# Buoyant forces in JSBSim

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## 1 Introduction

## 2 Usage

The general format of a gas cell and ballonet definition is shown in Figure 1. Below follows a detailed description of each configuration element.

### 2.1 type

The required attribute **type** in the **gas_cell** element defines the type of gas contained in the gas cell, one of HYDROGEN, HELIUM or AIR. Presently the gas is always 100% pure.

### 2.2 location

Location of the cell center in the aircraft's structural frame. Currently this is were the buoyancy and gravity forces of the cell are applied.

### 2.3 Gas cell shape

The elements {**x** | **y** | **z**}_{**radius** | **width**} define the shape and volume of the fully inflated cell in the structural frame. The supported shapes are ellipsoid (using x,y,z_radius) and cylindrical along X axis (using x_width and y,z_radius). The cell shape is used to compute the inertia tensor due to the mass of the contained gas.

### 2.4 Initial fullness

The element **fullness** defines the initial fullness fraction of the cell, normally in the interval $[0, 1]$. A fullness value greater than $1$ initialize the cell at higher than ambient pressure.

```
<buoyant_forces>
  <gas_cell type="{HYDROGEN | HELIUM | AIR}">
    <location unit="{M | IN}">
      <x> {number} </x>
      <y> {number} </y>
      <z> {number} </z>
    </location>
    <x_{radius|width} unit="{M | IN}"> {number} </x_{radius|width}>
    <y_{radius|width} unit="{M | IN}"> {number} </y_{radius|width}>
    <z_{radius|width} unit="{M | IN}"> {number} </z_{radius|width}>
    <max_overpressure unit="{PA | PSI}"> {number} </max_overpressure>
    [<valve_coefficient unit="{M4*SEC/KG | FT4*SEC/SLUG}"> {number} </valve_
icient>]
    [<fullness> {number} </fullness>]
    [<heat>
      {heat transfer coefficients} [lbs ft / sec]
    </heat>]
    [<ballonet>
      <location unit="{M | IN}">
        <x> {number} </x>
        <y> {number} </y>
        <z> {number} </z>
      </location>
      <x_{radius|width} unit="{M | IN}"> {number} </x_{radius|width}>
      <y_{radius|width} unit="{M | IN}"> {number} </y_{radius|width}>
      <z_{radius|width} unit="{M | IN}"> {number} </z_{radius|width}>
      <max_overpressure unit="{PA | PSI}"> {number} </max_overpressure>
      <valve_coefficient unit="{M4*SEC/KG | FT4*SEC/SLUG}"> {number} </valve
fficient>
      [<fullness> {number} </fullness>]
      [<heat>
       {heat transfer coefficients} [lb ft / (sec R)]
      </heat>]
      [<blower_input>
       {input air flow function} [ft^3 / sec]
      </blower_input>]
    </ballonet>]
  </gas_cell>
</buoyant_forces>
```

Figure 1: Gas cell and ballonet definition format.

## 2.5 Maximum cell pressure and pressure relief valve

The element **max_overpressure** defines the maximum allowed cell overpressure with respect to the surrounding atmosphere. If the cell pressure is about to exceed this limit the excess gas is automatically and instantly valved off. This models a pressure relief valve of sufficient capacity mounted at the bottom of the cell.

## 2.6 Manual gas valve

The **valve_coefficient** element defines the capacity of the manual valve. The valve is considered to be located at the top of the cell. The valve coefficient determine the flow out of the cell according to:

$$\frac{dVolume}{dt} = ValveOpen * ValveCoefficient * DeltaPressure,$$

where *DeltaPressure* is the difference between the internal pressure at the top of the cell and the surrounding atmosphere and *ValveOpen* is a non-negative number controlled by the user via the property *buoyant_forces/gas-cell[x]/valve_open*.

## 2.7 Heat flow and gas temperature

The element **heat** can contain zero or more FGFunction elements describing the heat flow from the atmosphere and surrounding environment into the gas cell. The unit is *lb ft / (sec R)*.

If there are no heat transfer functions at all the gas cell temperature will equal that of the surrounding atmosphere. A constant function returning 0 results in adiabatic behaviour (i.e. no heat exchange at all with the environment).

The following is an example of how the heat flow due to conduction and radiation can be modelled:

```
<heat>
 <function name="buoyant_forces/gas-cell/dU_conduction">
  <product>
   <value> 6282.25 </value> <!-- Surface area [ft2] -->
   <value> 0.05 </value>    <!-- Conductivity [lb / (R ft sec)] -->
   <difference>
    <property> atmosphere/T-R </property>
    <property> buoyant_forces/gas-cell/temp-R </property>
   </difference>
  </product>
 </function>
 <function name="buoyant_forces/gas-cell/dU_radiation">
```

```
    <product>
     <value> 0.1714e-8 </value> <!-- Stefan-Boltzmann's constant
                                     [Btu / (h ft^2 R^4)] -->
     <value>      0.05 </value> <!-- Emissivity [0,1] -->
     <value>   6282.25 </value> <!-- Surface area [ft2] -->
     <difference>
      <pow>
       <property> atmosphere/T-R </property>
       <value> 4.0 </value>
      </pow>
      <pow>
       <property> buoyant_forces/gas-cell/temp-R </property>
       <value> 4.0 </value>
      </pow>
     </difference>
    </product>
   </function>
  </heat>
```

## 2.8 Ballonets

A **gas_cell** element may contain zero or more **ballonet** elements. A ballonet is an air bag inside the gas cell in non-rigid or semi-rigid airships and is used to maintain the shape and volume of the gas cell/envelope and keep its internal pressure higher than that of the surrounding environment. It is common for such airships to have more than one ballonet, e.g. with one ballonet in the forward part and one in the aft part of the envelope the pitch attitude of the airship can be trimmed via the relative inflation of the two ballonets (as this moves part of the contained air forward or aft, respectively).

In JSBSim ballonets are modelled as being completely contained inside the enclosing gas cell (except for the inflow and outflow valves which serves air from and to the outside atmosphere).

- **location**
  Location of ballonet center in the aircraft's structural frame. The ballonet does not necessarily need to be contained inside the defined shape of the gas cell. However, the simulation will behave as if that is the case.

- {**x** | **y** | **z**}**_radius — {x** | **y**| **z**}**_width**
  The elements {**x** | **y** | **z**}_{**radius** | **width**} define the shape and volume of the fully inflated ballonet in the structural frame. The supported shapes are ellipsoid (using x,y,z_radius) and cylindrical along X axis (using x_width

and y,z_radius). The ballonet shape is used to compute the inertia tensor due to the mass of the contained air.

- **max_overpressure**
  Maximum ballonet overpressure with respect to the surrounding atmosphere pressure. If exceeded the ballonet relief valve is automatically opened and the contents is released according to the **valve_coefficient**.

- **valve_coefficient**
  Capacity of the exit valve between the ballonet and the atmosphere. The valve coefficient determines the airflow out of the cell according to:

$$\frac{dVolume}{dt} = ValveCoefficient * (InternalPressure - AtmospherePressure) .$$

- **heat**
  Zero or more FGFunction:s describing the heat flow from the enclosing gas cell into the ballonet. See Section 2.7 for more information.

- **blower_input**
  One FGFunction describing the air flow into the ballonet. Unit: $ft^3/sec$ at the temperature and pressure of the ballonet. The following example defines a (unrealistic) constant inflow of $15ft^3/sec$.

```
<blower_input>
 <function name="buoyant_forces/gas-cell/ballonet[0]/in-flow-ft3ps">
  <value> 15.0 </value>
 </function>
</blower_input>
```