Chapter 15. Reporting Mesh Statistics

The quality of a mesh is determined more effectively by looking at various statistics, such as maximum skewness, rather than just performing a visual inspection. Unlike structured grids, unstructured grids are nearly impossible to comprehend with only a graphical plot.

The types of mesh information that TGrid can report include minimum, maximum, and average values of cell size, skewness, aspect ratio, or change in size, warp, squish, edge ratio, and the total number of each element type. These reporting operations are described in the following sections.

15.1 Reporting the Mesh Size

The Report Mesh Size panel and associated text commands allow you to check the size of your mesh by reporting the number of nodes, faces, and cells in it.

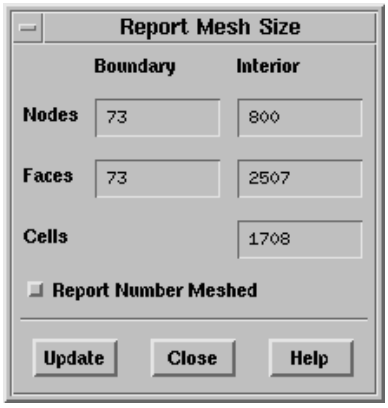
15.1.1 The Report Mesh Size Panel

The Report Mesh Size panel reports the number of nodes, faces, and cells. Nodes and faces are grouped into those defining the boundaries and those used inside cell zones.

If the generation of the initial mesh fails, you can determine how many boundary nodes and faces were not meshed by enabling Report Number Meshed in the Report Mesh Size panel. The total number of boundary nodes and faces will be reported along with the number that were meshed. The headings Boundary and Interior will be replaced by Total and Meshed, respectively when you use this option and the reported information will appear in the appropriate boxes.

If you used domains to generate the mesh or group zones for reporting (as described in Section 13.10: Using Domains to Group and Mesh Boundary Faces), the report will apply only to the active domain.

Report ⟶ Mesh Size...



Controls

Boundary indicates the number of boundary nodes and boundary faces.

Interior indicates the number of interior nodes, faces, and cells.

Total indicates the total number of nodes and faces when the Report Number Meshed option is enabled.

Total indicates the number of nodes and faces that have been meshed when the Report Number Meshed option is enabled.

Report Number Meshed toggles the reporting of the number of nodes and faces that have been meshed.

Update updates the reported values.

15.1.2 Text Commands for Reporting Mesh Size

Text commands for reporting the size of the mesh are as follows:

`/report/mesh-size` reports the number of nodes, faces, and cells.

`/report/number-meshed` reports the number of elements that have been meshed.

15.2 Reporting Face Limits

Before generating a 3D volume mesh, check the quality of the faces to get an indication of the overall mesh quality. The default quality measure is skewness, but you can also report the aspect ratio limits or the range in size change for a face zone. For 2D, a maximum skewness less than 0.5 and an average of 0.1 are good. For 3D, a maximum less than 0.9 and an average of 0.4 are good. The lower the maximum skewness, the better the mesh. See Section 15.5: Mesh Quality for information on face and cell quality measures in TGrid.

You can check face size and quality limits using the Report Face Limits panel or the associated text commands. Before creating a layer of pyramid cells, check the aspect ratio of the quadrilateral faces that will form the base of the pyramids. This aspect ratio should be less than 8. Otherwise, the triangular faces of the pyramids will be highly skewed. If the aspect ratio is greater than 8, regenerate the quadrilateral faces.

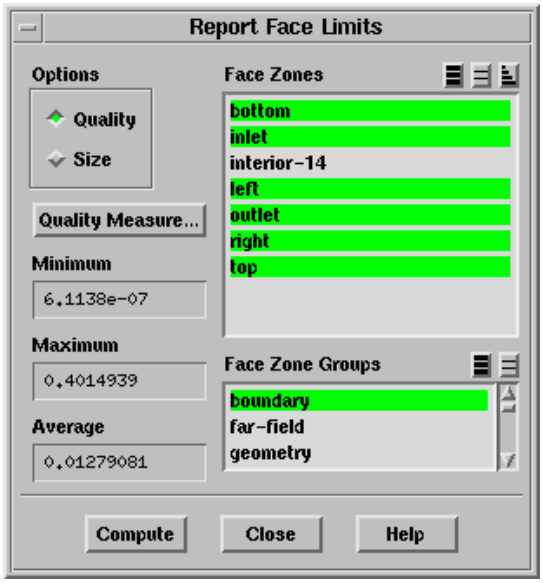
- If they were created in a different preprocessor, return to that application and try to reduce the aspect ratio of the faces in question.
- If they were created by TGrid during the building of prism layers, rebuild the prisms using a more gradual growth rate.

Check the skewness of triangular faces on a boundary from which you are going to build prisms, to ensure that the quality of the prism cells will be good. After you create the prisms, check the skewness of the triangular faces that were created during the prism generation.

15.2.1 The Report Face Limits Panel

The Report Face Limits panel reports on the size or quality limits of selected face zones. The minimum, maximum, and average values are reported. If you used domains to generate the mesh or group zones for reporting (as described in Section 13.10: Using Domains to Group and Mesh Boundary Faces), you can report face limits only for the face zones that are in the active domain.

Report ⟶Face Limits...



Controls

Options specifies either Quality or Size to be computed. Skewness is the default measure of quality.

Quality Measure... opens the Quality Measure panel (see Section 15.5.2: The Quality Measure Panel), in which you can select the measure of quality to be reported (skewness, aspect ratio, etc.).

Minimum/Maximum/Average report the computed values for size or quality.

Face Zones contains a list from which you can select the zones for the report.

Face Zone Groups contains a list of face zone types. If you select a face type from this list (e.g., inlet), all face zones of that type (for this example, all pressure-inlet and velocity-inlet boundaries) will be selected in the Face Zones list. This allows you to easily select all face zones of a certain type without selecting each zone individually. Select multiple types in the Face Zone Groups list to select all zones of several different types (e.g., inlet and outlet).

Compute calculates the Minimum, Maximum, and Average values for the selected option (size or quality) on the selected face zones.

15.2.2 Text Commands for Reporting Face Limits

Text commands with the same functionality as the controls in the Report Face Limits panel are:

`/report/face-size-limits` reports the face size limits.

`/report/face-quality-limits` reports the face quality limits.

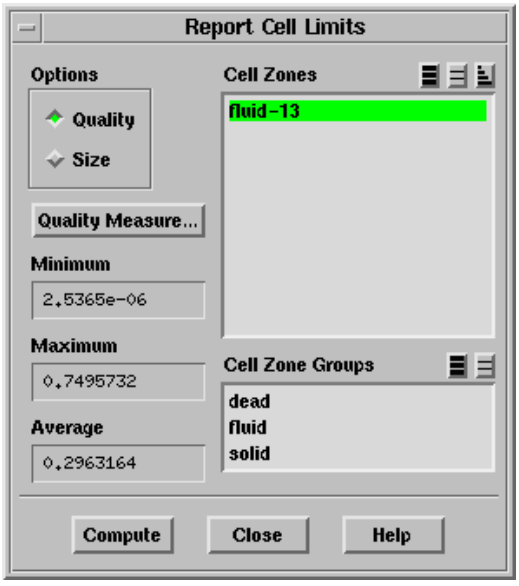
15.3 Reporting Cell Limits

TGrid allows you to report the quality of the cells in your volume mesh. The default quality measure is skewness, but you can also report the aspect ratio limits or the range of change in cell size. You can check cell size and quality limits using the Report Cell Limits panel or the associated text commands.

15.3.1 The Report Cell Limits Panel

The Report Cell Limits panel reports the size or quality limits of the selected cell zones. The minimum, maximum, and average values are reported. If you used domains to generate the mesh or group zones for reporting (as described in Section 13.10: Using Domains to Group and Mesh Boundary Faces), the report will apply only to the active domain.

Report ⟶Cell Limits...



Controls

Options specifies either Quality or Size to be computed. Skewness is the default measure of quality.

Quality Measure... opens the Quality Measure panel (see Section 15.5.2: The Quality Measure Panel), in which you can select the measure of quality to be reported (skewness, aspect ratio, change in size, etc.).

Minimum/Maximum/Average report the computed values for size or quality.

Cell Zones contains a list from which you can select the zones of interest.

Cell Zone Groups contains a list of cell zone types. If you select a zone type from this list (e.g., fluid), all cell zones of that type will be selected in the Cell Zones list. This shortcut allows you to easily select all zones of a certain type without having to select each zone individually. You can select multiple types in the Cell Zone Groups list to select all zones of several different types (e.g., fluid and solid).

Compute calculates the Minimum, Maximum, and Average values for the selected option (size or quality).

15.3.2 Text Commands for Reporting Cell Limits

Text commands with the same functionality as the controls in the Report Cell Limits panel are listed below:

`/report/cell-size-limits` reports the cell size limits.

`/report/cell-quality-limits` reports the cell quality limits.

`/report/neighborhood-quality` reports the maximum skewness, aspect ratio, or size change of all cells using a specified node.

15.4 Reporting Boundary Cell Limits

For boundary layer flows, boundary cells with low skewness are very important.

- In 2D triangular meshes, most boundary cells will be equilateral except in corners or if there is another boundary close by.

  If there are cells with a skewness above 0.25, the nodes are probably poorly distributed on the boundary.

- For 3D tetrahedral meshes, the maximum skewness will not be lower than the maximum face skewness, because the boundary cell skewness is limited by the boundary face skewness.

  Highly skewed 3D cells with two boundary faces will be removed using the Tri/Tet Improve panel (see Section 13.5: The Tri/Tet Improve Panel)).

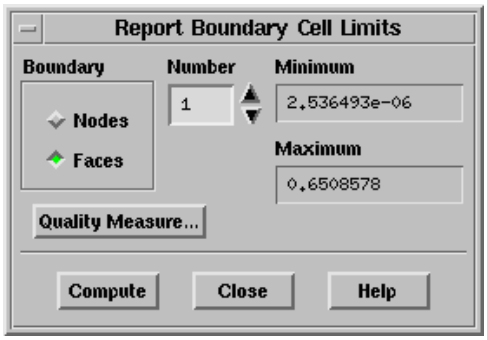
To check the skewness of boundary cells, use the Report Boundary Cell Limits panel or the associated text commands.

15.4.1 The Report Boundary Cell Limits Panel

The Report Boundary Cell Limits panel reports the quality of cells containing a specified number of boundary faces. The minimum and maximum skewness, aspect ratio, or size change values are reported. Though this panel can be used to check all quality measures and all boundary cell shapes, it is used primarily to check the skewness of triangular and tetrahedral boundary cells.

If you have used domains to generate the mesh or group zones for reporting (as described in Section 13.10: Using Domains to Group and Mesh Boundary Faces), the report will apply only to the active domain.

Report ⟶Boundary Cell Limits...



Controls

Boundary allows you to specify whether you want to set the number of boundary nodes or faces. Select Nodes or Faces, and specify the number of nodes/faces in the Number field. To obtain information about cells that touch the boundary (but do not actually have any boundary faces), specify the number of boundary nodes instead of the number of boundary faces.

Number sets the number of boundary nodes or faces (depending on the selection in the Boundary list). The quality of cells containing this number of boundary nodes or faces will be reported when you click on Compute.

Quality Measure... opens the Quality Measure panel (see Section 15.5.2: The Quality Measure Panel), in which you can select the measure of quality to be reported (skewness, aspect ratio, etc.).

Minimum shows the reported minimum quality measurement (skewness, by default) of the cells with the specified number of boundary nodes or faces.

Maximum shows the reported maximum quality measurement (skewness, by default) of the cells with the specified number of boundary nodes or faces.

Compute calculates the minimum and maximum quality measurement for boundary cells with the specified number of boundary nodes or faces.

15.4.2 Text Commands for Reporting Boundary Cell Limits

The following TUI command is associated with reporting boundary cell limits:

`/report/boundary-cell-quality` reports the quality of boundary cells. (If you specify zero for `number of boundary faces`, you will be prompted for `number of boundary nodes`.)

15.5 Mesh Quality

The quality of the mesh guarantees the best analysis results for the problem, minimizes the need for additional analysis runs, and improves one's predictive capabilities.

Mesh quality is determined by some measures which are described in briefly in this section. The basic measures include clustering, smoothness, skewness, and aspect ratio. The default quality measure is skewness.

You can check the quality of faces and cells using the following panels:

- Report Face Limits panel (see Section 15.2.1: The Report Face Limits Panel)
- Report Cell Limits panel (see Section 15.3.1: The Report Cell Limits Panel)
- Report Boundary Cell Limits panel (see Section 15.4.1: The Report Boundary Cell Limits Panel).

To specify the quality measure (skewness, aspect ratio, change in size, etc.), use the Quality Measure panel (see Section 15.5.2: The Quality Measure Panel).

15.5.1 Quality Measures Available in TGrid

Clustering

The requirement for clustering is that the mesh be fine enough to resolve the primary features of the flow being analyzed. The resolution depends on the boundary mesh that you start from and also the parameters controlling the generation of the interior mesh.

Smoothness

In a high-quality mesh, the change in size from one face or cell to the next should be gradual (smooth). Large differences in size between adjacent faces or cells will result in a poor computational grid because the differential equations being solved assume that the cells shrink or grow smoothly.

Figure 15.5.1 illustrates different changes in size for triangular cells.

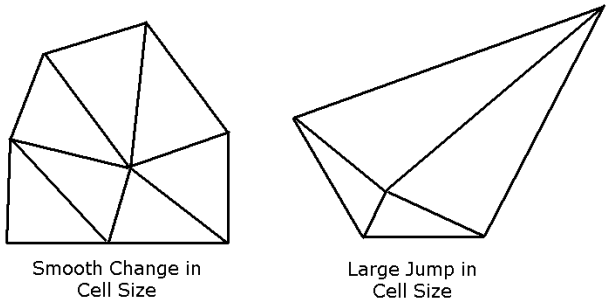


Figure 15.5.1: Smooth and Non-Smooth Transitions in Cell Size

Aspect Ratio

The aspect ratio of a face or cell is the ratio of the longest edge length to the shortest edge length. The aspect ratio applies to triangular, tetrahedral, quadrilateral, and hexahedral elements and is defined differently for each element type.

The aspect ratio can also be used to determine how close to ideal a face or cell is.

- For an equilateral face or cell (e.g., an equilateral triangle or a square), the aspect ratio will be 1.
- For less regularly-shaped faces or cells, the aspect ratio will be greater than 1, since the edges differ in length.
- For triangular and tetrahedral faces and cells and for pyramids, you can usually focus on improving the skewness, and the smoothness and aspect ratio will consequently be improved as well.

- For prisms (including 2D quadrilateral cells), it is important to check the aspect ratio and/or the change in size in addition to the skewness, because it is possible to have a large jump in cell size between two cells with low skewness or a high-aspect-ratio low-skew cell (such as the quadrilateral on the right in Figure 15.5.2).

Figure 15.5.2: Large Change in Size Between Low-Skew Quadrilaterals

Skewness

Skewness is one of the primary quality measures for a mesh. Skewness determines how close to ideal (i.e., equilateral or equiangular) a face or cell is (see Figure 15.5.3).

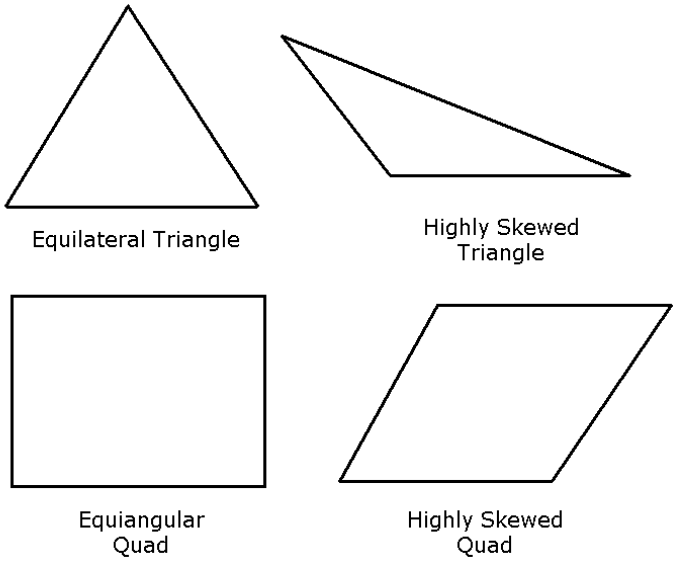


Figure 15.5.3: Ideal and Skewed Triangles and Quadrilaterals

Table 15.5.1 lists the range of skewness values and the corresponding cell quality.

According to the definition of skewness, a value of 0 indicates an equilateral cell (best) and a value of 1 indicates a completely degenerate cell (worst). Degenerate cells (slivers) are characterized by nodes that are nearly coplanar (collinear in 2D).

Value of Skewness	Cell Quality
1	degenerate
0.9–<1	bad (sliver)
0.75–0.9	poor
0.5–0.75	fair
0.25–0.5	good
>0–0.25	excellent
0	equilateral

Table 15.5.1: Skewness Ranges and Cell Quality

Highly skewed faces and cells are unacceptable because the equations being solved assume that the cells are relatively equilateral/equiangular.

Two methods for measuring skewness are:

- Based on the equilateral volume (applies only to triangles and tetrahedra).
- Based on the deviation from a normalized equilateral angle. This method applies to all cell and face shapes, e.g., pyramids and prisms.

The default skewness method for triangles and tetrahedra is the equilateral volume method. But you can change to the angle deviation method using the Quality Measure panel (see Section 15.5.2: The Quality Measure Panel).

Equilateral-Volume-Based Skewness

In the equilateral volume deviation method, skewness is defined as

$$\text{Skewness} = \frac{\text{Optimal Cell Size} - \text{Cell Size}}{\text{Optimal Cell Size}} \tag{15.5-1}$$

where, the optimal cell size is the size of an equilateral cell with the same circumradius.

Quality grids have a skewness value of approximately 0.1 for 2D and 0.4 for 3D. Table 15.5.1 provides a general guide to the relationship between cell skewness and quality.

In 2D, all cells should be good or better. The presence of cells that are fair or worse indicates poor boundary node placement. You should try to improve your boundary mesh as much as possible, because the quality of the overall mesh can be no better than that of the boundary mesh.

In 3D, most cells should be good or better, but a small percentage will generally be in the fair range and there are usually even a few poor cells.

Normalized Equiangular Skewness

In the normalized angle deviation method, skewness is defined (in general) as

$$\max\left[\frac{\theta_{\max}-\theta_e}{180-\theta_e}, \frac{\theta_e-\theta_{\min}}{\theta_e}\right] \tag{15.5-2}$$

where

$\theta_{\max}$ = largest angle in the face or cell
$\theta_{\min}$ = smallest angle in the face or cell
θ_e = angle for an equiangular face/cell (e.g., 60 for a triangle, 90 for a square)

For a pyramid, the cell skewness will be the maximum skewness computed for any face. An ideal pyramid (skewness = 0) is one in which the 4 triangular faces are equilateral (and equiangular) and the quadrilateral base face is a square. The guidelines in Table 15.5.1 apply to the normalized equiangular skewness as well.

Size Change

Size change is the ratio of the area (or volume) of a cell in the geometry to the area (or volume) of each neighboring face (or cell). This ratio is calculated for every face (or cell) in the domain. The minimum and maximum values are reported for the selected zones.

Squish

Squish is a measure used to quantify the non-orthogonality of a cell with respect to its faces. It is defined as follows:

$$1-(\mathbf{A}\cdot\mathbf{r}_c)/|\mathbf{r}_c| \tag{15.5-3}$$

where

$\mathbf{A}$ = face unit area vector
$\mathbf{r}_c$ = the vector connecting the adjacent cell centroids (for face squish) or and the cell face centroid (for cell squish)

Edge Ratio

The edge ratio is defined as the ratio of maximum length of the edge of the element to the minimum length of the edge of the element.

By definition, edge ratio is always greater than or equal to `1`. Higher the value of the edge ratio, the less regularly shaped is its associated element. For equilateral element shapes, the edge ratio is always equal to `1`.

Warp

Face warp applies only to quadrilateral elements and is defined as the variation of normals between the two triangular faces that can be constructed from the quadrilateral face. The actual value is the maximum of the two possible ways triangles can be created.

Mathematically, it is expressed as follows:

$$\frac{Z}{min[a,b]} \tag{15.5-4}$$

where

Z = the deviation from a best-fit plane that contains the element
a, b = the lengths of the line segments that bisect the edges of the element

The value of face warp ranges between 0 and 1. A value of 0 specifies an equilateral element and a value of 1 specifies a highly skewed element.

Dihedral Angle

Dihedral angle applies only to the faces and not cells. It highlights the faces with the dihedral angle between them in the range specified in the Cell Quality Range group box in the Cells tab of the Display Grid panel.

You can specify a range of values from 0-180. This quality measure is useful in locating the sharp corners in complicated geometries.

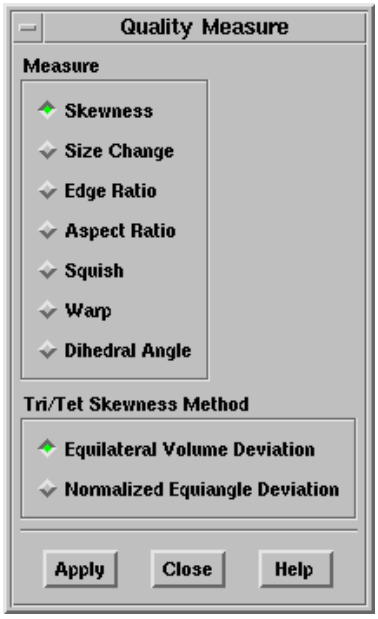
15.5.2 Specifying the Quality Measure

You can specify the quality measure in the Quality Measure panel.

The Quality Measure Panel

The Quality Measure panel allows you to specify the measure used to evaluate the quality of your mesh (skewness, change in size, edge ratio, aspect ratio, squish, warp, or dihedral angle). For triangular and tetrahedral faces/cells, you can also select the method to be used to report and display skewness.

Report ⟶Quality Measure...



Controls

Measure contains the available measures that you can use to check the quality of your mesh. See Section 15.5: Mesh Quality for details about these choices.

Skewness specifies that skewness is the quality measure to be reported or displayed.

Size Change specifies that change in face or cell size is the quality measure to be reported or displayed.

Edge Ratio specifies that edge ratio is the quality measure to be reported or displayed.

Aspect Ratio specifies that aspect ratio is the quality measure to be reported or displayed.

Squish specifies that squish is the quality measure to be reported or displayed.

Warp specifies that warp is the quality measure to be reported or displayed.

Dihedral Angle highlights the faces having the dihedral angle between them in the specified range in the Cell Quality Range box of the Display Grid panel.

For details, see Section 15.5.1: Aspect Ratio.

Tri/Tet Skewness Method indicates which method you want to use to report and display the skewness of triangles and tetrahedra.

The skewness method you choose will only affect reports and displays based on skewness. The triangular and tetrahedral meshing procedure will always be based on the equilateral volume skewness method.

Equilateral Volume Deviation selects the skewness method that is based on the volume of an ideal (equilateral) face or cell. This is the default method, that was available in previous releases of TGrid.

Normalized Equiangle Deviation selects the skewness method that is based on the deviation from a normalized equiangular angle. This method is always used for pyramids and prisms.

15.5.3 Text Commands for Selecting the Quality Measure

The following text command can be used for specifying the quality measure:

`/report/quality-method` specifies the method to be used for reporting face and cell quality.

15.6 Printing Grid Information

The `/report/print-info` text command allows you to obtain information about individual components of the mesh. This command also appears in the `boundary` menu. When you use this command, TGrid will prompt you for an "entity" (i.e., a node, face, or cell). An entity name consists of a prefix and an index.

The valid prefixes are: `bn` (boundary node), `n` (node), `bf` (boundary face), `f` (face), and `c` (cell). Hence, the name of the first boundary node would be `bn1`. If the first node is a boundary node, then both `bn1` and `n1` refer to the same node.

The output for each type of entity is as explained in this section.

15.6.1 Boundary Node

```
/report> print-info
entity [ ] bn1
bn1 = (3 (0 0 0) 0.1 (bf2099 bf1093 bf193))
```

The following information is listed for the boundary node:

- associated zone ID
- Cartesian coordinates of the node
- node radius
- faces using the node.

For boundary nodes, the node radius is the average distance to neighboring boundary nodes.

15.6.2 Node

```
/report> print-info
entity [ ] n30
n30 = (5 (2.433799 0.078610075 0.52846689) 0.12702106)
```

The following information is listed for a node:

- associated zone ID
- Cartesian coordinates of the node
- the node radius

For interior nodes, the node radius is the distance-weighted average of the surrounding nodes.

15.6.3 Boundary Face

```
/report> print-info
entity [ ] bf17
bf17 = (2 (bn1308 bn1314 bn1272) (() c1533) ()  0.014393554)
```

The following information is listed for a boundary face:

- associated zone ID
- the nodes forming the face
- the neighboring cells

- the periodic shadow (null if not periodic)
- the quality of the face

The default measure of quality is skewness, but you can use the Quality Measure panel (see Section 15.5.2: The Quality Measure Panel) to specify aspect ratio or change in size instead.

15.6.4 Cell

```
/report> print-info
entity [ ] c26
c26 = (1 (n262 n34 bn204 bn205) (f4743 f5372 f1822 f3426)
0.00020961983 (2.7032523 0.32941867 0.072823988)
0.0081779587 0.44769606)
```

The following information is listed for a cell:

- zone ID
- the nodes forming the cell
- the faces forming the cell
- the size
- the coordinates of the circumcenter (relevant for triangular and tetrahedral cells only)
- square of the circumcenter radius (relevant for triangular and tetrahedral cells only)
- the quality of the cell

The default measure of quality is skewness, but you can use the Quality Measure panel (see Section 15.5.2: The Quality Measure Panel) to specify aspect ratio or change in size instead.

15.6.5 Face

```
/report> print-info
entity [ ] f32
f32 = (4 (n95 bn197 n90) (c4599 c1279))
```

The following information is listed for a face:

- associated zone ID
- the nodes forming the face
- the neighboring cells

Due to the manner in which the algorithm maintains memory, not all indices will have values—that is, an empty slot can be caused by a delete operation. Empty slots are reused in subsequent operations, so the actual entity at a particular index may change as the mesh is generated.

15.7 Additional Text Commands for Reporting

Text interface commands related to the Report menu that are not available in the GUI are listed below:

`/report/cell-distribution` reports the distribution of cell quality.

`/report/cell-zone-a-location` reports the cell zone at the specified location.

`/report/cell-zone-volume` reports the volume of the specified cell zone in the console.

`/report/edge-size-limits` reports the edge size limits.

`/report/face-distribution` reports the distribution of face quality.

`/report/face-zone-area` reports the area of the specified face zone in the console.

`/report/face-zone-at-location` reports the face zone at the specified location.

`/report/list-cell-quality` reports a list of cells with the specified quality measure within a specified range.

`/report/memory-usage` reports the amount of memory used for all nodes, faces, and cells, and the total memory allocated.

`/report/mesh-statistics` writes mesh statistics (such as range of quality, range in size, and number of cells, faces, and nodes) to an external file.

`/report/unrefined-cells` reports the number of cells that have not been refined.

`/report/update-bounding-box` updates the extents of the bounding box.

`/report/verbosity-level` specifies how much information should be displayed during mesh initialization and refinement and other operations. Changing the value to 2 from the default value of 1 will result in more messages while changing it to 0 will disable all messages.