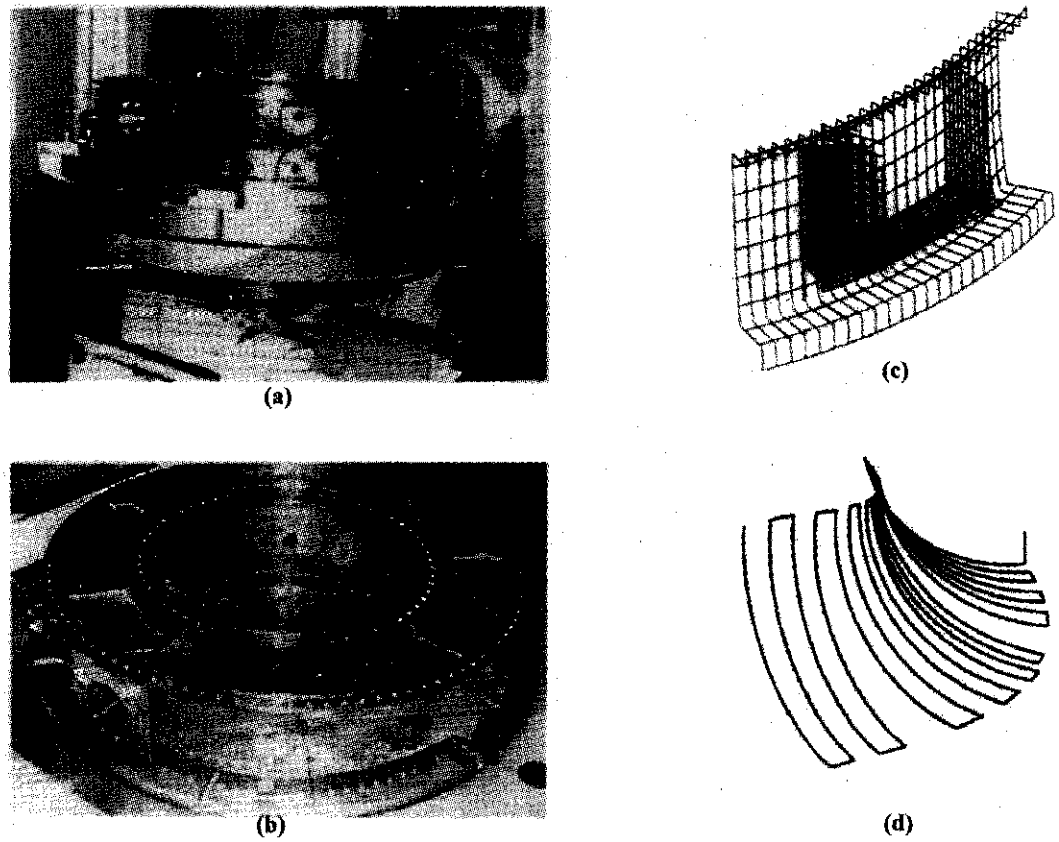


Figure 7. Photos (a) and (b) showing intercasing ring with basic unmachined trunnion block along with CAD drawings (c) and (d) for the main block and corners.

the ITP program can be developed *in situ*. Such an ITP is developed by a time consuming tool bit traverse over the surface generators and generation of cordinate files in the ITP module. Final NC program need not be written manually, rather automatic process using machine-specific translators is used on the ITP files to obtain machine-recognisable NC program.

- CAD surfaces prepared in the above described ways can be post-processed for machining by NC machines. However, the generators on the surfaces will need to be translated to NC machine code and to do this, a subsequent operation or simulation is needed on the CAD console using the CAM module (Fig. 6).

Joining with Attach Options and Patch Forming

- Tool cutter paths need to be established and surfaces on the CAD model are to be prepared accordingly. The various adjacent patches need to be connected using the soft attach option to avoid restarting on separate patches and to save time in the tool motion. Also the orientation of normal must be carefully done so that the under surface is not machined inadvertently.

- The tool path programme (TLP) is then obtained from the ITP files applying a machine-specific post-processor (eg, SINNUMERIK translator or post-processor). SIN3MMOD is used as it is compatible with the NC machines provided by HMT and DECKEL.

- Generation of cuts.

Ability to Simulate Entire Surface Machining in One Go

- The basic feature of most NC software programs is in defining tool path trajectories. In the present project, a ball cutter of 5 mm diameter was used. Also of importance is the size of the scallop created during one pass and the number of lines on the surface (U-V lines) so that the jerk to the next line (either U or V in x or y direction) is small and does not damage the tool bit. More passes will give a finer finish though consuming more time. A skilled machinist can always do finishing later. Typically, two hour was sufficient for simulation, on the IRIS machine. For the part discussed here with dimensions 92 mm on a side and 100 passes, about 1mm per cut occurs as a gap between each pass. The procedure should cause no problems with a 5 mm cutter.

6. POST-PROCESSING

After completion, a message appears on the computer screen and the file must be saved for post-processing. Graphical plots can be obtained using a laser or a pen plotter with appropriate interface. The CAD/CAM file containing the machine coordinates for the tool bit is known as the ITP file. To translate this for use on any NC machine, the file must finally be transferred into machine format. A SINNUMERIK system for a DECKEL-type machine (HMT-KTM make) was used. The SINNUMERIK system uses X, Y, Z coordinates and rotational degrees-of-freedom. To conserve memory, the final machine program has to be split into portions, and the tool restarted after each portion with some overlaps[3,4].

7. RESULTS

NC Machine Operation

The program was applied on a KTM machine using a scrap AI slab. A prior simulation on the machine console showed that the tool paths were smooth and the tool bit did not jerk or cut across the piece. Sometimes the swing-through may cause damage. Machining of phantom surfaces was also checked (when prior CAD profiles remain in the memory and are not erased on editing the surface). The machine origin settings were also checked and machining proper started.

Figure 7 illustrates the finished part. As the sides and the front face were machined separately, some roughness showed up where the overlaps occurred as machine origins were reset. Some porosity was also observed. Further machining tests may involve resetting machine origins and using better material. Also, continuous machining may give fewer irregularities due to errors in origin resetting between jobs, when other high-priority jobs force interruption of the experiments.

8. FURTHER UTILISATION OF THE TECHNOLOGY

The NC programs developed in the above exercise were applied in the fabrication of the K1 variant of the *Kaveri* engine. Subsequent prototypes used some modifications as the casing profiles continue to undergo change with a view to streamline production time and weight reduction. The casing profiles are now being redesigned with regard to possible SPD and diffusion bonding producibility.

CONCLUSION

The paper describes some of the essential features of numerical design development and machine design processes using CAMAND 3. CAMAND 5 with some additional features was available at an additional cost of Rs 20 lakhs. Procurement would have created delays due to red tape. However, using some generic design operations it may be possible to substitute for advanced design features incorporated in more advanced versions of the software. This is particularly true in case of fillet surfaces with variation in edge curvature where straight forward patching or lofting doesn't work.

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Dr Rahul D Basu obtained his MS (Superalloys and Composites) from the University of California in 1973. He was awarded PhD by Eurotechnical Research University in 1991 and subsequently studied 'frecking in IN718 and convective boundary conditions'. His areas of research are: Diffusion bonding studies on superalloys with low-cost non vacuum equipment and development of low-cost CAD and CAM software. He joined DRDO at the Gas Turbine Research Establishment (GTRE), Bangalore, in 1978 as Sci B. He worked as Principal Investigator of AR&DB project on rotor dynamics and squeeze films from 1980-84. He established a rotor dynamics-squeeze film rig to investigate rotor stability at supercritical speeds. From 1985-91, he took advance course in computational field dynamics in artificial intelligence and computer graphics, in USA.