# EXPERT SYSTEM FOR LAYOUT OF A FLAT PATTERN OF A WAFFLE STRUCTURE CONTAINING BOSSES

Paul Slysh
General Dynamics
Data Systems Division — Western Center
P.O. Box 85808, San Diego, California 92138
(619) 576-5272

## ABSTRACT

A microcomputer-hosted code, CVEX7, has been developed that generates a CV EXECUTE file that, in turn, produces a flat pattern layout of a waffle structure containing bosses. Inputs to CVEX7 can be provided interactively or through an interface with a CAE (Computer-Aided Engineering) code that generates structure definition parameters. The inputs include rib widths, spacings, skin thickness, and shell overall geometry at its centroidal planes. This paper describes the algorithms implemented in CVEX7. Results of test cases and examples are presented.

## INTRODUCTION

The capabilities of some CADDS 3 commands are exploited in this implementation of an expert system for the automatic generation of a flat pattern layout of a waffle structure containing bosses. The CVEX7 expert system developed for this purpose could reduce operator time needed to produce such layouts by at least two orders of magnitude. In addition to saving time, it also produces a fully commented execute file from which all the dimensional features of the layout can be easily identified.

Since CVEX7 is hosted on a microcomputer, the execute files can be generated and examined off line to CV.

## DESCRIPTION OF EXPERT SYSTEM

The system is described with reference to a simple cone containing a single boss (Figure 1). Assuming that the cone is of an integral waffle construction having constant rib widths, Figure 1 lists all the menu input items required by CVEX7 to create an execute file for the flat pattern layout of the cone. This includes the waffle pockets and the boss OD blended into waffle pocket pattern with the menu-selected fillet radii.

### Waffle Pocket

Figure 2 shows the geometry of a flat pattern waffle pocket including designations used for nodes, inflection points, fillet centers, and rib widths. Here the half rib widths in each pocket, C1 (J, K) to C4 (J, K), are indicated as variables that can be generated by other structural analysis programs or user-inputted.

The waffle pocket in Figure 2 is bounded by radials G-F and B-C and arcs D-E and A-I. Corner fillets are located at points K, L, M, and N.

## BOSS-POCKET INTERSECTION

The nature of the boss-pocket geometry is indicated in Figure 3 for a boss intersecting a radial G-F. The boss center is located at O. The figure indicates the boss radius RØ (at intersections with G-F) and all of the intersection parameters that have to be solved for this particular intersection condition.

There are many such intersection conditions that CVEX7 handles. These include single and double intersections between the boss and pocket radials, arcs, and fillets, as well as the several ways a boss can partially and totally enclose the pocket entities.

### Pattern Recognition

After creating the flat pattern pocket geometry and locating the boss on it, CVEX7 undertakes a comprehensive series of tests to recognize the geometry near the boss as well as the entity intersections and different blending fillets that can be inserted. The sequence and extent of these tests depend on progressive test results. To reduce the number crunching associated with the tests, a relatively simple algorithm sets up a limited region in which the pockets must be analyzed.

### Rules

In addition to basic rules implicit in using CADDS 3 commands, CVEX7 is governed, in part, by the following knowledge-based rules:

- When more than one boss blending fillet can be inserted, the one resulting in the shortest boss arc is selected.
- When the separation between two boss OD intersections or an entity is less than a selected minimum value (FF), no blending fillets are inserted.
- All entities totally enveloped by the boss OD are erased.
- Pocket radials and arcs intersected by boss are erased.
- Fillets whose circles are intersected by the boss are erased.
- Arc and radial segments are inserted and trimmed for fillet insertion when intersected arcs or radials are erased, and blending fillets must be inserted.

In addition to the above, CVEX7 performs and acts on feasibility tests of creating a flat pattern and tests to determine whether or not a boss is free-standing. That is, if the fillet radii are too large for the spacing between the waffle rings or longitudinal members, a flat pattern cannot be created. And, if a boss is in a pocket where no fillet can be inserted relative to it, it is drawn as a free-standing boss.

### Ensuring Correct Blending Fillet Insertions

To ensure correct boss blending fillet insertions under a wide range of geometric conditions, an algorithm is implemented in CVEX7 that always trims two entities between which a fillet is to be inserted. The trimming is such that extension of one of the entities will not intersect the other.

Figure 4 lists the variables and Figure 5 defines the symbols that are the coordinates to which intersecting entities are trimmed. These coordinates are generated by first shifting the pocket perimeter toward the pocket center and, secondly, by increasing the boss radius by a fixed incremental value.

The above coordinates are explicitly invoked in the INS FIL command unless one of the fillet placement rules call for alternate coordinates.

## MAJOR CVEX7 FUNCTIONS

The analysis flow and major functions performed by CVEX7 are indicated in the algorithm description in Figure 5 and the outline in Figure 6. Several versions of CVEX7 were developed and tested before this final version was selected. Its design is compatible with the CADDS 3 commands it uses.

## TYPICAL OUTPUTS

Figures 7, 8, and 9, respectively, are a CVEX7 execute file, debugging printout, and flat pattern layout of a simple test case. The cone in this case has only four pockets and the selected boss intersects only one radial member.

Comments in the execute file make it easy to see what functions are being performed by different parts of the file. The pockets and pocket entities being created or operated on are also easy to identify from the comments at the ends of the command lines.

The execute file actually submitted to CADDS 3 is derived from this file and is not as easy to read. It includes required line wrapping before the eightieth character and may exclude comments.

Figure 8 is a debugging printout containing a summary of all the input, output, and internally computed parameters. Definitions of variables in Figure 8 are given in Figure 5. The debugging printout is normally suppressed unless it is needed for debugging or variable values that are not output in the execute file.

At this point the plot, Figure 9, such things as dimensions, rib cross-sections, and boss internal features are not included. These can be generated by extensions to CVEX7, the execute file, or they may be manually inserted.

Other test results are shown in Figures 10 through 17. For clarity, all the test cases are simple. Creation of layouts with large numbers of pockets and bosses are possible and would produce the greatest cost- and time-saving benefits compared to conventionally produced layouts.

### Problem Area

Figure 16 illustrates a current unresolved problem. The missing fillet on the boss OD was not inserted with the correct INS FIL command. A "Fillet Undefined" error message is the output. However, the fillet does go in when the same command is implemented by actual digitizing on a tablet.

## SUMMARY

The described CVEX7 expert system demonstrates the feasibility of creating such a system for specialized structures. Deviations from and/or analogies with CVEX7 can provide the basis for creating expert systems for other structural types. These can include isogrid, skin stringer, and ring- or stringer-stiffened structures.

Possible enhancements to CVEX7 include:

- Application to multiple cylinder, cone shells.
- Multiple bosses.
- Automatically generated dimensions.
- Clustered bosses.
- Bosses falling on radial flat pattern split line.
- Auto-input of different rib widths.
- Numerical control tape generation for machining.
- Rectangular, triangular, or user-generated plan forum of boss contour.
- Transformation of flat pattern into a three-dimensional model.

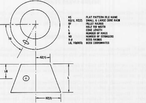


*Figure 1. CVEX7 menu input items.*

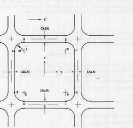


*Figure 2. Waffle pocket designations for modes, inflection points, fillet centers, and rib widths.*

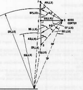


*Figure 3. Geometry at intersection of boss and G-F radial.*

| | INTERSECTIONS SHIFTED TOWARD POCKET CENTER | INTERSECTIONS BASED ALONG RADIALS & ARCS (BOSS RADIUS INCREASED) |
|---|---|---|
| ON CIRCUMFERENTIAL ARC | RA(J,K)+0 | RA(J,K) |
| | RD( )−0 | RD( ) |
| | RE( )−0 | RE( ) |
| | RF( )+0 | RF( ) |
| | FA(J,K) | GA(J,K) |
| | FD( ) | GD( ) |
| | FE( ) | GE( ) |
| | FF( ) | GF( ) |
| ON RADIALS | TD(J,K)−00 | TD(J,K) |
| | TE( )−00 | TE( ) |
| | TF( )+00 | TF( ) |
| | TG( )+00 | TG( ) |
| | ED(J,K) | HD(J,K) |
| | EE( ) | HE( ) |
| | EF( ) | HF( ) |
| | EG( ) | HG( ) |
| | SD(J,K) | UD(J,K) |
| | SE( ) | UE( ) |
| | SF( ) | UF( ) |
| | SG( ) | UG( ) |
| | ZJ% = 2 | ZJ% = 1 |

*Figure 4. Designations of angles and radii to pseudo-intersection between boss and arcs and radials.*

The purpose of CVEX7/DOC is to create a flat pattern layout of a cone cylinder waffle shell structure.

**Algorithm**

1. Menu input used for cone and waffle geometry
2. Convert cone to flat pattern
3. Generate execute file to layout flat pattern
4. Erase appropriate entities. Lay in boss OD arcs, pocket arcs & radial sections as a preliminary to fillet insertion
5. Lay out waffle grid pattern using lines arcs & fillets
6. Determine region of grid intersected by boss
7. If intersection exists between boss OD & OD formed by fillet, then erase fillet
8. If boss intersects 2 ODs formed by adjacent in-pocket fillets, then erase the joining line or arc
9. For each element, identify & use relative location of boss center
10. For each fillet, test for fillet insertability between remaining grid & boss OD. Insert fillets using flat pattern origin as a reference
11. Origin is selected to cause flat pattern to occur in first quadrant & avoid E-format NOS
12. Boss intersection points are biased away from true intersections toward center of pocket by shifting pocket radial & arcs before intersections are computed
13. Pocket radial & arc intersections on boss are shifted away from true intersections along radials & arcs by increasing RO before intersections are computed
14. Trimming is performed to intersections found in items 12 & 13. Result is a set of arcs and/or lines that will not intersect each other if only one is extended. This is necessary before of JFS peculiarities
15. Separate erase, trim & fillet insert modules are used for the different ways boss arc intersects circle extensions of pocket fillets
16. For case 2 or 3, corners enclosed or intersected by boss that does not intersect closeout radial and/or arc. The boss arc ends are switched from radial to arc or vice versa. There are 3 different termination modes. Unless otherwise indicated in definition of symbols, all printout data excludes biases per items 12 & 13. Note: RF .06 needed for INS FIL to work. All printout dimensions are in inches and degrees unless otherwise specified in definitions.

**Definitions of Symbols**

| | |
|---|---|
| AB(J,K) | Angle between B-O & B-X |
| AC(J,K) | Angle between C-O & C-X |
| AF(J,K) | Angle between F-O & F-X |
| AG(J,K) | Angle G-O & G-X |
| BB, BC, BF, BG(J,K) | Angle between RO & B-X, C-X, F-X, G-X at point of intersection of boss OD & radial |
| BD(J,K) | Distance B-C |
| C | Half rib width of stringers & ribs. Used as an alternative for C1 (J,K) to C4 (J,K) |
| C1(J,K) & C4(J,K) | Half rib width on lower left, upper right sides of pockets |
| CO(J,K) | Distance |
| DK(J,K) & DN(J,K) | Distance between point P & centers of pocket fillets |
| EB, EC, EF, EG(J,K) | Coordinate angle of intersection on boss OD with pocket radials near points. B, C, F, G shifted toward pocket center |
| EA$ | "ERS ARC:" |
| EL$ | "ERS LIN:" |
| FA, FD, FE, FI(J,K) | Coordinate angle of intersection on boss OD with pocket arc near A, D, E, I shifted toward pocket center (FE, FI for left & FA, FD for right boss) |
| FF | Minimum allowable separation between 2 intersections of boss OD & pocket OD & pocket arc or 1 intersection & inflection point |
| FG(J,K) | Distance F-G |
| FO(J,K) | Distance F-O |
| FT | Trap size in CADDS 3 |
| FZ% | Variable for number at end of file name |
| GA, GD, GE, GI(J,K) | Coordinate angle of intersection on boss OD with pocket arc near A, D, E, I (FE, FI for left & FA, FD for right boss) boss radius increased by O |
| GB, GC, GF, GG(J,K) | Angle between RP & B-O, C-O, F-O, G-O at their intersections |
| GO(J,K) | Distance G-O |
| HB, HC, HF, HG(J,K) | Coordinate angle of intersection on boss OD with pocket radials near point B, C, F, G boss radius increased by 0 |
| I% | Loop control variable |
| IO% | "INS LIN:" |
| I$ | Line input variable, original |
| IA$ | "INS ARC R:" Example 13 P.4378 |
| IC$ | "INS CIR R" |
| I1$, I2$ | Line output variables, final |
| IH$ | "INS FIL TRIMA R" |
| II$ | "INS FIL TRIMB R" |
| IL$ | "INS LIN:R" |

*Figure 5. Prologue to CVEX7 code.*

| | |
|---|---|
| IO$ | "INS ARC R:" Example 14 P.4-378 |
| J | Index variable for N. longitudinal |
| J1 | Minimum J near boss OD circumferential |
| J2 | Maximum J near boss OD |
| JF$ | "INS FIL R" |
| K | Index variable for NO |
| K1 | Minimum K near boss OD longitudinal |
| K2 | Maximum K near boss OD |
| L | Overall cone length |
| LQ | Location of boss center from small OD of cone |
| N | Number of longitudinal sections of equal length |
| N$ | Flat pattern file name |
| N1, N2 | Dummy variables for N, NO |
| NL% | Number of inches in CV execute file transferred in block |
| NO | Number of longitudinal ribs equals number of circumferential pockets |
| O | Linear offset for trim line |
| OO | Angular offset for trim arc or INS FIL, radians |
| OX(J,K) | Distance O-X, relative to line G-F |
| PI | 3.14159265 |
| O% | Index to secondary boss sector termination modes (see Item 16) |
| R(J) | Radius to ring centerline on lower side of pocket |
| RO(1)-(2) | Radius to ID, OD Of flat pattern perimeter |
| R1 | RO + RF |
| RA(J,K) & RN(J,K) | Coordinate radii to inflection points A to I relative to reference center. RE(J,K), R(J,K) are radii to coordinates shifted toward pocket center. |
| RD | Ring spacing |
| RF | Fillet radius |
| RK(J,K) & RN(J,K) | Coodinate radii to fillet center K to N in pockets |
| RP | Coordinate radius to boss center in flat pattern |
| RZ(1) & RZ(2) | Small and large cone radii |
| SB, SC, SF, SG(J,K) | Coordinate radius at intersection on boss OD with radial near B,C,F,G shifted toward pocket center |
| T5 | FNT5 |
| TO | Half cone angle |
| TA$ | "TRIM ARC:" |
| TA(J,K) & TI(J,K) | Coordinate angle of flat pattern inflection points A to I |
| TD | Stringer spacing angular increment |
| TH | Subtended flat pattern perimeter angle |
| TH(K) | Coordinate angle to pocket left edge center line of flat pattern |
| TK(J,K) & TN(J,K) | Coordinate angle of fillet centers at points K to N relative to reference center |
| TL$ | "TRIM LIN:" |
| TP | Coordinate angle to boss center in flat pattern |
| TQ | Coordinate angle form split line locating boss on cone |
| UB, UC, UF, UG(J,K) | Coordinate radius at intersection on boss OD with radial near B,C,F, G. Boss radius increased by O |
| X | Location of X-axis center of flat pattern layout |
| XO(J,K) | Distance X-O relative to line B-C |
| Y | Location along Y-axis of center of flat pattern |
| Z-Z3 | Reused variables |
| ZJ% | Bias mode designator: 2 for boss radius increased by 0; 1 for radials & arcs toward pocket center |
| ZZ | .01745329 radians to degrees conversions |
| <<<< | Variable name does not match point lettering |

*Figure 5. Prologue to CVEX7 code (continued).*

- Menu input items
- CADDS 3 command assignments
- Variables initialization, offsets, trap size, constants, etc
- Compute flat pattern geometry
- Test for fillet radius being small enough to fit ring & frame spacing. If yes, abort processing
- Locate inflection points, boss & fillet centers on flat pattern
- Determine the pocket number array subscripts of waffle pockets intersected by boss OD
- Computer coordinates for all intersection parameters between boss OD & radians, arcs & fillets for: (1) radians & arcs biased toward pocket center & (2) boss radius increased to bias intersection along pocket radials and arcs
- Test for boss inside of pocket and not intersecting pocket radials, arcs or fillet circles. If yes, produce only flat pattern of waffle grids & perimeter
- Create reference statement to locate flat pattern center
- Open buffer to create CV execute file
- Create commands for drawing complete flat pattern

*Figure 6. Outline of major CVEX7 program functions.*

```
      EXECUTE FILE FOR WAFFLE FLAT PATTERN WITH BOSS  CVEX7I ==============
DEL TMAP  .II
*
*CREATE FLAT PATTERN CONTOUR =========
INS ARC R 18.7181  AGO 51.5346  AEND 128.465 :X 100 Y 0 10       ,<CR>* CONTOUR INNER ARC
INS ARC R 51.4748  AGO 51.5346  AEND 128.465 :X 100 Y 0 10       ,<CR>* CONTOUR OUTER ARC
INS LIN:REF X 100 Y 0 10,IR 18.7181 A 51.5346 ,REF X 100 Y 0 10,IR 51.4748 A 51.5346          ,<CR>*CONTOUR RIGHT RADIAL
INS LIN:REF X 100 Y 0 10,IR 18.7181 A 128.465 ,REF X 100 Y 0 10,IR 51.4748 A 128.465          ,<CR>*CONTOUR LEFT RADIAL
ION ALL
*
* INSERT POCKET ARCS AND RADIALS ==========
INS LIN:REF X 100 Y 0 10,IR 37.056 A 126.919 ,REF X 100 Y 0 10,IR 49.4445 A 127.107           ,<CR>*LEFT RADIAL  J 1  K 1
INS LIN:REF X 100 Y 0 10,IR 37.056 A 91.2464 ,REF X 100 Y 0 10,IR 49.4445 A 91.1589           ,<CR>*RIGHT RADIAL  J 1  K 1
INS ARC R 50.4748  AGO 92.2267  AEND 126.339 :X 100 Y 0 10       ,<CR>* OUTER ARC  J 1  K 1
INS ARC R 36.0965  AGO 93.0905  AEND 125.375 :X 100 Y 0 10       ,<CR>* INNER ARC  J 1  K 1
INS LIN:REF X 100 Y 0 10,IR 37.056 A 88.4536 ,REF X 100 Y 0 10,IR 49.4445 A 88.8411           ,<CR>*LEFT RADIAL  J 1  K 2
INS LIN:REF X 100 Y 0 10,IR 37.056 A 53.081 ,REF X 100 Y 0 10,IR 49.4445 A 52.6925            ,<CR>*RIGHT RADIAL  J 1  K 2
INS ARC R 50.4748  AGO 53.7613  AEND 87.7733 :X 100 Y 0 10       ,<CR>* OUTER ARC  J 1  K 2
INS ARC R 36.0965  AGO 54.6251  AEND 86.5095 :X 100 Y 0 10       ,<CR>* INNER ARC  J 1  K 2
INS LIN:REF X 100 Y 0 10,IR 20.6456 A 125.688 ,REF X 100 Y 0 10,IR 33.0511 A 126.732          ,<CR>*LEFT RADIAL  J 2  K 1
INS LIN:REF X 100 Y 0 10,IR 20.6456 A 92.7763 ,REF X 100 Y 0 10,IR 33.0511 A 91.7338          ,<CR>*RIGHT RADIAL  J 2  K 1
INS ARC R 34.0965  AGO 93.2668  AEND 125.199 :X 100 Y 0 10       ,<CR>* OUTER ARC  J 2  K 1
INS ARC R 19.7181  AGO 95.5396  AEND 122.926 :X 100 Y 0 10       ,<CR>* INNER ARC  J 2  K 1
INS LIN:REF X 100 Y 0 10,IR 20.6456 A 87.2237 ,REF X 100 Y 0 10,IR 33.0511 A 88.2662          ,<CR>*LEFT RADIAL  J 2  K 2
INS LIN:REF X 100 Y 0 10,IR 20.6456 A 54.3109 ,REF X 100 Y 0 10,IR 33.0511 A 53.2684          ,<CR>*RIGHT RADIAL  J 2  K 2
INS ARC R 34.0965  AGO 54.8014  AEND 86.7332 :X 100 Y 0 10       ,<CR>* OUTER ARC  J 2  K 2
INS ARC R 19.7181  AGO 57.0742  AEND 84.4604 :X 100 Y 0 10       ,<CR>* INNER ARC  J 2  K 2
*
* INSERT FILLETS STARTING WITH UPPER LEFT  ========
* UPPER LEFT  J 1  K 1  ========
INS ARC R:REF X 100 Y 0 10,IR 49.4748 A 126.147 ,REF X 100 Y 0 10,IR 50.4748 A 126.339 ,REF X 100 Y 0 10,IR 49.4445 A 127.107 ,<CR>* UPP
ER LEFT  J 1  K 1
INS ARC R:REF X 100 Y 0 10,IR 37.0965 A 125.372 ,REF X 100 Y 0 10,IR 37.056 A 126.919 ,REF X 100 Y 0 10,IR 36.0965 A 125.375 ,<CR>* LOWE
R LEFT  J 1  K 1
INS ARC R:REF X 100 Y 0 10,IR 37.0965 A 93.0939 ,REF X 100 Y 0 10,IR 36.0965 A 93.0905 ,REF X 100 Y 0 10,IR 37.056 A 91.2464 ,<CR>* LOWE
R RIGHT  J 1  K 1
INS ARC R:REF X 100 Y 0 10,IR 49.4748 A 92.3182 ,REF X 100 Y 0 10,IR 49.4445 A 91.1589 ,REF X 100 Y 0 10,IR 50.4748 A 92.2267 ,<CR>* UPP
ER RIGHT  J 1  K 1
INS ARC R:REF X 100 Y 0 10,IR 49.4748 A 87.6818 ,REF X 100 Y 0 10,IR 50.4748 A 87.7733 ,REF X 100 Y 0 10,IR 49.4445 A 88.8411 ,<CR>* UPP
ER LEFT  J 1  K 2
INS ARC R:REF X 100 Y 0 10,IR 37.0965 A 86.9061 ,REF X 100 Y 0 10,IR 37.056 A 88.4536 ,REF X 100 Y 0 10,IR 36.0965 A 86.5095 ,<CR>* LOWE
R LEFT  J 1  K 2
INS ARC R:REF X 100 Y 0 10,IR 37.0965 A 54.6285 ,REF X 100 Y 0 10,IR 36.0965 A 54.6251 ,REF X 100 Y 0 10,IR 37.056 A 53.081 ,<CR>* LOWER
 RIGHT  J 1  K 2
INS ARC R:REF X 100 Y 0 10,IR 49.4748 A 53.8528 ,REF X 100 Y 0 10,IR 49.4445 A 52.6925 ,REF X 100 Y 0 10,IR 50.4748 A 53.7613 ,<CR>* UPP
ER RIGHT  J 1  K 2
INS ARC R:REF X 100 Y 0 10,IR 33.0965 A 124.996 ,REF X 100 Y 0 10,IR 34.0965 A 125.199 ,REF X 100 Y 0 10,IR 33.0511 A 126.732 ,<CR>* UPP
ER LEFT  J 2  K 1
INS ARC R:REF X 100 Y 0 10,IR 20.7181 A 122.906 ,REF X 100 Y 0 10,IR 20.6456 A 125.688 ,REF X 100 Y 0 10,IR 19.7181 A 122.926 ,<CR>* LOW
ER LEFT  J 2  K 1
INS ARC R:REF X 100 Y 0 10,IR 20.7181 A 95.5591 ,REF X 100 Y 0 10,IR 19.7181 A 95.5396 ,REF X 100 Y 0 10,IR 20.6456 A 92.7763 ,<CR>* LOW
ER RIGHT  J 2  K 1
INS ARC R:REF X 100 Y 0 10,IR 33.0965 A 93.4692 ,REF X 100 Y 0 10,IR 33.0511 A 91.7338 ,REF X 100 Y 0 10,IR 34.0965 A 93.2668 ,<CR>* UPP
ER RIGHT  J 2  K 1
INS ARC R:REF X 100 Y 0 10,IR 33.0965 A 86.5308 ,REF X 100 Y 0 10,IR 34.0965 A 86.7332 ,REF X 100 Y 0 10,IR 33.0511 A 88.2662 ,<CR>* UPP
ER LEFT  J 2  K 2
INS ARC R:REF X 100 Y 0 10,IR 20.7181 A 84.4409 ,REF X 100 Y 0 10,IR 20.6456 A 87.2237 ,REF X 100 Y 0 10,IR 19.7181 A 84.4604 ,<CR>* LOW
ER LEFT  J 2  K 2
INS ARC R:REF X 100 Y 0 10,IR 20.7181 A 57.0937 ,REF X 100 Y 0 10,IR 19.7181 A 57.0742 ,REF X 100 Y 0 10,IR 20.6456 A 54.3109 ,<CR>* LOW
ER RIGHT  J 2  K 2
INS ARC R:REF X 100 Y 0 10,IR 33.0965 A 55.0038 ,REF X 100 Y 0 10,IR 33.0511 A 53.2684 ,REF X 100 Y 0 10,IR 34.0965 A 54.8014 ,<CR>* UPP
ER RIGHT  J 2  K 2
*
* INSERTING BOSS BLENDING FILLETS =========
ERS ARC:X 99 Y 37.0425 ,<CR>* J 1  K 1
INS ARC R:      REF X 100 Y 0 10,IR 35.0965 A 90 ,REF X 100 Y 0 10,IR 36.9322 A 91.7741 ,REF X 100 Y 0 10,IR 36.4565 A 96.0283 ,<CR>* 90

 ARC G-F TO A-I  J 1  K 1
TRIM LIN:X 99 Y 37.0425 ,X 98.9874 Y 39.3398 ,<CR>* LIN ON G-F  J 1  K 1
TRIM ARC:X 98.0533 Y 36.044 ,X 95.7039 Y 35.8399 ,<CR>* ARC ON A-I  J 1  K 1
INS FIL R 1 :X 95.7039 Y 35.8398 ,X 96.1113 Y 36.2349 ,<CR>
INS FIL R 1 :X 98.7947 Y 38.9135 ,X 98.9874 Y 39.3398 ,<CR>* 2 FILLETS  J 1  K 1
ERS ARC:X 101 Y 37.0425 ,<CR>* J 1  K 2
INS ARC R:      REF X 100 Y 0 10,IR 35.0965 A 90 ,REF X 100 Y 0 10,IR 36.4565 A 83.9717 ,REF X 100 Y 0 10,IR 36.9322 A 88.2259 ,<CR>* 90

 ARC A-I TO B-C  J 1  K 2
TRIM LIN:X 101 Y 37.0425 ,X 101.013 Y 39.3398 ,<CR>* LIN ON B-C  J 1  K 2
TRIM ARC:X 101.946 Y 36.044 ,X 104.296 Y 35.8399 ,<CR>* ARC ON A-I  J 1  K 2
INS FIL R 1 :X 101.013 Y 39.3398 ,X 101.205 Y 38.9135 ,<CR>
INS FIL R 1 :X 103.889 Y 36.2349 ,X 104.296 Y 35.8399 ,<CR>* 2 FILLETS  J 1  K 2
ERS ARC:X 99 Y 33.036 ,<CR>* J 2  K 1
INS ARC R:      REF X 100 Y 0 10,IR 35.0965 A 90 ,REF X 100 Y 0 10,IR 33.7365 A 96.2668 ,REF X 100 Y 0 10,IR 31.2887 A 92.1691 ,<CR>* 90

 ARC D-E TO G-F  J 2  K 1
TRIM LIN:X 99 Y 33.036 ,X 98.9669 Y 30.8517 ,<CR>* LIN ON G-F  J 2  K 1
TRIM ARC:X 98.037 Y 34.041 ,X 95.825 Y 33.8399 ,<CR>* ARC ON D-E  J 2  K 1
INS FIL R 1 :X 98.9669 Y 30.8517 ,X 98.8158 Y 31.2663 ,<CR>
INS FIL R 1 :X 96.2174 Y 33.3349 ,X 95.825 Y 33.8398 ,<CR>* 2 FILLETS  J 2  K 1
ERS ARC:X 101 Y 33.036 ,<CR>* J 2  K 2
INS ARC R:      REF X 100 Y 0 10,IR 35.0965 A 90 ,REF X 100 Y 0 10,IR 31.2887 A 87.831 ,REF X 100 Y 0 10,IR 33.7365 A 83.7332 ,<CR>* 90

ARC B-C TO D-E  J 2  K 2
TRIM LIN:X 101 Y 33.036 ,X 101.033 Y 30.8517 ,<CR>* LIN ON B-C  J 2  K 2
TRIM ARC:X 101.963 Y 34.041 ,X 104.175 Y 33.8399 ,<CR>* ARC ON D-E  J 2  K 2
INS FIL R 1 :X 104.175 Y 33.8398 ,X 103.683 Y 33.3349 ,<CR>
INS FIL R 1 :X 101.184 Y 31.2663 ,X 101.033 Y 30.8517 ,<CR>* 2 FILLETS  J 2  K 2
RUN WNDCPY
 1
```

*Figure 7. Typical CVEX7 execute file.*

```
CVEX8 DEBUGGING PRINTOUT ************************************************************ CVTST1

C           J1          J2          K1          K2          L           LQ          N
ND          RD          RD(1)       RE(2)       RI          RO          BF          BP
TD          TB          TP          TQ          RI(1)       RI(2)       X           Y
FF          FT          O           DO          FI          EE          F2%

1           1           2           1           2           32          16          2
2           4           18.7181     51.4748     5           16.3783     1           35.0965
38.4654     76.9309     90          100         4           11          100         0
.91         .12         .36         5E-03       180         .0174533    1

R(J) ----------         R( 1 )= 35.0965                     R( 2 )= 18.7181

TH(K) ----------        TH( 1 )= 128.465                    TH( 2 )= 90

J           K
1           1
1           2
2           1
2           2

RA( ) - RI( )
A           B           C           D           E           F           G           I
36.0965     37.856      49.4445     50.4748     50.1140     49.4445     37.056      36.4565
36.0965     37.856      49.4445     50.4748     50.1140     49.4445     37.056      36.4565
19.7181     20.6456     33.0511     34.0965     33.7365     33.0511     20.6456     20.0781
19.7181     20.6456     33.0511     34.0965     33.7365     33.0511     20.6456     20.0781
TA( ) - TI( )
A           B           C           D           E           F           G           I
125.375     126.919     127.307     126.239     92.2267     91.1589     91.5464     93.0905
86.3095     88.4536     88.8411     87.7733     53.7613     52.6935     53.081      54.6251
122.928     125.689     126.732     125.199     93.2668     91.7338     92.7763     95.5396
84.4604     87.2237     88.2662     86.7332     54.8014     53.2684     54.3169     57.0742
BB( )       BC( )       BF( )       BG( )       J           K
0           0           17.0922     17.0922     1           1
17.0919     17.0919     0           0           1           2
0           0           17.0939     17.0939     2           1
17.0943     17.0943     0           0           2           2

DK( )       DL( )       DM( )       DN( )
22.0166     29.6397     14.4693     2.79067
2.79067     14.4693     29.6397     22.0166
20.984      20.7067     2.78844     14.6126
14.6126     2.7884      20.7066     .20.984

RE( )       RL( )       RM( )       RN( )
37.0965     49.4748     49.4748     37.0965
37.0965     49.4748     49.4748     37.0965
20.7181     33.0965     33.0965     20.7181
20.7181     33.0965     33.0965     20.7181

TX( )       TL( )       TM( )       TN( )
125.372     126.147     92.3182     93.0939
86.9061     87.6818     53.8528     54.6285
122.906     124.956     93.4692     95.5591
84.4409     86.5268     55.0038     57.0937

EB( )       EC( )       EF( )       EG( )       HB( )       HC( )       HF( )       HG( )
0           0           91.7741     92.0133     0           0           91.4745     91.7399
87.9868     88.2259     0           0           88.2602     88.5256     0           0
0           0           91.5265     92.1691     0           0           91.2047     91.9178
87.831      88.4736     0           0           88.0822     88.7954     0           0

FA( )       FD( )       FE( )       FI( )       GA( )       GD( )       GE( )       GI( )
96.0283     0           0           83.9717     96.8354     0           0           83.1646
96.0283     0           0           83.9717     96.8354     0           0           83.1646
0           96.2668     83.7332     0           0           97.0334     82.9666     0
0           96.2668     83.7332     0           0           97.0334     82.9666     0

GB( )       GC( )       GF( )       GG( )
76.374      98.3722     175.025     148.582
140.582     175.026     98.3722     76.374
33.2133     66.5686     29.4285     4.35657
4.35666     29.4285     66.5686     33.2133

SB( )       SC( )       SF( )       SG( )       UB( )       UC( )       UF( )       UG( )
0           0           38.9322     31.2887     0           0           39.3528     30.869
31.2887     38.9322     0           0           30.869      39.3529     0           0
0           0           38.9322     31.2887     0           0           39.3528     30.869
31.2887     38.9321     0           0           30.8689     39.3529     0           0

AB( )       AC( )       AF( )       AG( )
114.552     43.4492     4.68735     148.869
148.869     4.68727     43.449      114.553
71.3923     104.747     150.285     4.64386
4.64396     150.284     104.747     71.3923

FG( )       BD( )       PO( )       CO( )       OO( )       BO( )       OX( )       XO( )
12.3919     12.3919     14.3865     30.091      2.27396     22.751      1.17564     20.6939
12.3919     12.3919     30.0909     14.3865     22.751      2.27396     20.6938     1.17562
12.4146     12.4146     2.37197     21.3987     14.5223     21.8353     1.17576     20.6939
12.4146     12.4146     21.3987     2.37197     21.8353     14.5223     20.6939     1.17578
```

*Figure 8. CVEX7 debugging printout for CADDS 3 execute file CVTST1.*

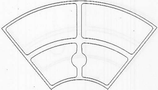

*Figure 9. Task 1.*

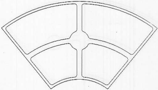

*Figure 10. Test 2.*

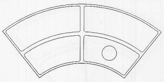

*Figure 11. Test 3.*

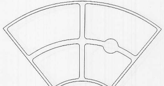

*Figure 12. Test 4.*

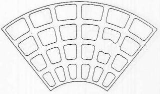

*Figure 13. Test 5.*

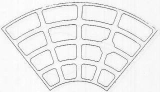

*Figure 14. Test 6.*

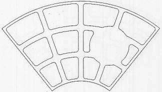

*Figure 15. Test 7.*

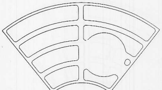

*Figure 16. Test 8.*

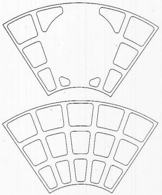

*Figure 17. Test 9.*

## BIOGRAPHY

**Paul Slysh** was born in Brooklyn, N.Y. He attended the College of the City of New York where he majored in Mechanical Engineering, and Brooklyn Polytechnic Institute where he majored in Mechanical and Electrical Engineering. He received a BME from the College of the City of New York and a MME from Brooklyn Polytechnic Institute. He has also done post-graduate work Columbia University and University of California at San Diego, has written a textbook, and has taught courses on servo control systems at the San Diego City College.

Paul Slysh has published numerous papers on structural analysis, tests, and concepts. He is currently a Senior Software Engineer in the CAD group of the General Dynamics Data Systems Division where he is now engaged in the development of CAE and CAD software for structural analysis and graphics. His previous experience includes program management and structural/mechanical design and analysis at General Dynamics, Convair Division Airborne Instruments Laboratory, ITE Circuit Breaker Co., and American Machine & Foundry Co.