



# The Use of Geometry from within the Engineering Sketch Pad The EGADS API

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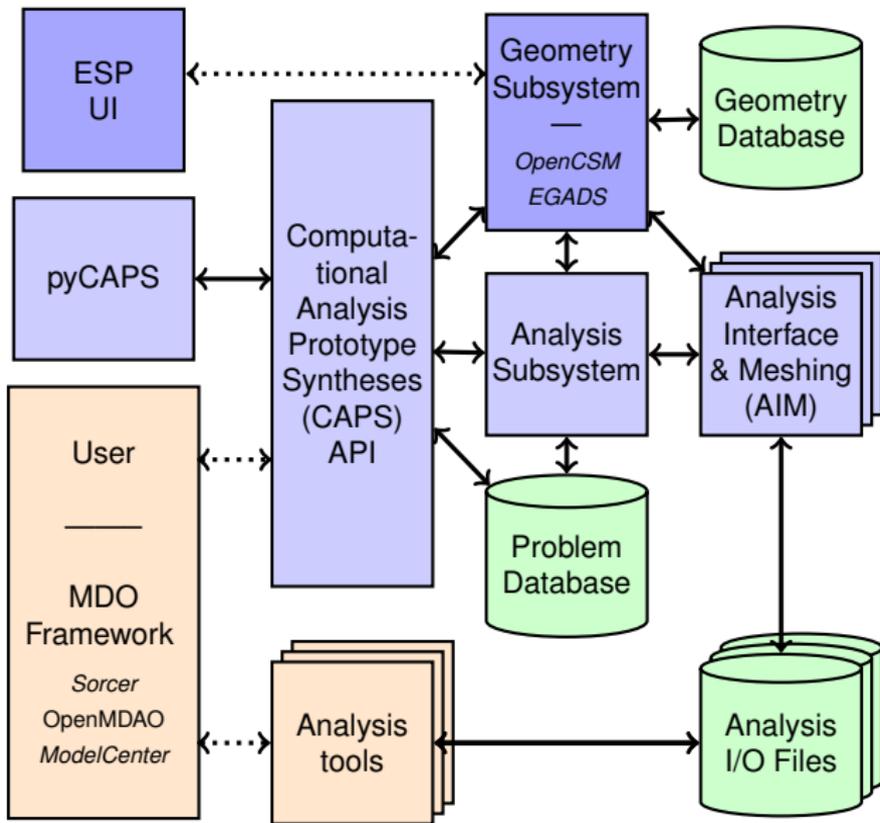
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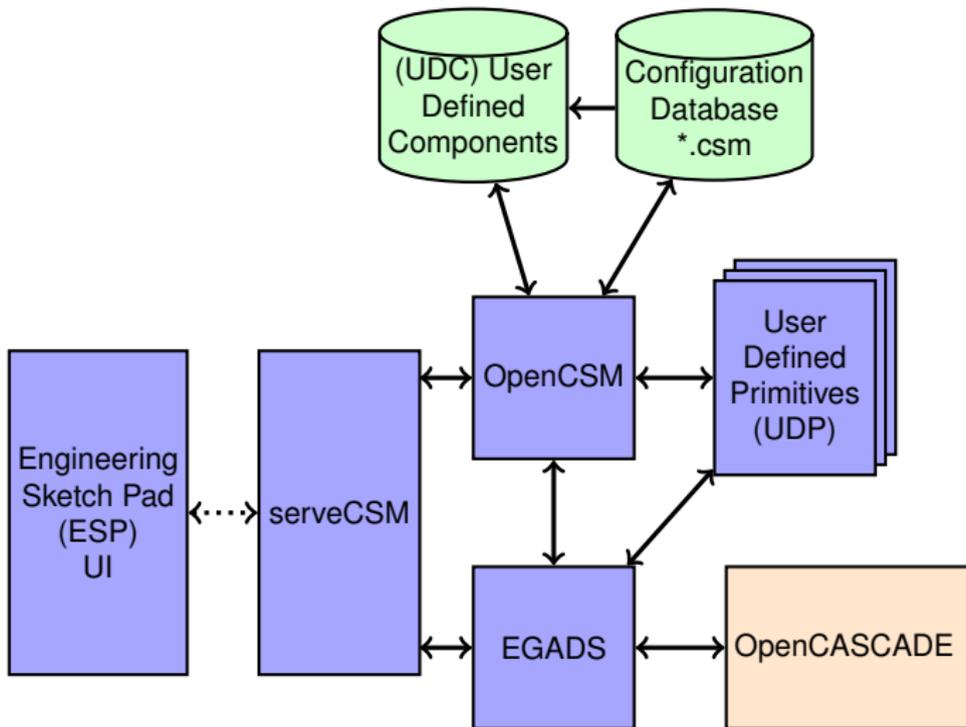
## ESP is:

- a parametric geometry creation and manipulation system designed to **fully support** the analysis and design of aerospace vehicles (**aCAD**)
- a stand-alone system for the development of models
- can be embedded into other software systems to support their geometric and process needs

## ESP is not:

- a full-featured mechanical computer-aided design (**mCAD**) system
- a system to be used for creating “drawings”
- an MDAO Framework





The Engineering Geometry Aircraft Design System (EGADS) is an open-source geometry interface to OpenCASCADE

- reduces OpenCASCADE's 17,000 methods to about 70 calls
  - Supports C, C++ & FORTRAN
- provides *bottom-up* and/or *top-down* construction
- geometric primitives
  - curve: line, circle, ellipse, parabola, hyperbola, offset, bezier, BSpline (including NURBS)
  - surface: plane, spherical, conical, cylindrical, toroidal, revolution, extrusion, offset, bezier, BSpline (including NURBS)
- solid creation and Boolean operations (*top-down*)
- provides persistent user-defined attributes on topological entities
- adjustable tessellator (*vs* a surface mesher) with support for finite-differencing in the calculation of parametric sensitivities

## System Support (32 & 64 bit)

- Mac OSX with **gcc**, **clang**, **ifort** and/or **gfortran**
- LINUX with **gcc**, **ifort** and/or **gfortran**
- Windows with Microsoft Visual Studio C++ and **ifort**
- No globals (but not thread-safe due to OpenCASCADE)
- Various levels of output (0-none, through 3-debug)
- Written in C and C++

## EGADS Objects (**egos**)

- Pointer to a C structure – allows for an *Object-based* API
- Treated as “blind” pointers (i.e., not meant to be dereferenced)
- **egos** are INTEGER\*8 variables in FORTRAN

- Context – Holds the *globals*
- Transform
- Tessellation
- Nil (allocated but not assigned) – internal
- Empty – internal
- Reference – internal
- Geometry
  - pcurve, curve, surface
- Topology
  - Node, Edge, Loop, Face, Shell, Body, Model

- Attributes – metadata consisting of name/value pairs
  - Unique name – no spaces
  - A single type: Integer, Real, String, CSys
  - A length (not for strings)
- Objects
  - Any (non-internal) Object can have multiple Attributes
  - Only Attributes on Topological Objects are copied and are persistent (saved)
- SBO & Intersection Functions
  - Unmodified Topological Objects maintain their Attributes
  - Face Attributes are carried through to the resultant fragments
  - All other Attributes are lost
- CSys Attributes are modified through Transformations

## surface

- 3D surfaces of 2 parameters  $[u, v]$
- **Types:** Plane, Spherical, Cylindrical, Revolution, Toriodal, Trimmed, Bezier, BSpline, Offset, Conical, Extrusion
- All types abstracted to  $[x, y, z] = f(u, v)$

## pcurve – Parameter Space Curves

- 2D curves in the Parametric space  $[u, v]$  of a surface
- **Types:** Line, Circle, Ellipse, Parabola, Hyperbola, Trimmed, Bezier, BSpline, Offset
- All types abstracted to  $[u, v] = g(t)$

## curve

- 3D curve – single running parameter ( $t$ )
- Same types as pcurve but abstracted to  $[x, y, z] = g(t)$

## Boundary Representation – BRep

	Topological Entity	Geometric Entity	Function
<i>Top</i> <i>Down</i>   <i>Bottom</i> <i>Up</i>	Model		
	Body	Solid, Sheet, Wire	
	Shell		
	Face	<b>surface</b>	$(x, y, z) = \mathbf{f}(u, v)$
	Loop		
	Edge	<b>curve</b>	$(x, y, z) = \mathbf{g}(t)$
	Node	<b>point</b>	

- Nodes that bound Edges may not be on underlying curves
- Edges in the Loops that trim the Face may not sit on the surface hence the use of pcurves

## Node

- Contains  $[x, y, z]$
- Types: none

## Edge

- Has a 3D curve (if not Degenerate)
- Has a  $t$  range ( $t_{min}$  to  $t_{max}$ , where  $t_{min} < t_{max}$ )  
Note: The positive orientation is going from  $t_{min}$  to  $t_{max}$
- Has a Node for  $t_{min}$  and for  $t_{max}$  – can be the same Node
- Types:
  - OneNode – periodic
  - TwoNode – normal
  - Degenerate – single Node,  $t$  range used for the associated pcurve

## Loop – without a reference surface

- 1 Free standing connected Edges that can be used in a non-manifold setting (for example in WireBodies)
  - 2 A list of connected Edges associated with a Plane (which does not require pcurves)
- An ordered collection of Edge objects with associated senses that define the connected *Wire/Contour/Loop*
  - Segregates space by maintaining material to the left of the running Loop (or traversed right-handed pointing out of the intended volume)
  - No Edges should be Degenerate
  - Types: Open or Closed (comes back on itself)

## Loop – with a reference surface

- ① Collections of Edges (like without a surface) followed by a corresponding collection of pcurves that define the  $[u, v]$  trimming on the surface
- Degenerate Edges are required when the  $[u, v]$  mapping collapses like at the apex of a cone (note that the pcurve is needed to be fully defined using the Edge's  $t$  range)
- An Edge may be found in a Loop twice (with opposite senses) and with different pcurves. For example a closed cylindrical surface at the seam – one pcurve would represent the beginning of the period where the other is the end of the periodic range.
- Types: Open or Closed (comes back on itself)

## Face

- A surface bounded by one or more Loops with associated senses
- Only one outer Loop (sense = 1) and any number of inner Loops (sense = -1). Note that under very rare conditions a Loop may be found in more than 1 Face – in this case the one marked with sense = +/- 2 must be used in a reverse manner.
- All Loops must be Closed
- Loop(s) must not contain reference geometry for Planar surfaces
- If the surface is not a Plane then the Loops reference Object must match that of the Face
- Type is the orientation of the Face based on surface's  $U \otimes V$ :
  - SFORWARD or SREVERSE when the orientations are opposed

Note that this is coupled with the Loop's orientation (i.e. an outer Loop traverses the Face in a right-handed manner defining the outward direction)

## Shell

- A collection of one or more connected Faces that if Closed segregates regions of 3-Space
- All Faces must be properly oriented
- Non-manifold Shells can have more than 2 Faces sharing an Edge
- Types: Open (including non-manifold) or Closed

## SolidBody

- A manifold collection of one or more Closed Shells with associated senses
- There may be only one outer Shell (sense = 1) and any number of inner Shells (sense = -1)
- Edges (except Degenerate) are found exactly twice (sense =  $\pm 1$ )

## Body – including SolidBody

- Container used to aggregate Topology
- Connected to support non-manifold collections at the Model level
- *Owns* all the Objects contained within
- Types:
  - A WireBody contains a single Loop
  - A FaceBody contains a single Face – IGES import
  - A SheetBody contains a single Shell which can be either non-manifold or manifold (though usually a manifold Body of this type is promoted to a SolidBody)

## Model

- A collection of Bodies – becomes the *Owner* of contained Objects
- Returned by SBO & Sew Functions
- Read and Written by EGADS

## Helper Functions

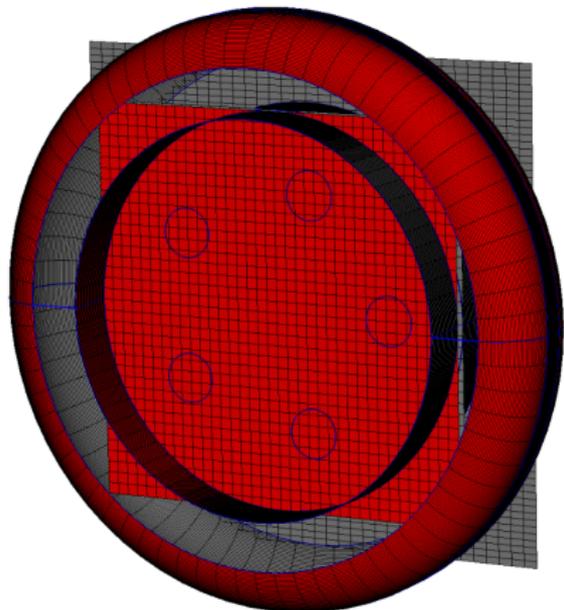
- makeLoop
  - Connects unrelated (via Nodes) Edges from a list
  - Uses input tolerance to match entities
  - Result may be multiple Loops
- makeFace
  - From Closed Planar Loop
  - From surface with limits
- sewFaces
  - Connects Faces with unrelated Topology
  - Uses input tolerance to match entities
  - Returns a Model – may have multiple Bodies
  - Can connect in a nonmanifold manner

## Geometry

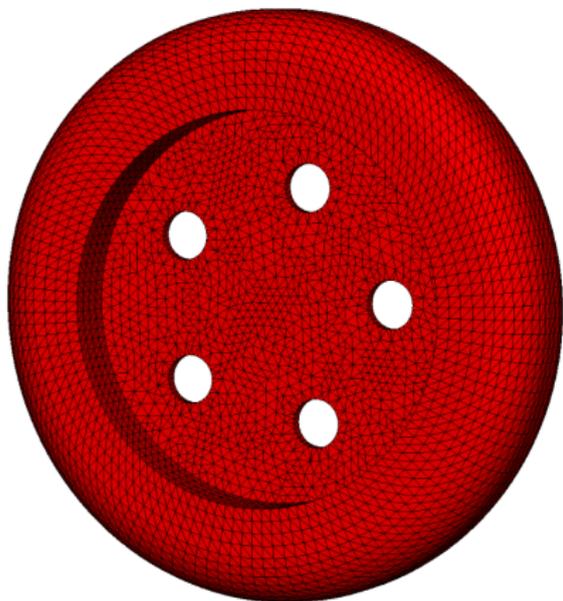
- Unconnected discretization of a range of the Object
  - Polyline for curves at constant  $t$  increments
  - Regular grid for surfaces at constant increments (isoclines)

## Body Topology

- Connected and trimmed tessellation including:
  - Polyline for Edges
  - Triangulation for Faces
  - Optional Quadrilateral Patching for Faces
- Ownership and Geometric Parameters for Vertices
- Adjustable parameters for side length and curvature (x2)
- Watertight
- Exposed per Face/Edge or Global indexing



from `$ESP_ROOT/bin/vGeom`



from `$ESP_ROOT/bin/vTess`

- Function names begin with “EG\_” – or – “IG\_” for the FORTRAN bindings
- Functions almost always return an integer *error code*
- *Object-based* – procedural, usually with the first argument an **ego**
- Signatures usually have the inputs first, then output argument(s)
- Some outputs may be pointers to lists of *things*  
EG\_free needs to be used when marked as “freeable”
- **egos** have:
  - *Owner*: Context, Body, or Model
  - Reference Objects (objects they depend upon)
- When a Body is made, all included Objects are copied – not referenced

## Deleting Objects

- Use the function “EG\_deleteObject” (or “ig\_deleteobject”)
- The Object must be reference *free* – i.e. not used by another
  - Delete in the opposite order of creation
  - If in a Body, delete the Body (unless the Body is in a Model)
- “EG\_deleteObject” on a Context does not delete the Context
  - Deletes all Objects in the Context that are not in a Body
  - Use “EG\_close” to delete all objects in a Context (and the Context)

## Another Rule

- A Body can only be in one Model
  - Copy the Body of interest, then include the copy in the new Model

```

void EG_revision( int *major, int *minor, const char **OCCrev )
int EG_open( ego *context )
int EG_loadModel( ego contxt, int bflg, const char *name, ego *model )
int EG_saveModel( const ego model, const char *name )
int EG_deleteObject( ego object )
int EG_makeTransform( ego context, const double *xform, ego *oform )
int EG_getTransformation( const ego oform, double *xform )
int EG_getContext( ego object, ego *context )
int EG_setOutLevel( ego context, int outLevel )
int EG_getInfo( const ego object, int *oclass, int *mtype,
               ego *topObj, ego *prev, ego *next )
int EG_copyObject( const ego obj, /*@null@*/ void *oform, ego *copy )
int EG_flipObject( const ego object, ego *flippedCopy )
int EG_close( ego context )

/*@null@*/ /*@out@*/ /*@only@*/ void *EG_alloc( int nbytes )
/*@null@*/ /*@only@*/ void *EG_calloc( int nele, int size )
/*@null@*/ /*@only@*/ void *EG_reall( /*@null@*/ /*@returned@*/
                                   /*@only@*/ void *ptr, int nbyts )
void EG_free( /*@null@*/ /*@only@*/ void *pointer )

```

```
int EG_attributeAdd( ego object, const char *name, int type, int len,
                   /*@null@*/ const int *ints,
                   /*@null@*/ const double *reals,
                   /*@null@*/ const char *str )

int EG_attributeDel( ego object, /*@null@*/ const char *name )

int EG_attributeNum( const ego object, int *num )

int EG_attributeGet( const ego object, int index, const char **name,
                   int *atype, int *len,
                   /*@null@*/ const int **ints,
                   /*@null@*/ const double **reals,
                   /*@null@*/ const char **str )

int EG_attributeRet( const ego object, const char *name, int *atype,
                   int *len,
                   /*@null@*/ const int **ints,
                   /*@null@*/ const double **reals,
                   /*@null@*/ const char **str )

int EG_attributeDup( const ego srcObj, ego dstObj )
```

```
int EG_makeGeometry( ego context, int oclass, int mtype,
                    /*@null@*/ ego ref, /*@null@*/ const int *ivec,
                    const double *rvec, ego *geom )
int EG_getGeometry( const ego geom, int *oclass, int *mtype,
                  ego *refGeom, int **ivec, double **rvec )

int EG_approximate( ego context, int maxdeg, double tol,
                  const int *sizes, const double *xyzs, ego *bsplin )
int EG_fitTriangles( ego context, int npts, double *xyzs, int ntris,
                  const int *tris, /*@null@*/ const int *tric,
                  double tol, ego *bspline )
int EG_otherCurve( const ego surface, const ego curve, double tol,
                 ego *newcurve )
int EG_isoCline( const ego surface, int UV, double val, ego *newcurve )
```

```
int EG_getRange( const ego obj, double *range, int *periodic )
int EG_getArea( ego obj, /*@null*/ const double *limits,
               double *area )
int EG_evaluate( const ego obj, const double *param, double *results )
int EG_invEvaluate( const ego obj, double *xyz, double *param,
                  double *results )
int EG_invEvaluateGuess( const ego obj, double *xyz, double *param,
                       double *results )
int EG_arcLength( const ego obj, double t1, double t2, double *alen )
int EG_curvature( const ego obj, const double *parm, double *results )
int EG_isSame( const ego obj1, const ego obj2 )
int EG_convertToBSpline( ego obj, ego *bspline )
```

```
int EG_makeTopology( ego context, /*@null@*/ ego geom, int oclass,
                    int mtype, /*@null@*/ double *limits,
                    int nChildren, /*@null@*/ ego *children,
                    /*@null@*/ int *senses, ego *topo )

int EG_makeSolidBody( ego context, int stype, const double *rvec,
                     ego *body )

int EG_getTopology( const ego topo, ego *geom, int *oclass, int *type,
                  /*@null@*/ double *limits, int *nChildren,
                  ego **children, int **senses )

int EG_makeLoop( int nedge, ego *edges, /*@null@*/ ego geom,
                double toler, ego *result )

int EG_makeFace( ego object, int mtype,
                /*@null@*/ const double *limits, ego *face )

int EG_sewFaces( int nobj, const ego *faces, double toler, int flag,
                ego *model )

int EG_getEdgeUV( const ego face, const ego edge, int sense, double t,
                 double *UV )

int EG_getBoundingBox( const ego topo, double *bbox )

int EG_getMassProperties( const ego topo, double *result )

int EG_isEquivalent( const ego topo1, const ego topo2 )
```

```
int EG_getBody( const ego topo, ego *body )
int EG_getBodyTopos( const ego body, /*@null@*/ ego src, int oclass,
                    int *ntopo, ego **topos )
int EG_indexBodyTopo( const ego body, const ego src )
int EG_inTopology( const ego topo, const double *xyz )
int EG_inFace( const ego face, const double *uv )

int EG_getTolerance( const ego topo, double *tol )
int EG_setTolerance( ego topo, double tol )

int EG_replaceFaces( const ego body, int nobj, ego *objs, ego *result )
int EG_mapBody( const ego sBody, const ego dBody, const char *fAttr,
              ego *mapBody )
int EG_matchBodyFaces( const ego body1, const ego body2, double toler,
                     int *nmatch, int **match )
```

```

int EG_makeTessGeom( ego obj, double *params, int *sizes, ego *tess )
int EG_getTessGeom( const ego tess, int *sizes, double **xyz )

int EG_makeTessBody( ego body, double *params, ego *tess )
int EG_mapTessBody( ego tess, ego body, ego *mapTess )
int EG_getTessEdge( const ego tess, int eIndex, int *len,
                   const double **xyz, const double **t )
int EG_getTessFace( const ego tess, int fIndex, int *len,
                   const double **xyz, const double **uv,
                   const int **ptype, const int **pindex,
                   int *ntri, const int **tris, const int **tric )
int EG_statusTessBody( ego tess, ego *body, int *state, int *nGlobal )
int EG_localToGlobal( const ego tess, int index, int local,
                    int *global )
int EG_getGlobal( const ego tess, int global, int *ptype, int *pindex,
                /*@null@*/ double *xyz )

```

**Note:** All numbering in EGADS is 1-biased

`ptype` – the point type: (-) Face local index, (0) Node, (+) Edge local index

`pindex` – the point topological index (1 bias)

```
int EG_solidBoolean( const ego src, const ego tool, int oper,
                    ego *model )
int EG_intersection( const ego src, const ego tool, int *nedge,
                   /*@null@*/ ego **facEdg, ego *model )
int EG_imprintBody( const ego src, int nedge,
                   const ego *facEdg, ego *result )
int EG_filletBody( const ego src, int nedge, const ego *edges,
                  double radius, ego *result,
                  /*@null@*/ int **facemap )
int EG_chamferBody( const ego src, int nedge, const ego *edges,
                   const ego *faces, double dis1, double dis2,
                   ego *result, /*@null@*/ int **facemap )
int EG_hollowBody( const ego src, int nface, const ego *faces,
                  double offset, int join, ego *result,
                  /*@null@*/ int **facemap )
int EG_extrude( const ego src, double dist, const double *dir,
               ego *result )
int EG_rotate( const ego src, double angle, const double *axis,
              ego *result )
int EG_sweep( const ego src, const ego spine, int mode, ego *result )
int EG_blend( int nsec, const ego *secs, /*@null@*/ double *rc1,
             /*@null@*/ double *rcN, ego *result )
int EG_ruled( int nsec, const ego *secs, ego *result )
```

```

#include "egads.h"
#include <math.h>
#include <string.h>

#ifdef WIN32
#define snprintf _snprintf
#endif

int main(int argc, char *argv[])
{
    int          i, j, k, status, oclass, mtype, nbody, nvert, ntriang, nface;
    int          plen, tlen, pty, pin, tin[3], *senses;
    const int    *ptype, *pindex, *tris, *tric;
    char         filename[20];
    const char   *OCCrev;
    float        arg;
    double       params[3], box[6], size, verts[3];
    const double *points, *uv;
    FILE         *fp;
    ego          context, model, geom, solid, *bodies, tess, *dum, *faces;

    if ((argc != 2) && (argc != 5)) {
        printf(" Usage: egads2tri Model [angle relSide relSag]\n\n");
        return 1;
    }

    /* look at EGADS revision */
    EG_revision(&i, &j, &OCCrev);
    printf("\n Using EGADS %2d.%02d with %s\n\n", i, j, OCCrev);

```

```

/* initialize */
status = EG_open(&context);

if (status != EGADS_SUCCESS) {
    printf(" EG_open = %d!\n\n", status);
    return 1;
}

status = EG_loadModel(context, 0, argv[1], &model);

if (status != EGADS_SUCCESS) {
    printf(" EG_loadModel = %d!\n\n", status);
    return 1;
}

status = EG_getBoundingBox(model, box);

if (status != EGADS_SUCCESS) {
    printf(" EG_getBoundingBox = %d!\n\n", status);
    return 1;
}

size = sqrt((box[0]-box[3])*(box[0]-box[3]) + (box[1]-box[4])*(box[1]-box[4]) +
            (box[2]-box[5])*(box[2]-box[5]));

/* get all bodies */
status = EG_getTopology(model, &geom, &oclass, &mtype, NULL, &nbody,
                        &bodies, &senses);

if (status != EGADS_SUCCESS) {
    printf(" EG_getTopology = %d!\n\n", status);
    return 1;
}

```

```

params[0] = 0.025*size;
params[1] = 0.001*size;
params[2] = 15.0;
if (argc == 5) {
    sscanf(argv[2], "%f", &arg);
    params[2] = arg;
    sscanf(argv[3], "%f", &arg);
    params[0] = arg;
    sscanf(argv[4], "%f", &arg);
    params[1] = arg;
    printf(" Using angle = %lf, relSide = %lf, relSag = %lf\n", params[2], params[0], params[1]);
    params[0] *= size;
    params[1] *= size;
}
printf(" Number of Bodies = %d\n\n", nbody);

/* write out each body as a different Cart3D ASCII tri file */
for (i = 0; i < nbody; i++) {
    snprintf(filename, 20, "egads.%3d.a.tri", i+1);
    solid = bodies[i];
    mtype = 0;
    EG_getTopology(bodies[i], &geom, &oclass, &mtype, NULL, &j, &dum, &senses);
    if (mtype == SHEETBODY) {
        status = EG_makeTopology(context, NULL, BODY, SOLIDBODY, NULL, j, dum, NULL, &solid);
        if (status == EGADS_SUCCESS) {
            printf(" SheetBody %d promoted to SolidBody\n", i);
            mtype = SOLIDBODY;
        } else {
            printf(" SheetBody %d cannot be promoted to SolidBody\n", i);
        }
    }
}
if (mtype != SOLIDBODY) continue; /* only Solid Bodies! */

```

```

status = EG_makeTessBody(solid, params, &tess);
if (status != EGADS_SUCCESS) {
    printf(" EG_makeTessBody %d = %d\n", i, status);
    if (solid != bodies[i]) EG_deleteObject(solid);
    continue;
}

status = EG_getBodyTopos(solid, NULL, FACE, &face, &faces);
if (status != EGADS_SUCCESS) {
    printf(" EG_getBodyTopos %d = %d\n", i, status);
    if (solid != bodies[i]) EG_deleteObject(solid);
    EG_deleteObject(tess);
    continue;
}
EG_free(faces);

/* get counts */
status = EG_statusTessBody(tess, &geom, &j, &nvert);
printf(" statusTessBody = %d %d npts = %d\n", status, j, nvert);
if (status != EGADS_SUCCESS) continue;
ntriang = 0;
for (j = 0; j < nface; j++) {
    status = EG_getTessFace(tess, j+1, &plen, &points, &uv, &pctype, &pindex,
                          &tlen, &tris, &trict);
    if (status != EGADS_SUCCESS) {
        printf(" Error: EG_getTessFace %d/%d = %d\n", j+1, nvert, status);
        continue;
    }
    ntriang += tlen;
}

```

```

/* write it out */
fp = fopen(filename, "w");
if (fp == NULL) {
    printf(" Can not Open file %s! NO FILE WRITTEN\n", filename);
    if (solid != bodies[i]) EG_deleteObject(solid);
    continue;
}
printf("\nWriting Cart3D component tri file %s\n", filename);
/* header */
fprintf(fp, "%d %d\n", nvert, ntriang);
/* ...vertList */
for (j = 0; j < nvert; j++) {
    status = EG_getGlobal(tess, j+1, &pty, &pin, verts);
    if (status != EGADS_SUCCESS)
        printf(" Error: EG_getGlobal %d/%d = %d\n", j+1, nvert, status);
    fprintf(fp, " %20.13le %20.13le %20.13le\n", verts[0], verts[1], verts[2]);
}
/* ...Connectivity */
for (j = 0; j < nface; j++) {
    status = EG_getTessFace(tess, j+1, &plen, &points, &uv, &ptype, &pin,
        &tlen, &tris, &tric);
    if (status != EGADS_SUCCESS) continue;
    for (k = 0; k < tlen; k++) {
        status = EG_localToGlobal(tess, j+1, tris[3*k ], &tin[0]);
        if (status != EGADS_SUCCESS)
            printf(" Error: EG_localToGlobal %d/%d = %d\n", j+1, tris[3*k ], status);
        status = EG_localToGlobal(tess, j+1, tris[3*k+1], &tin[1]);
        if (status != EGADS_SUCCESS)
            printf(" Error: EG_localToGlobal %d/%d = %d\n", j+1, tris[3*k+1], status);
    }
}

```

```
    status = EG_localToGlobal(tess, j+1, tris[3*k+2], &tin[2]);

    if (status != EGADS_SUCCESS)
        printf(" Error: EG_localToGlobal %d/%d = %d\n", j+1, tris[3*k+2], status);
    fprintf(fp, "%6d %6d %6d\n",tin[0], tin[1], tin[2]);
}
}
/* ...Component list*/
for (j = 0; j < ntriang; j++) fprintf(fp, "%6d\n", 1);
fclose(fp);

if (solid != bodies[i]) EG_deleteObject(solid);

}

/* cleanup and close */

status = EG_deleteObject(tess);

if (status != EGADS_SUCCESS) printf(" EG_deleteObject tess = %d\n", status);

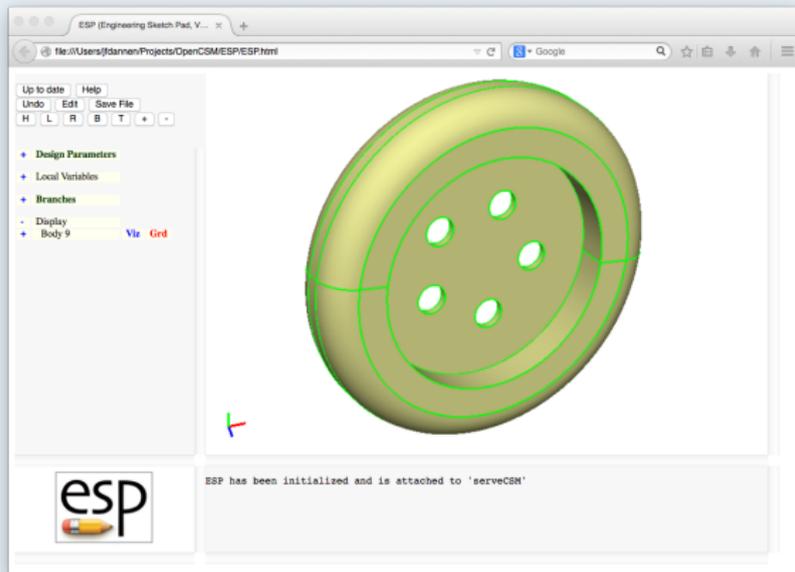
status = EG_deleteObject(model);

if (status != EGADS_SUCCESS) printf(" EG_deleteObject model = %d\n", status);

EG_close(context);

return 0;
}
```

## Example of both *Bottom Up* and *Top Down* Construction



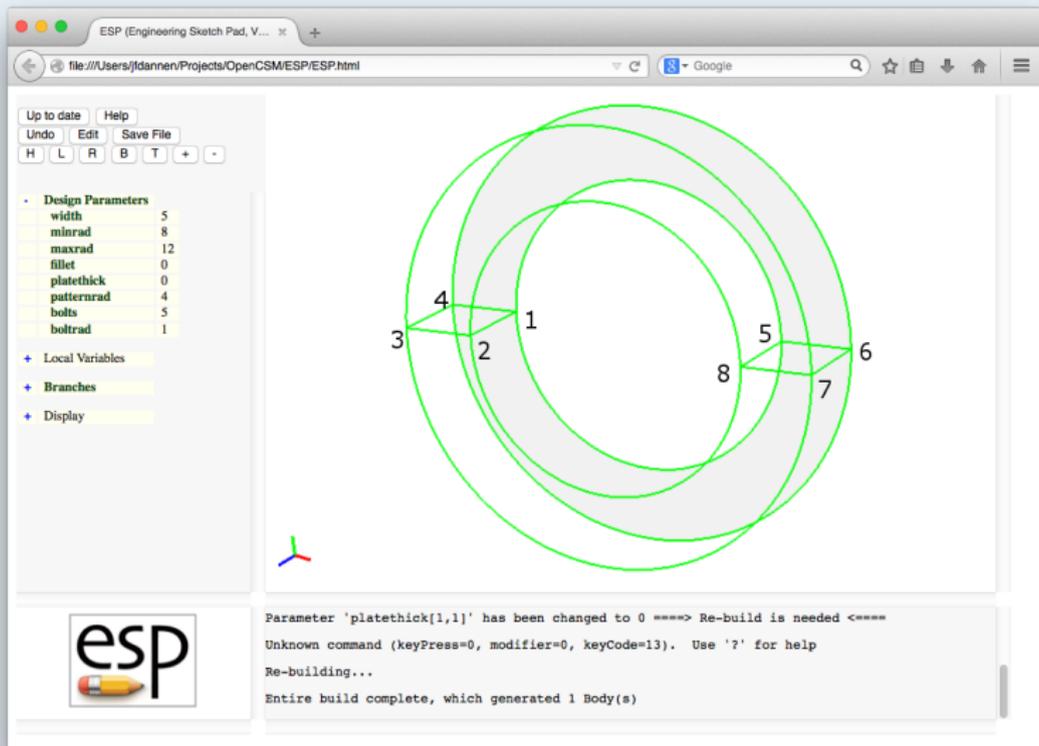
Name	Description
width	width
minrad	minimum radius
maxrad	maximum radius
fillet	fillet radius at outside
thick	wheel thickness
bolts	number of bolt holes
crad	radius of bolt circle
brad	radius of bolt hole

```
#define TWOPI      6.2831853071795862319959269

/* declarations */
int      status = EGADS_SUCCESS;
int      sense[20], oclass, mtype, nchild, *senses, i;
int      bolts;
double   width, minrad, maxrad, fillet, thick, crad, brad;
double   node1[3], node2[3], node3[3], node4[3], node5[3], node6[3], node7[3], node8[3];
double   cent1[3], cent2[3], axis1[3], axis2[3], axis3[3];
double   data[18], trange[2];
ego      context, enodes[8], ecurve[16], eedges[16], eloop, efaces[8], eshell;
ego      esurface[4], epcurve[4], ebody1, ebody2, ebody3, ebody4;
ego      elist[20], emodel, *echilds2, source, *echilds, eref, ebody;

/* set the parameter values */
width = 5.0;
minrad = 8.0;
maxrad = 12.0;
fillet = 2.0;
thick = 0.5;
bolts = 5;
crad = 5.0;
brad = 1.0;
```

## Locate and Make the Nodes



The screenshot shows the ESP (Engineering Sketch Pad) software interface. The main window displays a parametric tire model with 8 nodes (1-8) and a console window showing error messages.

**Design Parameters:**

Parameter	Value
width	5
minrad	8
maxrad	12
fillet	0
platethick	0
patternrad	4
bolts	5
boltrad	1

**Local Variables:**

- Branches
- Display

**Console Window:**

```
Parameter 'platethick[1,1]' has been changed to 0 ==> Re-build is needed <==>
Unknown command (keyPress=0, modifier=0, keyCode=13). Use '?' for help
Re-building...
Entire build complete, which generated 1 Body(s)
```

```

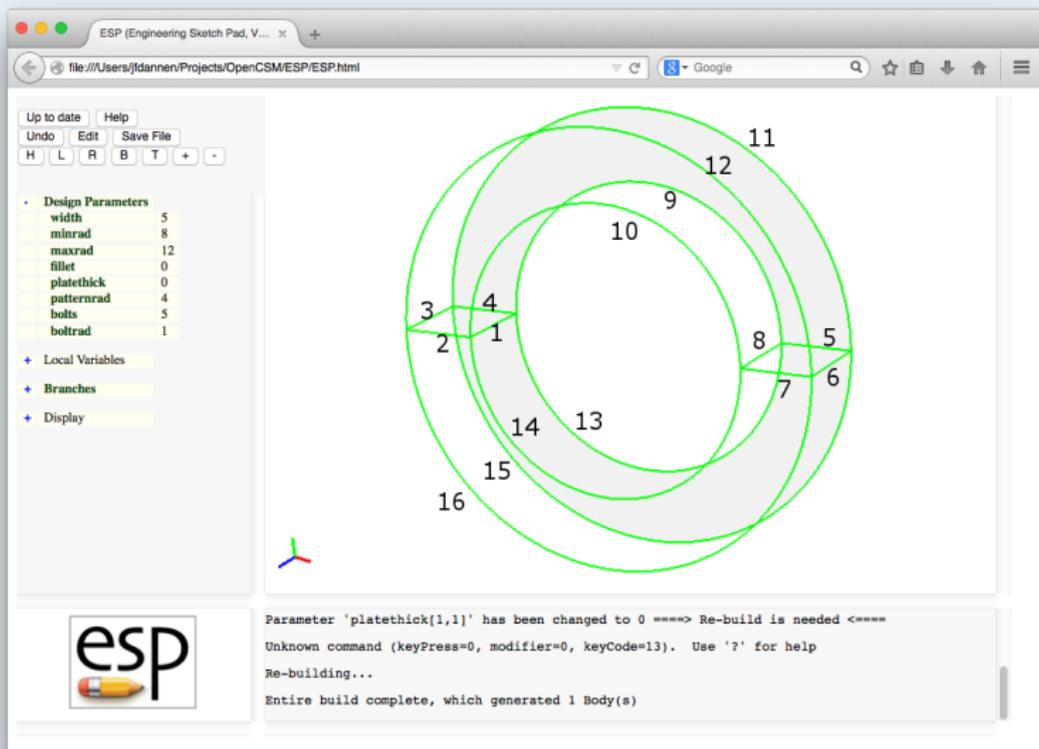
/* define a context */
status = EG_open(&context);
printf("EG_open -> status=%d\n", status);
if (status < EGADS_SUCCESS) exit(1);

/* Node locations */
node1[0] = -minrad; node1[1] = 0.0; node1[2] = -width / 2.0;
node2[0] = -minrad; node2[1] = 0.0; node2[2] = width / 2.0;
node3[0] = -maxrad; node3[1] = 0.0; node3[2] = width / 2.0;
node4[0] = -maxrad; node4[1] = 0.0; node4[2] = -width / 2.0;
node5[0] = minrad; node5[1] = 0.0; node5[2] = -width / 2.0;
node6[0] = maxrad; node6[1] = 0.0; node6[2] = -width / 2.0;
node7[0] = maxrad; node7[1] = 0.0; node7[2] = width / 2.0;
node8[0] = minrad; node8[1] = 0.0; node8[2] = width / 2.0;

/* make the Nodes */
status = EG_makeTopology(context, NULL, NODE, 0, node1, 0, NULL, NULL, &enodes[0]);
if (status != EGADS_SUCCESS) goto cleanup;
status = EG_makeTopology(context, NULL, NODE, 0, node2, 0, NULL, NULL, &enodes[1]);
if (status != EGADS_SUCCESS) goto cleanup;
status = EG_makeTopology(context, NULL, NODE, 0, node3, 0, NULL, NULL, &enodes[2]);
if (status != EGADS_SUCCESS) goto cleanup;
status = EG_makeTopology(context, NULL, NODE, 0, node4, 0, NULL, NULL, &enodes[3]);
if (status != EGADS_SUCCESS) goto cleanup;
status = EG_makeTopology(context, NULL, NODE, 0, node5, 0, NULL, NULL, &enodes[4]);
if (status != EGADS_SUCCESS) goto cleanup;
status = EG_makeTopology(context, NULL, NODE, 0, node6, 0, NULL, NULL, &enodes[5]);
if (status != EGADS_SUCCESS) goto cleanup;
status = EG_makeTopology(context, NULL, NODE, 0, node7, 0, NULL, NULL, &enodes[6]);
if (status != EGADS_SUCCESS) goto cleanup;
status = EG_makeTopology(context, NULL, NODE, 0, node8, 0, NULL, NULL, &enodes[7]);
if (status != EGADS_SUCCESS) goto cleanup;

```

## Locate and Make the Edges



The screenshot shows the ESP (Engineering Sketch Pad) software interface. The main workspace displays a 3D model of a tire with 16 edges highlighted in green and numbered 1 through 16. The edges are arranged in a circular pattern, with 1-4 on the left side, 5-8 on the right side, and 9-16 forming the rest of the tire's profile.

On the left side, there is a menu bar with options: Up to date, Help, Undo, Edit, Save File, and a toolbar with icons for Home (H), Left (L), Right (R), Bold (B), Text (T), and a minus sign (-). Below the menu is a list of Design Parameters:

- width: 5
- minrad: 8
- maxrad: 12
- fillet: 0
- platethick: 0
- patternrad: 4
- bolts: 5
- boltrad: 1

Below the design parameters are sections for Local Variables, Branches, and Display, each with a plus sign icon.

At the bottom of the interface, there is a console window with the following text:

```
Parameter 'platethick[1,1]' has been changed to 0 ===== Re-build is needed <=====  
Unknown command (keyPress=0, modifier=0, keyCode=13). Use '?' for help  
Re-building...  
Entire build complete, which generated 1 Body(s)
```

```

/* make (linear) Edge 1 */
data[0] = node1[0];
data[1] = node1[1];
data[2] = node1[2];
data[3] = node2[0] - node1[0];
data[4] = node2[1] - node1[1];
data[5] = node2[2] - node1[2];

status = EG_makeGeometry(context, CURVE, LINE, NULL, NULL, data, &ecurve[0]);

if (status != EGADS_SUCCESS) goto cleanup;

status = EG_invEvaluate(ecurve[0], node1, &trange[0], data);

if (status != EGADS_SUCCESS) goto cleanup;

status = EG_invEvaluate(ecurve[0], node2, &trange[1], data);

if (status != EGADS_SUCCESS) goto cleanup;

elist[0] = enodes[0];
elist[1] = enodes[1];

status = EG_makeTopology(context, ecurve[0], EDGE, TWONODE, trange, 2, elist, NULL,
                        &edges[0]);

if (status != EGADS_SUCCESS) goto cleanup;

```

```

/* data used in creating the arcs */
axis1[0] = 1;   axis1[1] = 0;   axis1[2] = 0;
axis2[0] = 0;   axis2[1] = 1;   axis2[2] = 0;
axis3[0] = 0;   axis3[1] = 0;   axis3[2] = 1;
cent1[0] = 0;   cent1[1] = 0;   cent1[2] = -width / 2;
cent2[0] = 0;   cent2[1] = 0;   cent2[2] = width / 2;

/* make (circular) Edge 9 */
data[0] = cent1[0];   data[1] = cent1[1];   data[2] = cent1[2];
data[3] = axis1[0];   data[4] = axis1[1];   data[5] = axis1[2];
data[6] = axis2[0];   data[7] = axis2[1];   data[8] = axis2[2];   data[9] = minrad;

status = EG_makeGeometry(context, CURVE, CIRCLE, NULL, NULL, data, &ecurve[8]);
if (status != EGADS_SUCCESS) goto cleanup;

status = EG_invEvaluate(ecurve[8], node5, &trange[0], data);
if (status != EGADS_SUCCESS) goto cleanup;

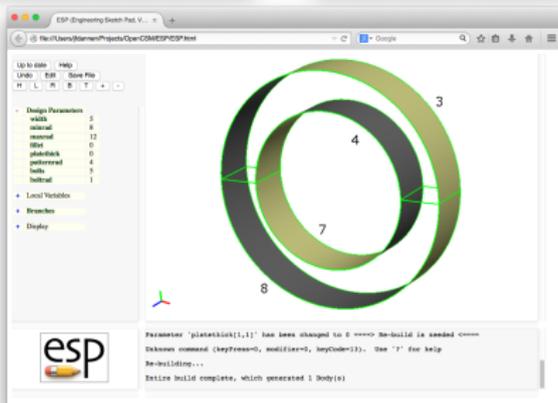
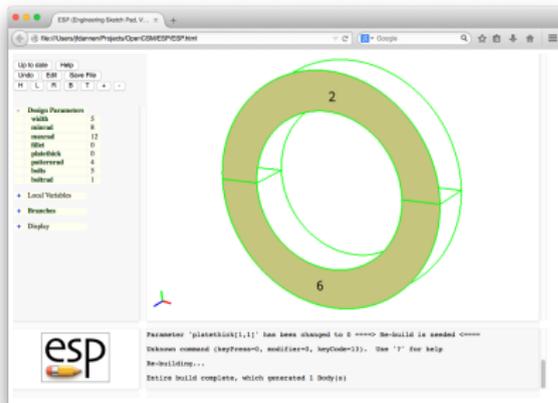
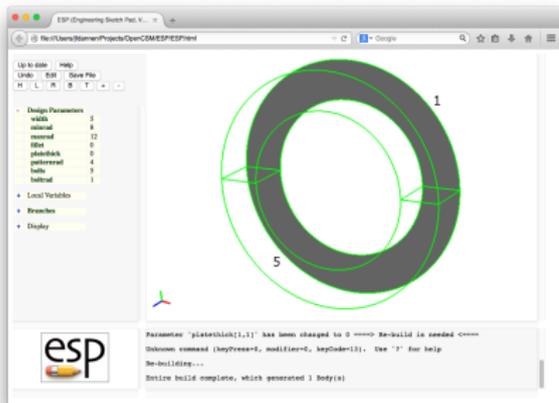
status = EG_invEvaluate(ecurve[8], node1, &trange[1], data);
if (status != EGADS_SUCCESS) goto cleanup;
if (trange[0] > trange[1]) trange[1] += TWOPI;   /* ensure trange[1] > trange[0] */

elist[0] = enodes[4];
elist[1] = enodes[0];
status = EG_makeTopology(context, ecurve[8], EDGE, TWONODE, trange, 2, elist, NULL,
                        &edges[8]);

if (status != EGADS_SUCCESS) goto cleanup;

```

# Programming Example – Parametric Tire (8)



```

/* make the outer cylindrical surface */
data[0] = cent1[0];   data[1] = cent1[1];   data[2] = cent1[2];
data[3] = axis1[0];  data[4] = axis1[1];   data[5] = axis1[2];
data[6] = axis2[0];  data[7] = axis2[1];   data[8] = axis2[2];
data[9] = axis3[0];  data[10] = axis3[1];  data[11] = axis3[2];  data[12] = maxrad;
status = EG_makeGeometry(context, SURFACE, CYLINDRICAL, NULL, NULL, data, &esurface[0]);

if (status != EGADS_SUCCESS) goto cleanup;

/* make the inner cylindrical surface */
data[0] = cent1[0];   data[1] = cent1[1];   data[2] = cent1[2];
data[3] = axis1[0];  data[4] = axis1[1];   data[5] = axis1[2];
data[6] = axis2[0];  data[7] = axis2[1];   data[8] = axis2[2];
data[9] = axis3[0];  data[10] = axis3[1];  data[11] = axis3[2];  data[12] = minrad;

status = EG_makeGeometry(context, SURFACE, CYLINDRICAL, NULL, NULL, data, &esurface[1]);

if (status != EGADS_SUCCESS) goto cleanup;

/* make (planar) Face 1 */
sense[0] = SFORWARD;  sense[1] = SREVERSE;  sense[2] = SFORWARD;  sense[3] = SFORWARD;
elist[0] = eedges[3];  elist[1] = eedges[8];  elist[2] = eedges[4];  elist[3] = eedges[10];
status = EG_makeTopology(context, NULL, LOOP, CLOSED, NULL, 4, elist, sense, &eloop);

if (status != EGADS_SUCCESS) goto cleanup;

status = EG_makeFace(eloop, SFORWARD, NULL, &efaces[0]);

if (status != EGADS_SUCCESS) goto cleanup;

```

```

/* make (cylindrical) Face 3 */
status = EG_otherCurve(esurface[0], ecurve[2], 0, &pcurve[0]);
if (status != EGADS_SUCCESS) goto cleanup;

status = EG_otherCurve(esurface[0], ecurve[10], 0, &pcurve[1]);
if (status != EGADS_SUCCESS) goto cleanup;

status = EG_otherCurve(esurface[0], ecurve[5], 0, &pcurve[2]);
if (status != EGADS_SUCCESS) goto cleanup;

status = EG_otherCurve(esurface[0], ecurve[11], 0, &pcurve[3]);
if (status != EGADS_SUCCESS) goto cleanup;

sense[0] = SFORWARD;   sense[1] = SREVERSE;   sense[2] = SFORWARD;   sense[3] = SFORWARD;
elist[0] = eedges[2];  elist[1] = eedges[10];  elist[2] = eedges[5];  elist[3] = eedges[11];
elist[4] = epcurve[0]; elist[5] = epcurve[1];  elist[6] = epcurve[2]; elist[7] = epcurve[3];
status = EG_makeTopology(context, esurface[0], LOOP, CLOSED, NULL, 4, elist, sense, &eloop);
if (status != EGADS_SUCCESS) goto cleanup;

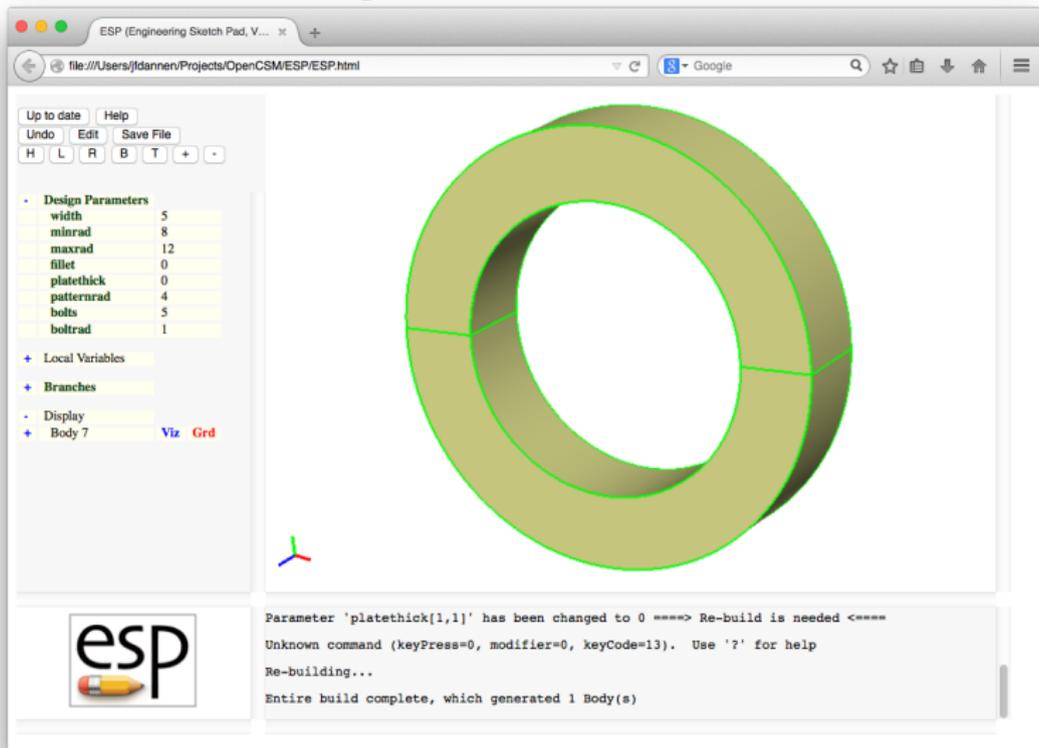
status = EG_makeTopology(context, esurface[0], FACE, SREVERSE, NULL, 1, &eloop, sense,
                          &efaces[2]);
if (status != EGADS_SUCCESS) goto cleanup;
:
:

/* make the shell and initial Body */
status = EG_makeTopology(context, NULL, SHELL, CLOSED, NULL, 8, efaces, NULL, &eshell);
if (status != EGADS_SUCCESS) goto cleanup;

status = EG_makeTopology(context, NULL, BODY, SOLIDBODY, NULL, 1, &eshell, NULL, &ebody1);
if (status != EGADS_SUCCESS) goto cleanup;

```

## Complete *Bottom UP* build



The screenshot shows the ESP (Engineering Sketch Pad) software interface. The main window displays a 3D model of a tire, which is a torus-like shape with a central hole. The tire is rendered in a light green color with a darker green outline. The interface includes a menu bar at the top with options like 'Up to date', 'Help', 'Undo', 'Edit', and 'Save File'. Below the menu bar is a toolbar with icons for 'H', 'L', 'R', 'B', 'T', '+', and '-'. On the left side, there is a 'Design Parameters' panel with a table of parameters:

Design Parameters	Value
width	5
minrad	8
maxrad	12
fillet	0
platethick	0
patternrad	4
bolts	5
boltrad	1

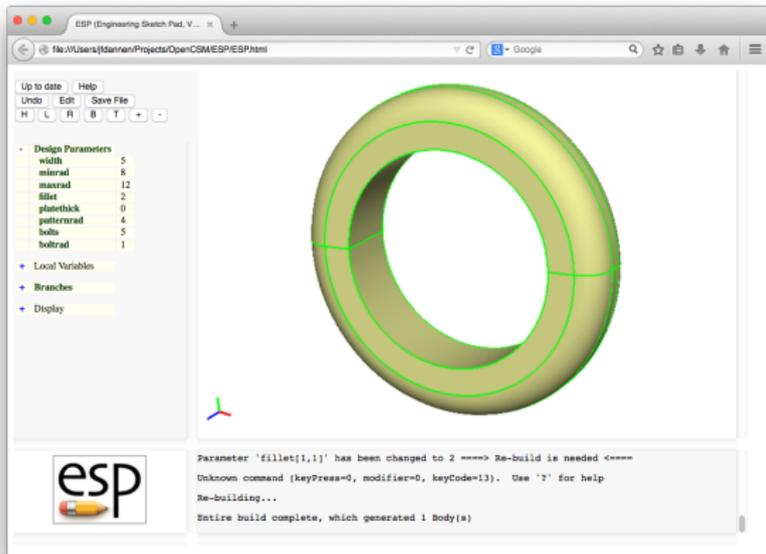
Below the design parameters panel, there are sections for 'Local Variables', 'Branches', 'Display', and 'Body 7' (with 'Viz' and 'Grd' options). At the bottom of the interface, there is a console window displaying the following text:

```
Parameter 'platethick[1,1]' has been changed to 0 =====> Re-build is needed <=====
Unknown command (keyPress=0, modifier=0, keyCode=13). Use '?' for help
Re-building...
Entire build complete, which generated 1 Body(s)
```

```

/* add fillets if desired (result is ebody2) */
if (fillet > 0.0) {
  eelist[0] = eedges[10]; eelist[1] = eedges[11]; eelist[2] = eedges[14]; eelist[3] = eedges[15];
  status = EG_filletBody(ebody1, 4, eelist, fillet, &ebody2, NULL);
  if (status != EGADS_SUCCESS) goto cleanup;
  status = EG_deleteObject(ebody1);
  if (status != EGADS_SUCCESS) goto cleanup;
} else {
  ebody2 = ebody1;
}

```



```

if (thick > 0.0) {
    data[0] = 0;    data[1] = 0;    data[2] = thick / 2;
    data[3] = 0;    data[4] = 0;    data[5] = -thick / 2;
    data[6] = (minrad + maxrad) / 2;
    status = EG_makeSolidBody(context, CYLINDER, data, &tbody3);
    if (status != EGADS_SUCCESS) goto cleanup;

    status = EG_solidBoolean(ebody2, ebody3, FUSION, &emodel);
    if (status != EGADS_SUCCESS) goto cleanup;

    status = EG_deleteObject(ebody2);
    if (status != EGADS_SUCCESS) goto cleanup;
    status = EG_deleteObject(ebody3);
    if (status != EGADS_SUCCESS) goto cleanup;
    status = EG_getTopology(emodel, &eref, &oclass, &mtype, data, &nchild, &echilds, &senses);
    if (status != EGADS_SUCCESS) goto cleanup;

    if (oclass != MODEL || nchild != 1) {
        printf("No model or are returning more than one body ochild = %d, nchild = %d/n",
            oclass, nchild);
        status = -999;
        goto cleanup;
    }

    status = EG_copyObject(echild[0], NULL, &source);
    if (status != EGADS_SUCCESS) goto cleanup;
    status = EG_deleteObject(emodel);
    if (status != EGADS_SUCCESS) goto cleanup;
}

```

```
/* add bolt holes */
for (i = 0; i < bolts; i++) {
    data[0] = crad * cos(i * (TWOPI / bolts));
    data[1] = crad * sin(i * (TWOPI / bolts));
    data[2] = thick / 2.0;
    data[3] = crad * cos(i * (TWOPI / bolts));
    data[4] = crad * sin(i * (TWOPI / bolts));
    data[5] = -thick / 2.0;
    data[6] = brad;

    status = EG_makeSolidBody(context, CYLINDER, data, &ebody4);
    if (status != EGADS_SUCCESS) goto cleanup;

    status = EG_solidBoolean(source, ebody4, SUBTRACTION, &emodel);
    if (status != EGADS_SUCCESS) goto cleanup;

    status = EG_deleteObject(source);
    if (status != EGADS_SUCCESS) goto cleanup;
    status = EG_deleteObject(ebody4);
    if (status != EGADS_SUCCESS) goto cleanup;

    status = EG_getTopology(emodel, &eref, &oclass, &mtype, data, &nchild, &echilds2,
        &senses);
    if (status != EGADS_SUCCESS) goto cleanup;

    if (oclass != MODEL || nchild != 1) {
        printf("Not a model or are returning more than one body ochild = %d, nchild = %d/n",
            oclass, nchild);
        status = -999;
        goto cleanup;
    }
}
```

```

    status = EG_copyObject(echilds2[0], NULL, &source);
    if (status != EGADS_SUCCESS) goto cleanup;

    status = EG_deleteObject(emodel);
    if (status != EGADS_SUCCESS) goto cleanup;
}
    ebody = source;
} else {
    ebody = ebody2;
}

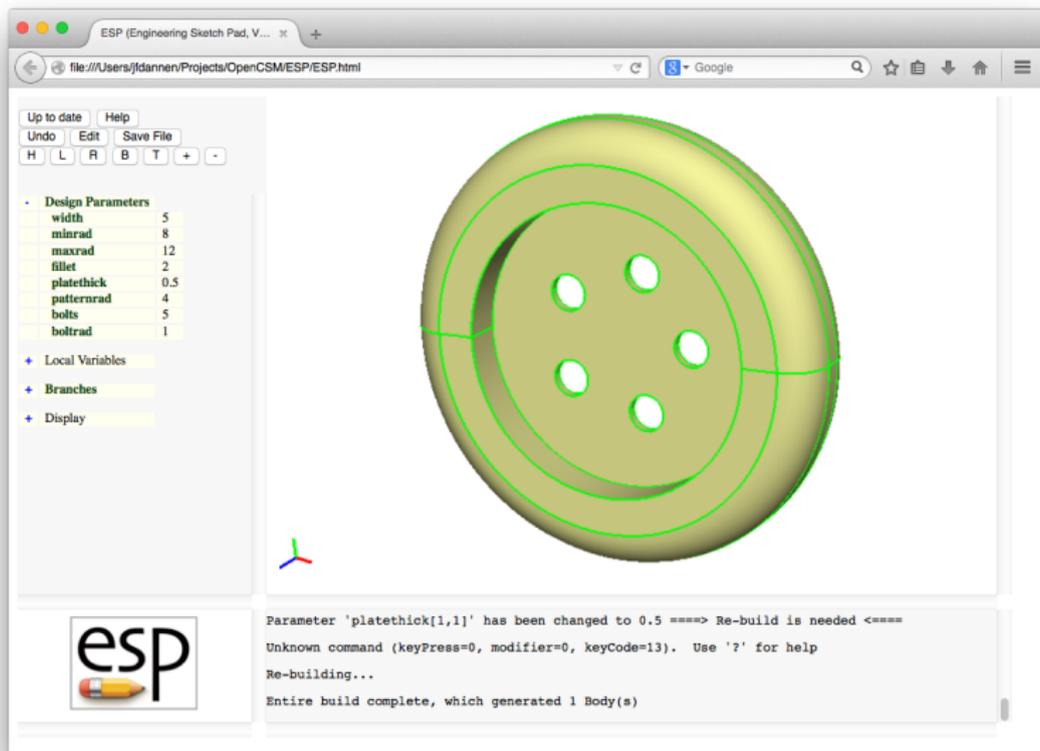
/* make and dump the model */
status = EG_makeTopology(context, NULL, MODEL, 0, NULL, 1, &ebody, NULL, &emodel);
printf("EG_makeTopology -> status=%d\n", status);
if (status != EGADS_SUCCESS) goto cleanup;

status = EG_saveModel(emodel, "tire.egads");
printf("EG_saveModel -> status=%d\n", status);

/* cleanup */
status = EG_deleteObject(emodel);
printf("EG_close -> status=%d\n", status);

cleanup:
    status = EG_close(context);
    printf("EG_close -> status=%d\n", status);
    return 0;
}

```



The screenshot shows the ESP (Engineering Sketch Pad) software interface. The main window displays a 3D model of a parametric tire. The left sidebar contains a menu with options like 'Up to date', 'Help', 'Undo', 'Edit', 'Save File', and 'Design Parameters'. The 'Design Parameters' section lists various parameters such as width, minrad, maxrad, fillet, platethick, patternrad, bolts, and boltrad. The console window at the bottom shows a message indicating that the parameter 'platethick[1,1]' has been changed to 0.5, requiring a re-build. The console also displays an error message: 'Unknown command (keyPress=0, modifier=0, keyCode=13). Use '?' for help' and 'Re-building...'. The console concludes with 'Entire build complete, which generated 1 Body(\*)'.

Parameter 'platethick[1,1]' has been changed to 0.5 ==> Re-build is needed <==>  
 Unknown command (keyPress=0, modifier=0, keyCode=13). Use '?' for help  
 Re-building...  
 Entire build complete, which generated 1 Body(\*)

- The source to these programming examples can be found at:  
\$ESP\_ROOT/doc/EGADS/Tutorial
- Other EGADS examples can be found in the ESP Distribution:  
\$ESP\_ROOT/src/EGADS/examples
- OpenCSM
  - The parametric *engine* on top of EGADS (like SolidWorks is to Parasolid)
  - Basically *Top Down* but can support *Bottom Up* builds by UDPs
  - Tire UDP – \$ESP\_ROOT/data/training/session8/udpTire.c
  - OpenCSM **User Tutorial** coming up next
- A note on OpenCASCADE:  
Though EGADS was originally a *thin* layer over OpenCASCADE many of the methods that did not work well have been replaced.  
Next on the list – the SBOs!

## ESP's Current Support

- Computational Aircraft Prototype Synthesis (CAPS)  
AFRL Contract FA8050-14-C-2472  
Ed Alyanak (AFRL/RQVC), Technical Monitor
- PAGODA: PARallel GeOMetry for Design and Analysis  
NASA Aeronautics NRA #NNX16AQ15A  
Bill Jones (LaRC), Technical Monitor
  - EGADS-lite for HPC environments & threaded SBOs

Software available at:

**<http://acdl.mit.edu/ESP>**