CNG Tank Design

A Freshman Engineering Design Project

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Overview:
In this lesson, student teams will be designing a tank to store compressed natural gas (CNG) for use in automobiles. The "client" is a local newspaper publisher, who believes that by operating several newspaper delivery cars on natural gas, the paper can both save money and become more environmentally "friendly."
Learning Objectives or Student Outcomes:
By the end of this project, students will be able to 1. work with a team to select the inner and outer diameters and the length of the CNG tank that will fit in the trunk of a selected automobile to be used to deliver newspapers; 2. create a scaled orthographic and isometric sketch of the CNG tank; and 3. work with a team to complete a final written and oral presentation of the CNG tank designed.
Length of Lesson:
The length of the lesson will depend on how much in-class time is devoted to the lesson and what other activities are happening in the class during the duration of this project.
Team Size:
Teams of four work best. If necessary, a few teams of 3 or 5 people each may be formed.
How is *positive interdependence* ensured?
The team must work together to turn in one final written report and to complete one oral presentation of the CNG tank designed.
How is *individual accountability* ensured?
Each team member must create a scaled orthographic and isometric sketch of the CNG tank in the trunk of the automobile. These sketches are all to be included in the written *team* report.
Assessment:
Student teams are required to communicate their final designs to the "client" through both a written report and an oral presentation. Written team reports must contain the following *<u>from each team member</u>*: a scaled orthographic and isometric sketch of the CNG tank in the trunk. More information on the assessment can be found in the Deliverables section below.

Team Skills Needed for Success:
The teams need solid communication skills and the ability to work cohesively as a group.

Materials Needed by Students:	**Multimedia Needs for Instructor:**
Students will need to decide in what medium to represent their designs and to deliver their oral presentations. (For example, they may decide to use a graphics software to represent their design and PowerPoint to present their design.)	This will depend on the students' choices for presenting. (For example, if a team chooses to use PowerPoint in their presentation, the instructor should have a projection system on hand for them.)

Instructions to Students:

1	**Project Description** Your "client," the local newspaper, has several contracted individuals that deliver their newspapers in rural areas. The new publisher believes that by operating several cars on natural gas, the paper can both save money and become more environmentally "friendly." The client will base their decision on a combination of: 1. estimated savings from lower fuel costs (simple payback period), and 2. your justification of any necessary assumptions.
2	**Design Goal** The design goal for this project is to select CNG tank size(s) for an automobile used to deliver newspapers along a rural route in Alabama. Specifically, select the inner and outer diameters and the length of the tank that will fit in the trunk of the team-selected automobile. 
3	**Design Constraints from Client** Your client wishes to modify standard gasoline powered automobiles to operate on natural gas. Some of the client's constraints on your design are:

	1. entire paper delivery trip to be made using natural gas as a fuel (although the car will still have a gasoline supply for use in emergencies); 2. re-fueling occurs only once per day (overnight at a special facility); and 3. the CNG fuel cylinder(s) must be located in the trunk of the car.
4	**Design Procedure** 1. Determine the amount of natural gas required to make the delivery route for the selected automobile. 2. Determine the compressed volume of this quantity of natural gas that will be the inner volume of the CNG tank. 3. Select the inner and outer diameters of the tank based on the maximum stress formula. (See handout on Useful Relations.) 4. The length can then be determined to give the required volume. You will be given three handouts—Background Information, Useful Relations, and Other Sources of Information—to aid you in completing this assignment.
5	**Deliverables** Each team must communicate its final design to the client in both written and oral form. Your written team report must contain the following *from each team member*: a scaled orthographic and isometric sketch of the CNG tank in the trunk. Your written and oral presentations should also address the following questions. 1. What are the difficulties associated with this conversion? 2. Are their any potential tax breaks for our investment? 3. How much less carbon dioxide could you expect to produce in a year?

Handouts

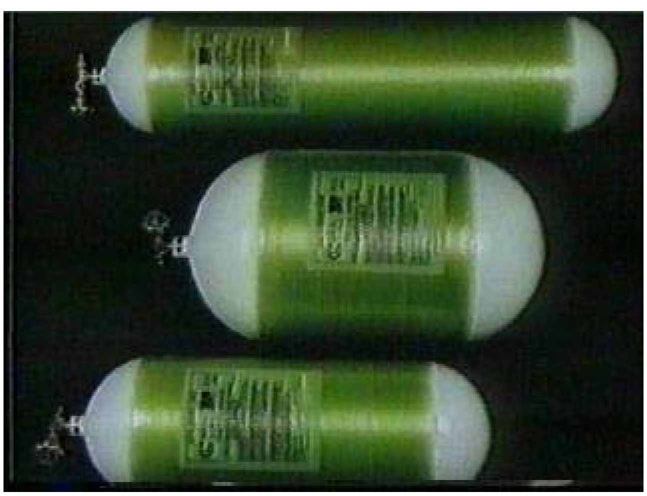
1. Background Information
2. Useful Relations
3. Other Sources for Information

Background Information

Natural gas is becoming an increasingly attractive fuel for many transportation uses. Fuel costs are significantly less than with gasoline, although the cost of the conversion kits and required accessories are not insignificant. Abundant reserves of natural gas are available in the U.S., which reduces energy dependence on foreign suppliers. Most importantly, significantly lower emissions are possible due to the simple chemical structure of natural gas (primarily methane - CH_4). Natural gas composition varies considerably over time and from location to location. Methane content is typically 85-95% with the remainder primarily ethane, propane, and carbon dioxide. Much of the natural gas produced from coal seams in Tuscaloosa county is quite high in methane content, often over 95%. The combustion characteristics of methane are similar enough that unmodified gasoline engines may be successfully operated using natural gas.

The primary disadvantage of natural gas as a transportation fuel is that under standard conditions it exists as a gas, and thus has a low density. At atmospheric pressures and temperatures, a "gallon" (231 in^3 or 0.00379 m^3) of natural gas at standard atmospheric conditions contains about 1.4×10^5 joules of energy, compared to 1.3×10^8 joules for a gallon of gasoline. Since the volumetric energy density (joules/m^3) is so low, natural gas is often stored in a compressed state at high pressure.

Large steel or composite wrapped aluminum pressure vessels (similar to those used with torch welding systems) store the compressed natural gas (CNG) at pressures of 3000 psi (2.07×10^7 Pa). Tanks are readily available in a variety of lengths and diameters, as shown in the figure below.



Steel tanks are significantly cheaper (material and fabrication costs) than the aluminum/composite wound tanks that are sometimes used. However, the weight penalty for steel tanks may be prohibitive in load-sensitive applications (tractor-trailer trucks for example). A relatively new entry into the CNG tank market is the composite reinforced steel tank shown below.

Note the shape of the tanks shown above. Pressure vessels are almost exclusively spherical or cylindrical in shape due to fabrication ease as well as strength. A "box" type construction would be difficult to seal (welds on the edges) and of lower strength per unit volume and per unit weight. Cylindrical tanks are easily fabricated (rolled or extruded seamless tube) with hemispherical end-caps welded on. The hemispherical end-caps represent a major portion of the cost for cylindrical cylinders. Spherical tanks are not space and size efficient in trunks or other potential locations for automobiles or light trucks.

Regardless of the shape and construction material used for the tank, the ideal gas law can be used to estimate the mass of natural gas stored at any given pressure once the volume and temperature are known.

Useful Relations

Given Assumptions

In "real world" design problems, an engineer must make valid assumptions in order to proceed with a design. In an academic setting, the instructor often guides the initial design efforts of the students by the choices of assumptions and constraints. Since this is your first lengthy design project, some of the basic assumptions you will need to get started are given below:

1. The ideal gas law applies to natural gas.
2. The CNG is stored at a maximum pressure of 3000 psi (lb/in^2).
3. All physical properties of natural gas are assumed to be identical to pure methane.
4. Tanks are hollow cylindrical shapes (with hemispherical end caps) made of steel.

Cylinder Stress

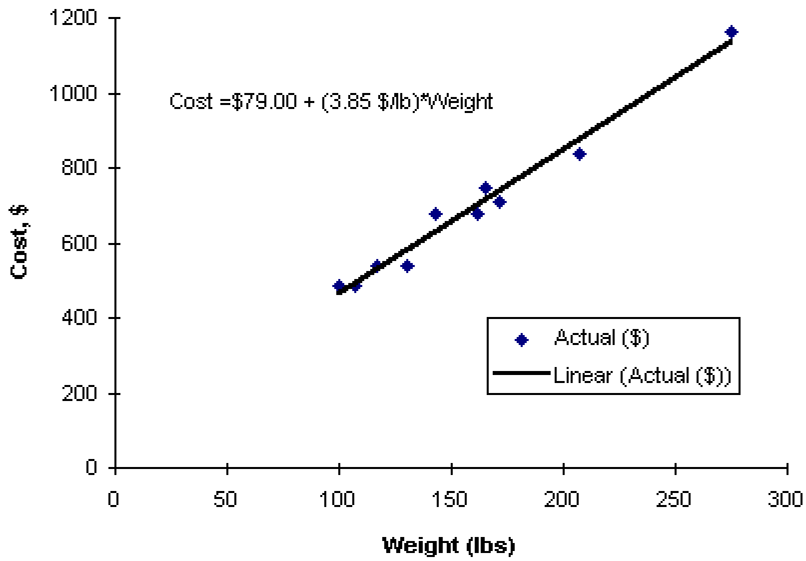
The design of real "pressure vessels" (such as the CNG tank) is governed by an elaborate set of codes and standards developed by the ASME (American Society of Mechanical Engineers). However, a relatively simple design equation can be used as a first approximation. The diameters and wall thickness of the CNG tank are limited by the maximum stress on the inner surface of the tank. This maximum stress can be estimated by the formula

$$\sigma = \left(\frac{D_o^{\,2} + D_i^{\,2}}{D_o^{\,2} - D_i^{\,2}} \right) \left(3000 \frac{lb}{in^2} \right)$$

The term on the left side of the equation represents the maximum tangential stress on the inside surface of an infinitely long cylinder subjected to an inner pressure of 3000 psi (pounds per square inch). Engineers generally limit the maximum allowable stress to a value based on the material properties with a significant factor of safety built-in. For this design, a limit of 60,000 psi on the maximum stress will be satisfactory. *Note that this high limit is due to the use of composite wrapping along the length of the cylinder and does NOT represent a limit that can be used for other designs!*

Costs for Conversion to CNG

There are two costs associated with a conversion of an automobile to operate on natural gas. There is the fixed cost of the regulators, hoses, valves, carburetor adaptor, and installation labor. We will assume that this cost is $1000, regardless of the vehicle make and model. The other cost is associated with the CNG tank. For our purposes, we will assume that the cost of the tank is a function of its weight, and can be estimated from the formulas fitted to the data shown below:



Simple Payback Period

The Simple Payback Period (SPP) is the time in years required for the savings to offset the initial, up-front costs.

For a replacement project: SPP = (Initial Cost) / (Annual Savings)

CNG Refueling Stations

A number of service stations across the country provide CNG at a pump - just like for gasoline.

The table below indicates the relative costs of CNG and regular unleaded gasoline at several locations across the U.S.

Station	Location	CNG (equivalent gallon)	Regular Unleaded (gallon)
Amoco	Minneapolis, MN	$0.969	$1.269
Exxon	Billings, MT	$0.750	$1.299
Unocal	Vista, CA	$0.880	$1.319
Total	Denver, CO	$0.809	$1.199
Sinclair	Salt Lake City, UT	$0.602	$1.159
Mobil	Garland, TX	$0.799	$1.179
Shell	Houston, TX	$0.899	$1.199
Chevron	Houston, TX	$0.799	$1.189
Phillips 66	Oklahoma City, OK	$0.799	$1.069
Amoco	Topeka, KS	$0.859	$1.079
Conoco	Mobile, AL	$0.799	$1.149
Shell	Palm Beach Gardens, FL	$0.999	$1.339
Amoco	Atlanta, GA	$0.799	$1.039
Amoco	Tucker, GA	$0.799	$1.029
Amoco	Naperville, IL	$0.959	$1.299
Texaco	Hartford, CT	$0.999	$1.399
Mobil	Brooklyn, NY	$1.139	$1.419

(table from Natural Gas Fuels, Vol. 4, No. 2, August 1995, page 14)

Other Sources of Information

Additional background information on the use of natural gas as an alternative fuel for transportation can be found at the following Web sites:

The Environmental Protection Agency (EPA) has a separate Web site with relevant information about the environmental aspects of alternative fuels. (http://www.epa.gov/)

The Department of Energy also has a Web page for natural gas applications. (http://www.doe.gov/html/fe/natgas.html)

EPA mileage estimates for many late model cars can be found on the DealerNet. (http://www.dealernet.com/)