



The Use of Geometry from within the Engineering Sketch Pad – Rev 1.19 The EGADS API

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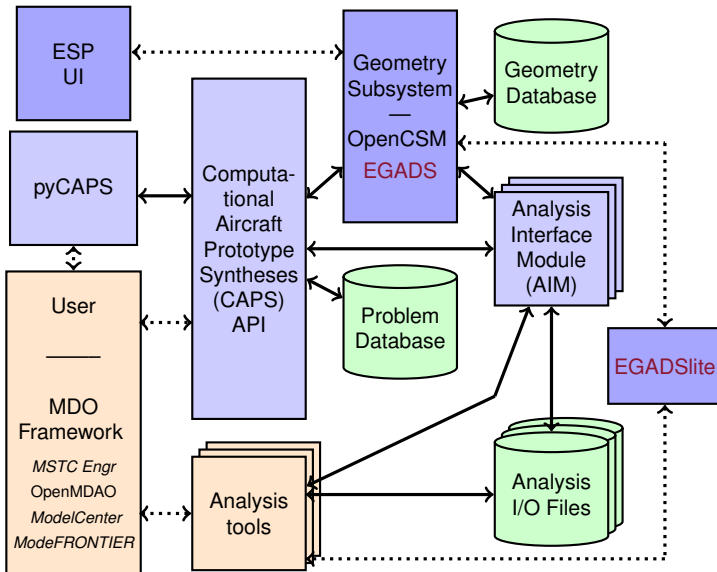
- Background & ESP
- Objects
 - Geometry
 - Topology
 - Tessellation
- Meshing
- Programming Examples
- Closing Remarks

ESP is:

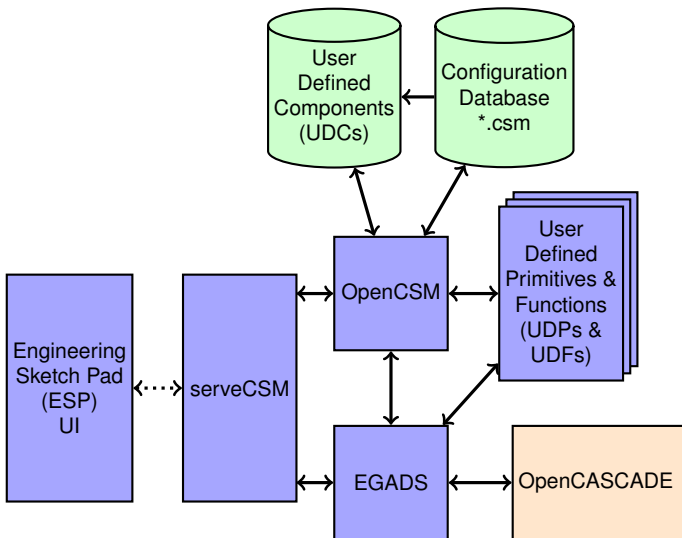
- a parametric geometry creation and manipulation system designed to **fully support** the analysis and design of aerospace vehicles (**aCAD**)
- a stand-alone system for the development of geometric models
- can be embedded into other software systems to support their geometric and process needs

ESP is not:

- a full-featured mechanical computer-aided design (**mCAD**) system
- a system to be used for creating “drawings”
- an MDO Framework (but can support them)



ESP's Geometry Subsystem Architecture



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

- reduces OpenCASCADE's 17,000 methods to about ~100 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

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

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

EGADSlite – for HPC Environments

- No construction supported
- Same API and Object model as EGADS
 - Can use EGADS to prototype/build EGADSlite code
- Suitable for an MPI setup:
 - Data export from EGADS via a *stream*
 - Data import to EGADSlite from the *stream*
 - *Stream* setup to Broadcast (or write to disk)
- ANSI C – No OpenCASCADE
- Tiny memory footprint
- Thread safe and scalable
 - EGADS' OpenCASCADE evaluation functions replaced with those written for EGADSlite
- See [\\$ESP_ROOT/externApps/Pagoda/EGADSserver](#) for an MPI example

- 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
- *Effective Topology*
 - EEdge, ELoop, EFace, EShell, EBody

See `$ESP_ROOT/include/egadsTypes.h` for a list of **defines**

- Attributes – metadata consisting of name/value pairs
 - Unique name – no spaces
 - A single type: Integer, Real, String, CSys, Pointer (not persistent)
 - A length (for Integers & Reals)
- 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 may be 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 $[u, v] = h(t)$

curve

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

Boundary Representation – BRep

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

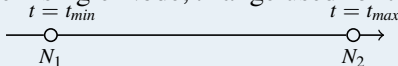
- Nodes that bound Edges may not be on underlying curves
- Edges in the Loops that trim the Face may not sit on the surface hence the use of pcurses

Node

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

Edge

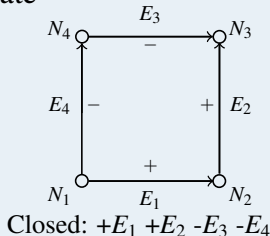
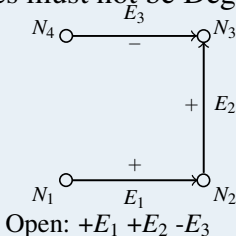
- Has a 3D curve (if not Degenerate)
- Has a t range (t_{min} to t_{max} , where $t_{min} < t_{max}$)
Note: The positive orientation is going from t_{min} to t_{max}
- Has a Node for t_{min} and for t_{max} – can be the same Node
- Types:
 - OneNode – periodic
 - TwoNode – normal
 - Degenerate – single 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
 - No Edges must not be Degenerate

Types:



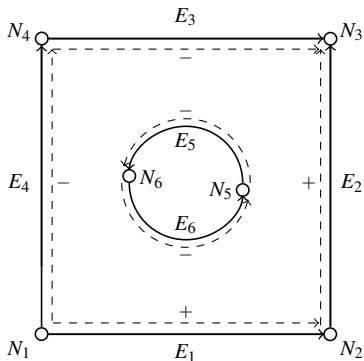
Loop – with a reference surface

- ① Collections of Edges followed by a corresponding collection of pcurves that define the $[u, v]$ trimming on the surface
- An ordered collection of Edge objects with associated senses
- 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)
- Trims the surface by maintaining material to the left of the running Loop
- An Edge may be found in a Loop twice (with opposite senses) and with different pcurves.
- Types: Open or Closed (comes back on itself)

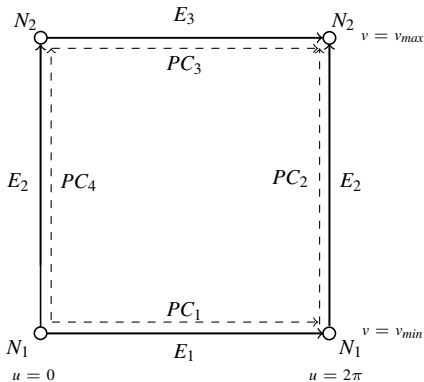
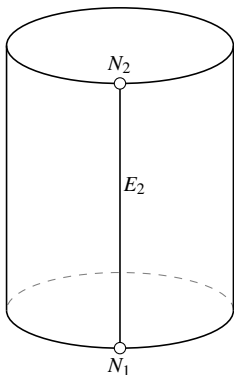
Face

- 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 Loop's 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)



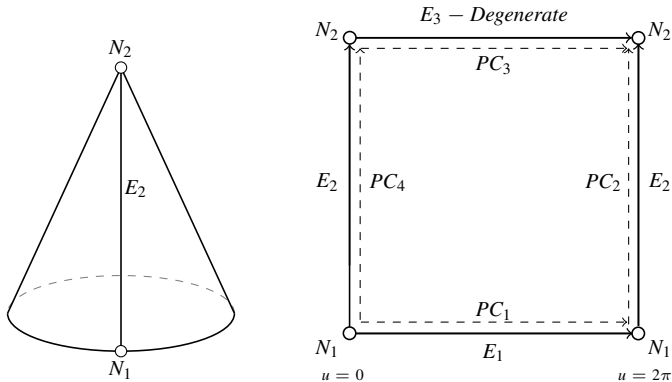
- Outer Loop – right handed/counterclockwise: $+E_1 +E_2 -E_3 -E_4$
- Inner Loop – left handed/clockwise: $-E_5 -E_6$



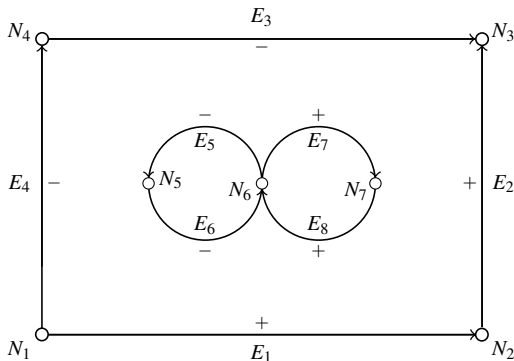
Unrolled periodic cylinder Face

Single Outer Loop – right handed/counterclockwise:

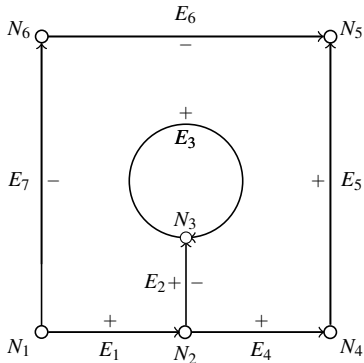
$$+E_1 +E_2 -E_3 -E_2$$



Unrolled Cone



- Outer Loop – right handed/counterclockwise: $+E_1 +E_2 -E_3 -E_4$
- Inner Loop #1 – left handed/clockwise: $-E_5 -E_6$
- Inner Loop #2 – left handed/clockwise: $+E_7 +E_8$



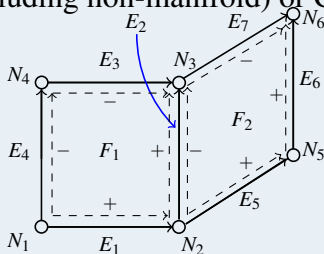
Single Outer Loop – right handed/counterclockwise:

$$+E_1 +E_2 +E_3 -E_2 +E_4 +E_5 -E_6 -E_7$$

Note: PCurve the same for both sides of E_2

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

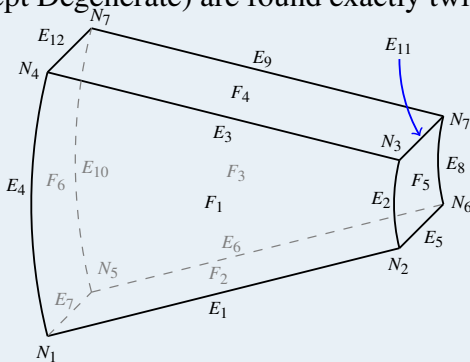


Face #1 Loop: $+E_1 +E_2 -E_3 -E_4$

Face #2 Loop: $+E_5 +E_6 -E_7 -E_2$

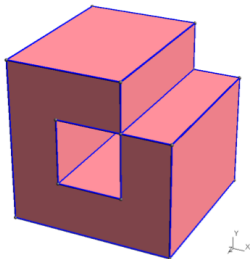
SolidBody

- Manifold collection of one or more Closed Shells
- One outer Shell (sense = 1); any number of inner (sense = -1)
- Edges (except Degenerate) are found exactly twice (sense = ± 1)

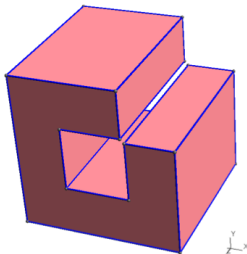


Simple SolidBody: 8 Nodes, 12 Edges, 6 Loops and 6 Faces

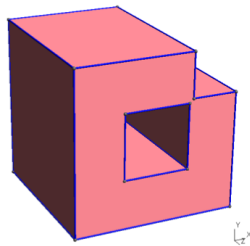
Manifold vs. Nonmanifold



nonmanifold



manifold



manifold

figure stolen from "An introduction to Geometrical Modelling and Mesh Generation: The Gmsh Companion" by Christophe Geuzaine, Emilie Marchandise & Jean-François Remacle – used without permission!

Can the geometry be manufactured?

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

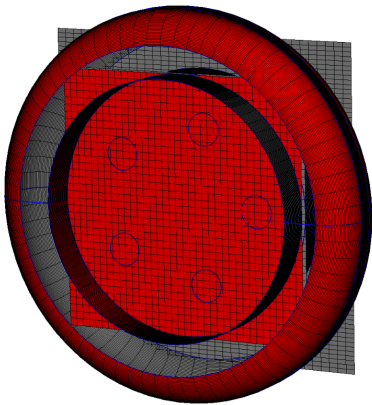
- **makeLoop**
 - Connects unrelated (via Nodes) Edges from a list
 - Uses input tolerance to match entities
 - Result may be multiple Loops
- **makeFace**
 - From Closed Planar Loop
 - From surface with limits
- **sewFaces**
 - Connects Faces with unrelated Topology
 - Uses input tolerance to match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

Geometry

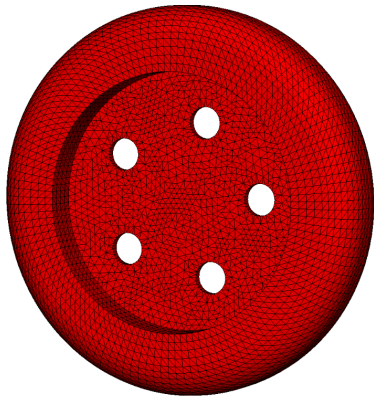
- Unconnected discretization of a range of the Object
 - Polyline for curves at constant t increments
 - Regular grid for surfaces at constant increments (isoclines)

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

See [\\$ESP_ROOT/doc/EGADS/egads.pdf](#) for a detailed description of all of the functions.

See [\\$ESP_ROOT/include/egads.h](#) for a complete listing of the functions.

See [\\$ESP_ROOT/include/egadsErrors.h](#) for a list of the return code *defines*.

Deleting Objects

- Use the function `EG_deleteObject` (or `ig_deleteobject`)
EGADSLite has a limited ability to delete Objects
- 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

Point Queries – Evaluations

- Derivatives – EGADS/EGADSLite provides 1st and 2nd
 - Curves: at $t \Rightarrow X, \frac{dX}{dt}$ and $\frac{d^2X}{dt^2}$
tangency & curvature*
 - Surfaces: at $[u, v] \Rightarrow X, \frac{dX}{du}, \frac{dX}{dv}, \frac{d^2X}{du^2}, \frac{d^2X}{dv^2}$ and $\frac{d^2X}{dudv}$
normal $(\frac{dX}{du} \otimes \frac{dX}{dv})^\dagger$ & curvature*
- Continuity – Derivative unavailable for less than C^2
 - Degenerate points (Poles of a sphere, Apex of a cone)
 - BSpline/NURBS with *multiplicity of knots*
 - Appropriate derivatives are returned as 0.0

* Note: Returns Radius of Curvature(s) and the associated direction(s)

† Note: The Face normal may be opposite that of the surface

Point Queries – Inverse Evaluations

pcurve: $t = \mathbf{h}^{-1}(u, v)$

curve/Edge: $t = \mathbf{g}^{-1}(x, y, z)$

surface/Face: $[u, v] = \mathbf{f}^{-1}(x, y, z)$

Accomplished with 1st and 2nd derivatives from Evaluation

- Optimization (Newton-Raphson)
 - Minimize distance to requested position – needs start location not projection in a particular direction
 - stopping criteria – only as accurate as this ϵ
 - needs clear line-of-site to target (wing near TE on wrong side)
 - can get stuck in local minima
 - periodicity – result may need to be adjusted by the period
- Costly when robust (requires many seed locations)
- When invoked with Edge/Face will limit to result to the bounds

Point Queries – Contained within Predicates

Answers the question: Is the specified location in this entity?

Useful meshing queries:

- Is this $[u, v]$ in the Face (`EG_inFace`)?
 - Is this $[u, v]$ in the Face's valid parametric box?
 - Is this $[u, v]$ trimmed away or in a hole?
- Is this X contained within the *Solid* (`EG_inTopology`)?
 - Performed by ray-casting and counting crossings
 - Can be expensive
- Ambiguous (within the tolerance and) near bounds

It may be better to answer these queries in a discrete setting

Surface Degeneracies

If the surface meshing algorithm has smoothness assumptions, then knowledge of degenerate locations is critical!

- Degenerate points (Poles of a sphere, Apex of a cone)
 - You can depend on these points being Nodes
 - Degenerate Edges mark these locations
 - Zero (or close) derivatives are returned for an Evaluation
- BSpline/NURBS with *multiplicity of knots* — C^1 or C^0
 - Much harder to deal with!
 - Will probably also have Edge curves with *kinks*
 - EG_loadModel has a flag that splits Faces/Edges at C^1 and/or C^0 locations (does not change the geometry) and places *kinks* at topological bounds
 - If you are constructing the geometry – **DON'T DO THIS!**

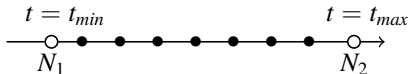
Dimensional Strategy

First mesh all of the Edges and then the Faces:

- Set the boundary vertices from lower in the topological hierarchy
- Mesh the interior
- Assume that C^0 locations are at bounds

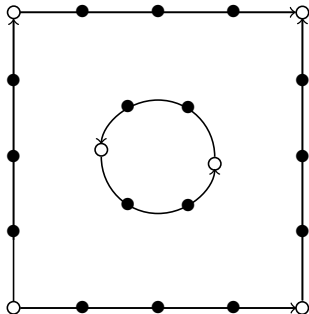
Discretizing Edges

- Set the start and end Node positions (can be the same)
- Evaluate at t_{min} & t_{max} and compare to Node positions
gets local (endpoint) tolerances
- Use a scheme to distribute vertices along the Edge (t or other)
do not add vertices at the ends within the Node's local tolerance



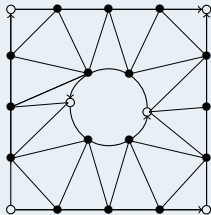
Discretizing Faces

- Foreach Loop that bounds the Face:
 - Collect the Edge discretization *tail to head-1* or *head to tail-1* based on the Edge's sense in the Loop
 - Use the Edge vertex t value `EG_getEdgeUV` to get $[u, v]$
 - Makes a 2D closed set of line segments & 3D bounds for the Face



Discretizing Faces – continued

- Any closed 2D region can be triangulated
No additional vertices are needed



- Use a scheme to enhance the initial triangulation
 - Query in X and insert in $[u, v]$
 - When a triangle side is on an Edge/Node care should be taken:
Compare X with the surface/Face evaluation at $[u, v]$
Do not add vertices within that local tolerance

```
#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, &nface, &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, &tric);

    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, &pinindex,
                           &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);

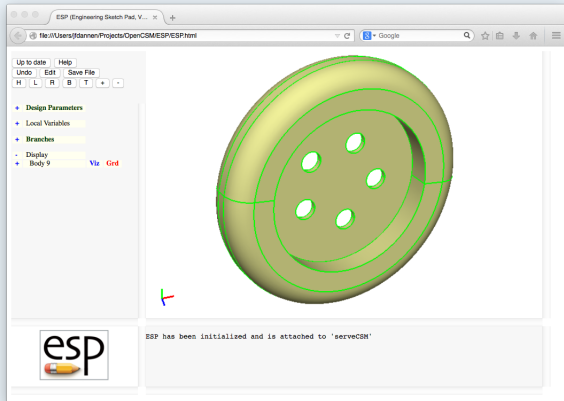
if (status != EGADS_SUCCESS) printf(" EG_deleteObject model = %d\n", status);

EG_close(context);

return 0;
}

```

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



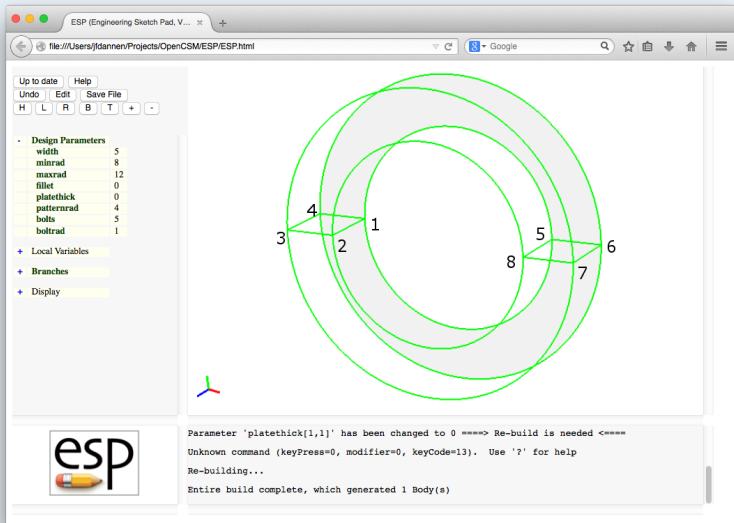
Name	Description
width	width
minrad	minimum radius
maxrad	maximum radius
fillet	fillet radius at outside
thick	wheel thickness
bolts	number of bolt holes
crad	radius of bolt circle
brad	radius of bolt hole

```
#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 green outline. The left sidebar contains a menu with 'Up to date', 'Help', 'Undo', 'Edit', 'Save File', and 'H L R B T + -'. Below the menu is a 'Design Parameters' section with a table of parameters:

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

Below the table are sections for 'Local Variables', 'Branches', and 'Display'. The bottom console window shows 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)
```

```

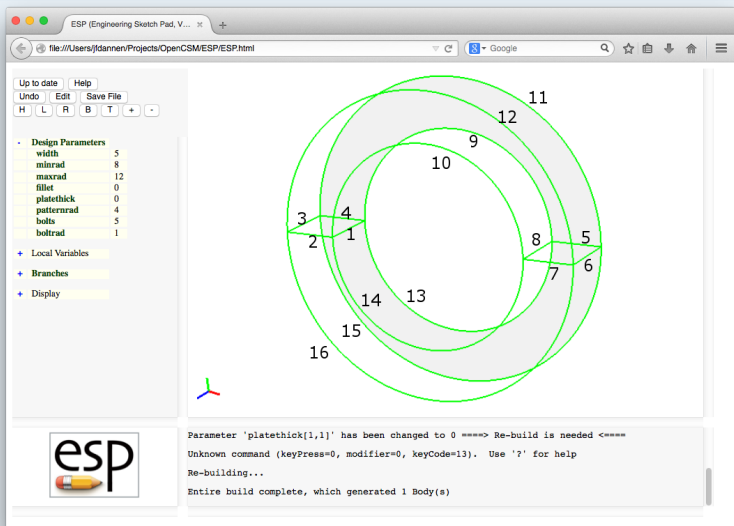
/* define a context */
status = EG_open(&context);
printf("EG_open -> status=%d\n", status);
if (status < EGADS_SUCCESS) exit(1);

/* 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 window displays a parametric tire model with 16 numbered edges. The edges are labeled 1 through 16, with 1-4 forming the top rim, 5-8 forming the right side, 9-12 forming the bottom rim, and 13-16 forming the left side. The tire is shaded in light gray.

On the left side, there is a menu bar with options: Up to date, Help, Undo, Edit, Save File. Below the menu bar is a toolbar with icons for H, L, R, B, T, and a minus sign. A list of Design Parameters is shown:

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

Below the design parameters are sections for Local Variables, Branches, and Display.

At the bottom left is the ESP logo. At the bottom right 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] */

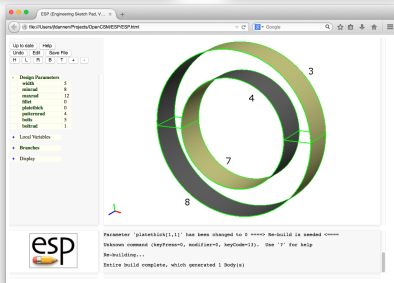
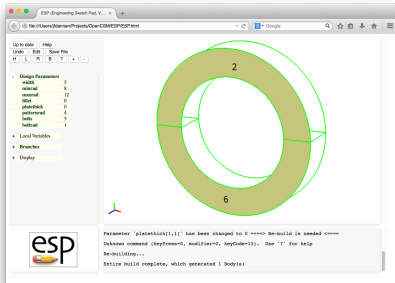
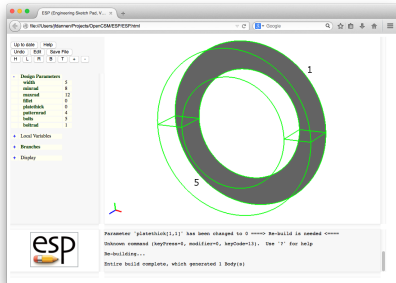
elist[0] = enodes[4];
elist[1] = enodes[0];

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;

```

```

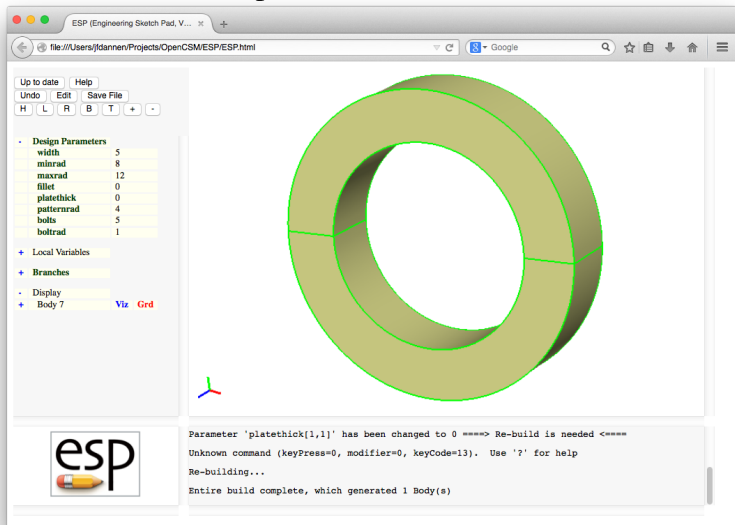
/* make (cylindrical) Face 3 */
status = EG_otherCurve(esurface[0], ecurve[2], 0, &epcurve[0]);
if (status != EGADS_SUCCESS) goto cleanup;
status = EG_otherCurve(esurface[0], ecurve[10], 0, &epcurve[1]);
if (status != EGADS_SUCCESS) goto cleanup;
status = EG_otherCurve(esurface[0], ecurve[5], 0, &epcurve[2]);
if (status != EGADS_SUCCESS) goto cleanup;
status = EG_otherCurve(esurface[0], ecurve[11], 0, &epcurve[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;
:
:

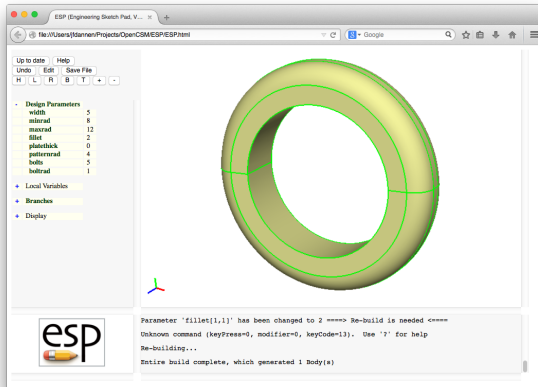
/* make the shell and initial Body */
status = EG_makeTopology(context, NULL, SHELL, CLOSED, NULL, 8, efaces, NULL, &eshell);
if (status != EGADS_SUCCESS) goto cleanup;
status = EG_makeTopology(context, NULL, BODY, SOLIDBODY, NULL, 1, &eshell, NULL, &ebody1);
if (status != EGADS_SUCCESS) goto cleanup;

```

Complete *Bottom UP* build



```
/* add fillets if desired (result is ebody2) */
if (fillet > 0.0) {
    elist[0] = eedges[10]; elist[1] = eedges[11]; elist[2] = eedges[14]; elist[3] = eedges[15];
    status = EG_filletBody(ebody1, 4, elist, 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, &ebody3);
    if (status != EGADS_SUCCESS) goto cleanup;

    status = EG_generalBoolean(ebody2, ebody3, FUSION, 0.0, &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_generalBoolean(source, ebody4, SUBTRACTION, 0.0, &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;
}

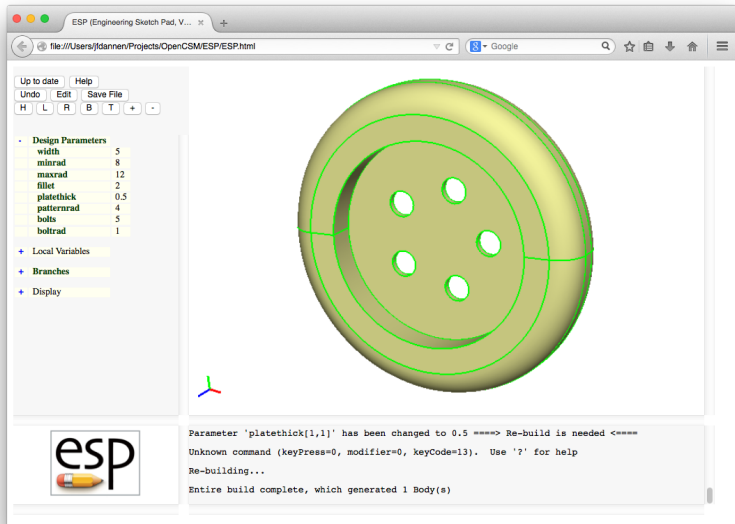
/* make and dump the model */
status = EG_makeTopology(context, NULL, MODEL, 0, NULL, 1, &ebody, NULL, &emodel);
printf("EG_makeTopology -> status=%d\n", status);
if (status != EGADS_SUCCESS) goto cleanup;

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 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/doc/UDP_UDF/data/udpTire.c](#)
- 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.