



# The Use of Geometry from within the Engineering Sketch Pad – Rev 1.27 The EGADS API

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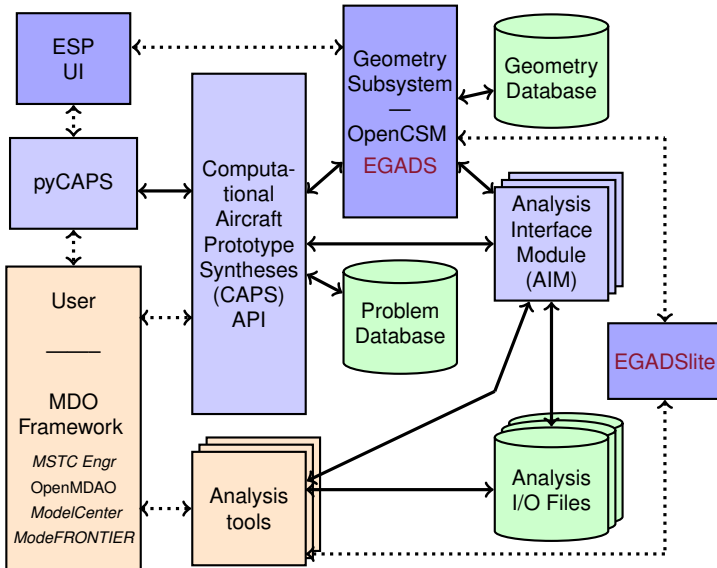
- Background & ESP
- Objects
  - Geometry
  - Topology
  - Tessellation
- Meshing
- Programming Examples
- Closing Remarks

## ESP is:

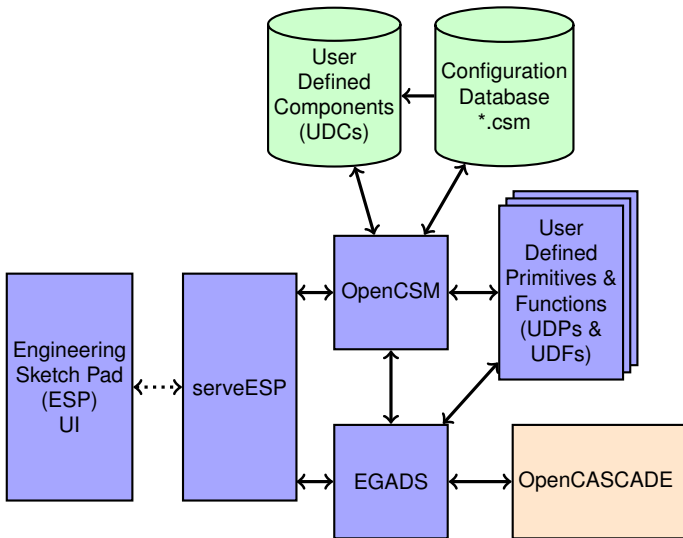
- a parametric geometry creation and manipulation system designed to **fully support** the analysis and design of aerospace vehicles (**aCAD**)
- a stand-alone system for the development of geometric models
- can be embedded into other software systems to support their geometric and process needs

## 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><br><i>Down</i><br><br><br><br><i>Bottom</i><br><i>Up</i> | Topological Entity | Geometric Entity   | Function                       |
|---|--------------------|--------------------|--------------------------------|
|   | 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>       |                                |

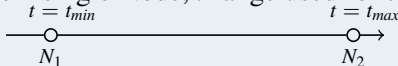
- Nodes that bound Edges may not be on underlying curves
- Edges in the Loops that trim the Face may not sit on the surface hence the use of pcurses

## Node

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

## Edge

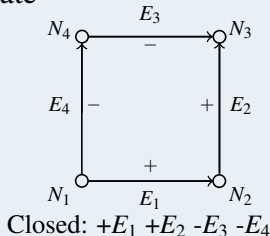
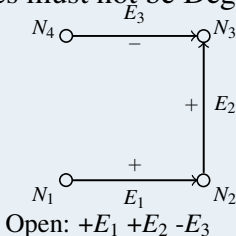
- Has a 3D curve (if not Degenerate)
- Has a  $t$  range ( $t_{min}$  to  $t_{max}$ , where  $t_{min} < t_{max}$ )  
Note: The positive orientation is going from  $t_{min}$  to  $t_{max}$
- Has a Node for  $t_{min}$  and for  $t_{max}$  – can be the same Node
- Types:
  - OneNode – periodic
  - TwoNode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

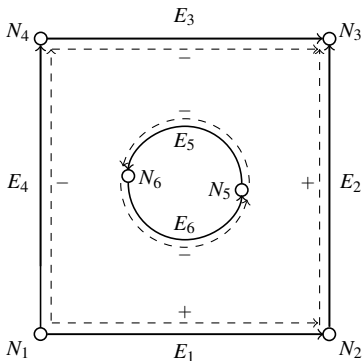
- ➊ Collections of Edges followed by a corresponding collection of pcurves that define the  $[u, v]$  trimming on the surface
- An ordered collection of Edge objects with associated senses
- Degenerate Edges are required when the  $[u, v]$  mapping collapses like at the apex of a cone (note that the 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

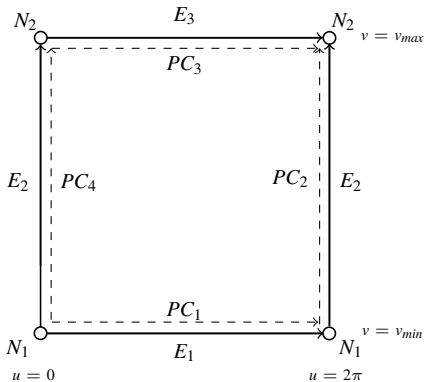
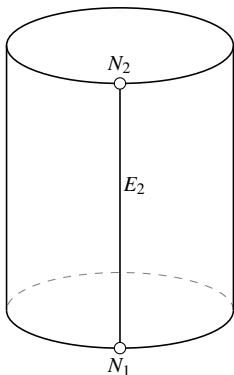
- A surface bounded by one or more Loops with associated senses
- Only one outer Loop (sense = 1) and any number of inner Loops (sense = -1). Note that under very rare conditions a Loop may be found in more than 1 Face – in this case the one marked with sense = +/- 2 must be used in a reverse manner.
- 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)





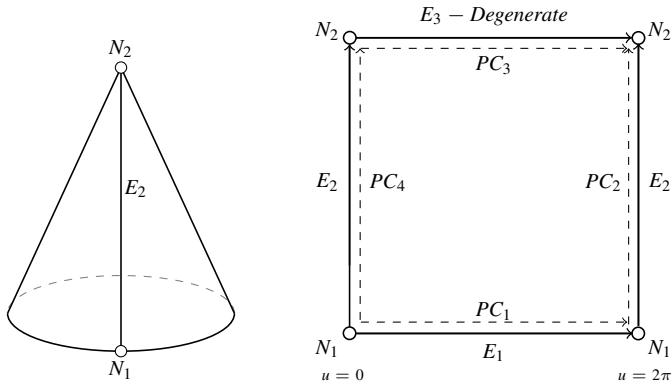
- Outer Loop – right handed/counterclockwise:  $+E_1 +E_2 -E_3 -E_4$
- Inner Loop – left handed/clockwise:  $-E_5 -E_6$



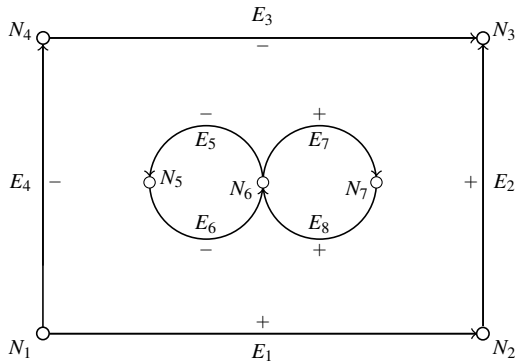
Unrolled periodic cylinder Face

Single Outer Loop – right handed/counterclockwise:

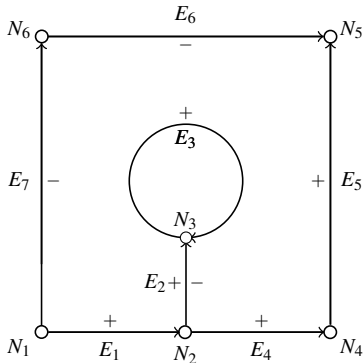
$$+E_1 +E_2 -E_3 -E_2$$



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:  $+E_7 +E_8$



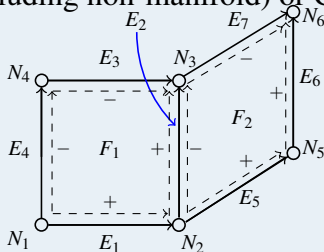
Single Outer Loop – right handed/counterclockwise:

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

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

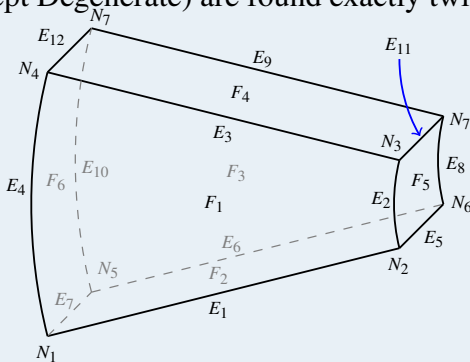


Face #1 Loop:  $+E_1 +E_2 -E_3 -E_4$

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

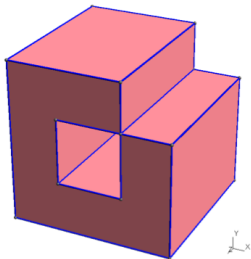
## SolidBody

- 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 =  $\pm 1$ )

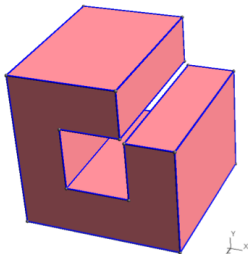


Simple SolidBody: 8 Nodes, 12 Edges, 6 Loops and 6 Faces

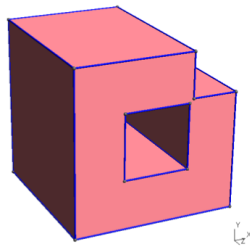
## Manifold vs. Nonmanifold



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

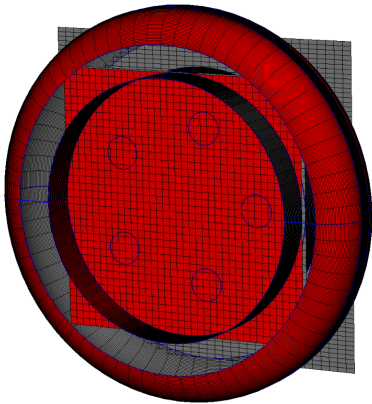
- **makeLoop**
  - Connects unrelated (via Nodes) Edges from a list
  - Uses input tolerance to match entities
  - Result may be multiple Loops
- **makeFace**
  - From Closed Planar Loop
  - From surface with limits
- **sewFaces**
  - Connects Faces with unrelated Topology
  - Uses input tolerance to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

## Geometry

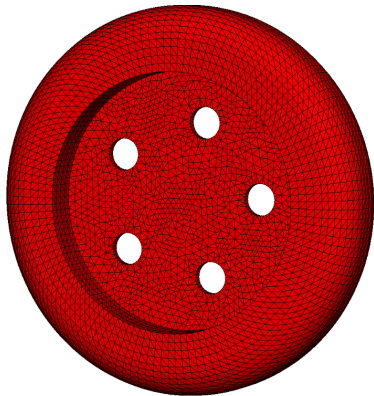
- Unconnected discretization of a range of the Object
  - Polyline for curves at constant  $t$  increments
  - Regular grid for surfaces at constant increments (isoclines)

## 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 1<sup>st</sup> and 2<sup>nd</sup>
  - 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 1<sup>st</sup> and 2<sup>nd</sup> 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  $\epsilon$
  - 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!**

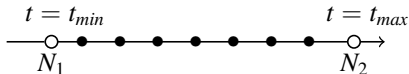
## Dimensional Strategy

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

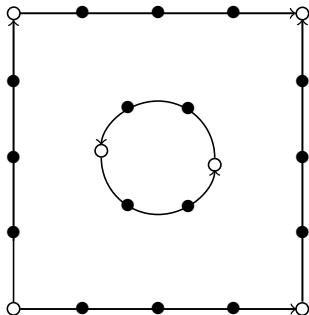
## Discretizing Edges

- 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



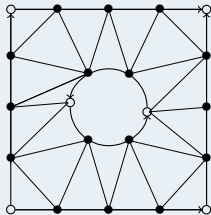
## Discretizing Faces

- 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;
}

```

# Programming Example – Cart3D Tri File (3)

```

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, &p1en, &points, &uv, &p1type, &p1index,
                           &tlen, &tris, &tr1c);
    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, &pindex,
                           &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);

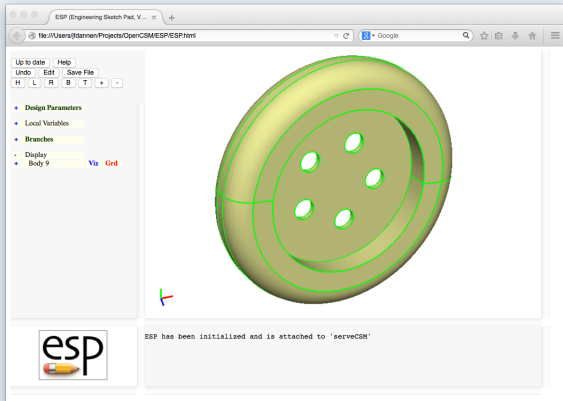
if (status != EGADS_SUCCESS) printf(" EG_deleteObject model = %d\n", status);

EG_close(context);

return 0;
}

```

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



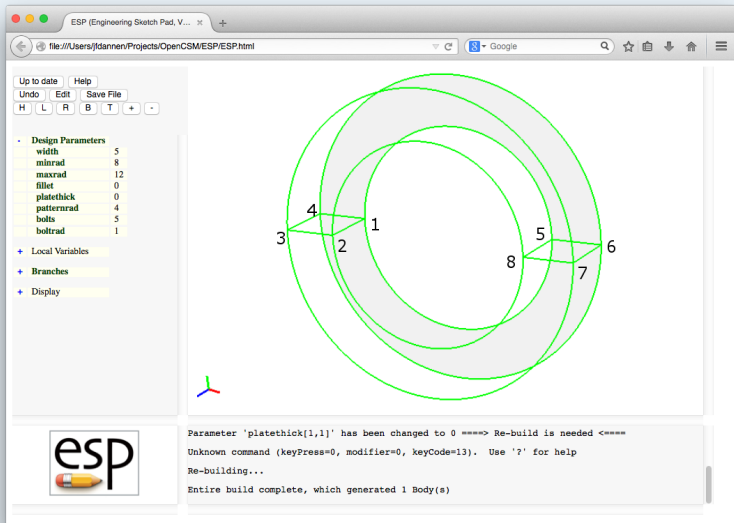
| Name   | Description              |
|--------|--------------------------|
| width  | width                    |
| minrad | minimum radius           |
| maxrad | maximum radius           |
| fillet | fillet radius at outside |
| thick  | wheel thickness          |
| bolts  | number of bolt holes     |
| 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 list of parameters and their values:

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

Below the parameters are sections for 'Local Variables', 'Branches', and 'Display'. The bottom console window shows the following log:

```
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)
```

```

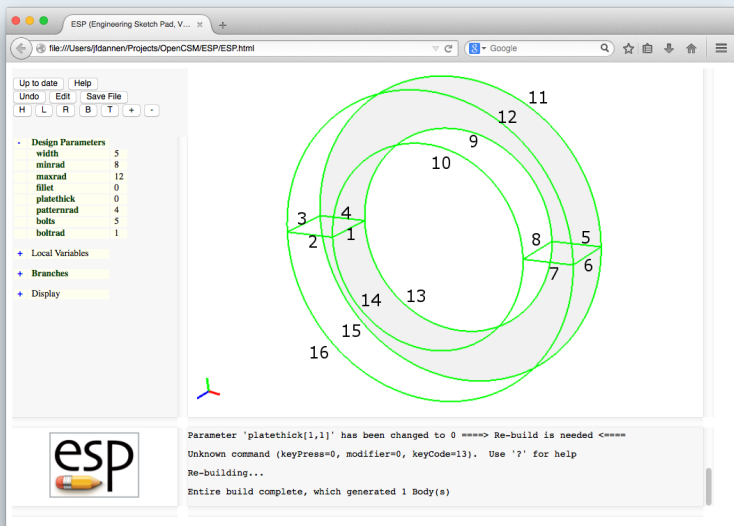
/* define a context */
status = EG_open(&context);
printf("EG_open -> status=%d\n", status);
if (status < EGADS_SUCCESS) exit(1);

/* 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





```

/* 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];

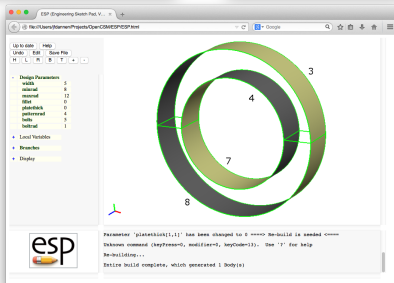
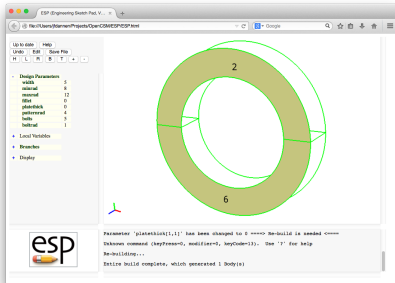
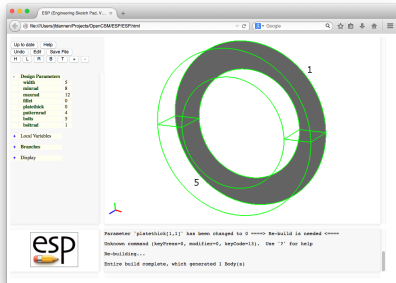
status = EG_makeTopology(context, ecurve[8], EDGE, TWONODE, trange, 2, elist, NULL,
                        &edges[8]);

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;

```

```

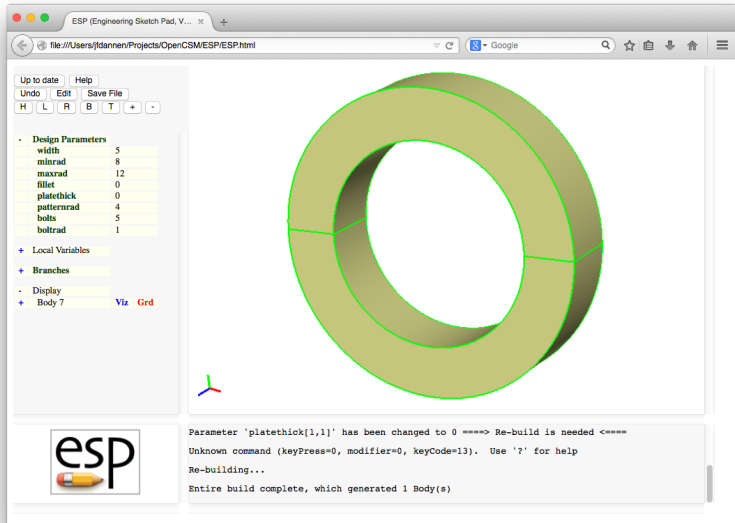
/* make (cylindrical) Face 3 */
status = EG_otherCurve(esurface[0], ecurve[2], 0, &epcurve[0]);
if (status != EGADS_SUCCESS) goto cleanup;
status = EG_otherCurve(esurface[0], ecurve[10], 0, &epcurve[1]);
if (status != EGADS_SUCCESS) goto cleanup;
status = EG_otherCurve(esurface[0], ecurve[5], 0, &epcurve[2]);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

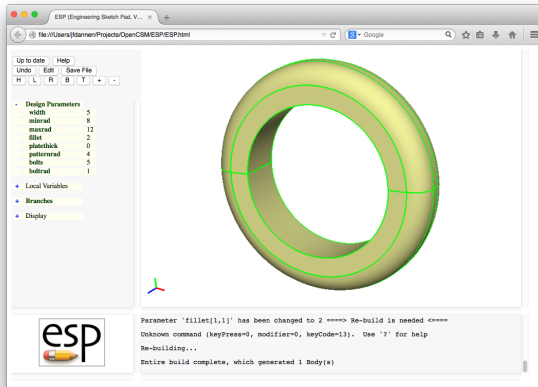
```

## Complete *Bottom UP* build



# Programming Example – Parametric Tire (12)

```
/* 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, &body3);
    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;
}

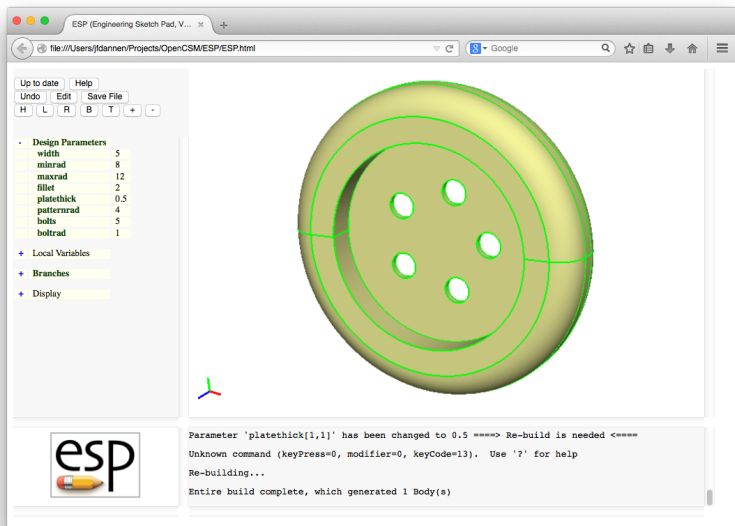
/* make and dump the model */
status = EG_makeTopology(context, NULL, MODEL, 0, NULL, 1, &ebody, NULL, &emodel);
printf("EG_makeTopology -> status=%d\n", status);
if (status != EGADS_SUCCESS) goto cleanup;

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.