TITTLE: Discussion of CGA Standard and the ASME Code for a Cylindrical Shell with an External Pressure.

AUTHOR: Ang Lee and Ron Fast

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Discussion: This design note contains a discussion of the ASME code design standard for a cylindrical shell with an external pressure. The ASME code starts with a Sturm[1,2] equation to calculate a collapsing pressure P_c for a cylindrical shell as

$$P_c = KE(\frac{t}{D})^3 \qquad (1)$$

where E is the material modulus, t is the shell thickness, D is the diameter of the shell and K is a constant depending on the geometry only. If both sides of Equation 1 are multiplied by (r/t), a critical hoop stress can be obtained

$$\sigma_c = P_c \cdot (\frac{r}{t}) = KE(\frac{t}{D})^3 \cdot \frac{r}{t} \qquad (2)$$

and a critical strain ε_c is given by dividing above equation both sides by modulus E,

$$\varepsilon_c = (\frac{\sigma_c}{E}) = P_c \cdot (\frac{r}{Et}) = K(\frac{t}{D})^3 \cdot \frac{r}{t} \qquad (3)$$

or

$$\varepsilon_c = K(\frac{t}{D})^3 \cdot \frac{r}{t} = \frac{K}{2} \cdot (\frac{t}{D})^2 = A \tag{4}$$

The ASME code defines this critical strain ε_c as a factor A, which is only related to the geometry. For a given geometry t, D and L, a critical strain ε_c, (factor A), can be found from Equation 4, or from ASME code section VIII, DIVISION1, Fig. 5-UGO-28.0 (graphic solution of Equation 4). The stress σ_c corresponding to this strain is given by the ASME code in the following ways [1,2,3]:

(1) if buckling occurs in the elastic region, the critical stress σ_c can be found as

$$\sigma_c = \varepsilon_c \mathrm{E} = \mathrm{AE} \tag{5}$$

and a collapsing P_c can be found from relation between the hoop stress and external pressure as

$$\mathrm{P_c} = \sigma_c \cdot \frac{\mathrm{t}}{\mathrm{r}} = \mathrm{AE}(\frac{\mathrm{t}}{\mathrm{r}}) = \frac{2\mathrm{AE}}{(\mathrm{D}/\mathrm{t})} \tag{6}$$

The ASME code uses safety factor (SF) of 3 in the above equation to calculate an allowable working pressure P_a :

$$P_a = P_c / SF = \frac{2AE}{SF(D/t)} = \frac{2AE}{3(D/t)} \tag{7}$$

which appears in the ASME code section VIII, DIVISION 1 UG-28.

(2) If buckling occurs in the plastic region, the stress σ_c associated with this critical strain A can be obtained from a quasi-stress-strain curve[1,2,3] (B curve) for a particular material. Thus, a critical stress is given as

$$\sigma_c(\varepsilon_c) = 2B \tag{8}$$

and its collapsing pressure P_c is

$$P_c = \sigma_c \cdot \frac{t}{r} = \frac{2Bt}{r} = \frac{4B}{(D/t)} \tag{9}$$

Again, the ASME code places safety factor of 3 into above equation for calculation of the allowable working pressure P_a:

$$P_a = P_c / SF = \frac{4B}{SF(D/t)} = \frac{4B}{3(D/t)} \tag{10}$$

which is given in the ASME code section VIII, DIV 1, UG-28

According to CGA-341-1987 standard[4], a vacuum shell with an allowable working pressure P_a =15 psi should be designed for a collapsing pressure P_c of at least 30 psi as determined by the equation

$$P_c = \frac{2.6E(t/D)^{2.5}}{\left[L/D - 0.45(t/D)^{0.5}\right]} = P_a \cdot SF \qquad (11)$$

where the safety factor, SF, is equal to 2. Apparently, for a given thickness t, the CGA design standard gives a higher allowable working pressure than the ASME code design due to the different safety factor involved. To illustrate this, we take SF away from both the ASME code equation (Eq.7) and CGA equation (Eq.11), and note that they give identical solutions for the collapsing pressure as shown Fig1. Furthermore, it is also found that these solutions are identical to those appearing in reference 5 and reference 6 for a cylindrical shell subjected to a side and lateral pressure without the consideration of safety factor (Fig. 2). In fact, the ASME code, CGA standard, NASA standard (SP-8007) and Roark & Young solutions are fundamentally the same. In conclusion, we found that the difference between the ASME code design and CGA -341 design is a choice of safety factor SF. (The CGA has been asked to explain their selection of SF=2. Their reply is pending)

REFERENCES:

1.M.H. Jawad and J.R. Farr,"Structural Analysis and Design of Process Equipment" John Wiley & Sons, 1984, pp218-241

2. ASME boiler and Pressure Vessel Code, Section VIII, Division 1, American Society of Mechanical Engineers, New York, 1987

3. G.D.Galletly,"Buckling of Fabricated Cylinder Subjected to Compressive Axial Loads and /or External Pressure - A Comparison of Several Codes",Pressure Vessel and Piping Conference And Exhibition, PVP-Vol 57, pp29-47

4. Compressed Gas Association For Cryogenic Liquid Cargo Specification For Cryogenics Liquid (CGA-341-1987)

5. W.C. Young, "Roarks Formulas For Stress and Strain", Sixth Edition, Mcgraw-Hill, 1989, pp690

6. L.W. Swenson, "Buckling and Stress Analysis of SDC (Isogrid) Vacuum Shell",SDC, DN-156, Aug. 30, 1991, pp7

Appendix A   CGA responses

Fig-1

Comparison between CGA and ASME code without Safety Factor

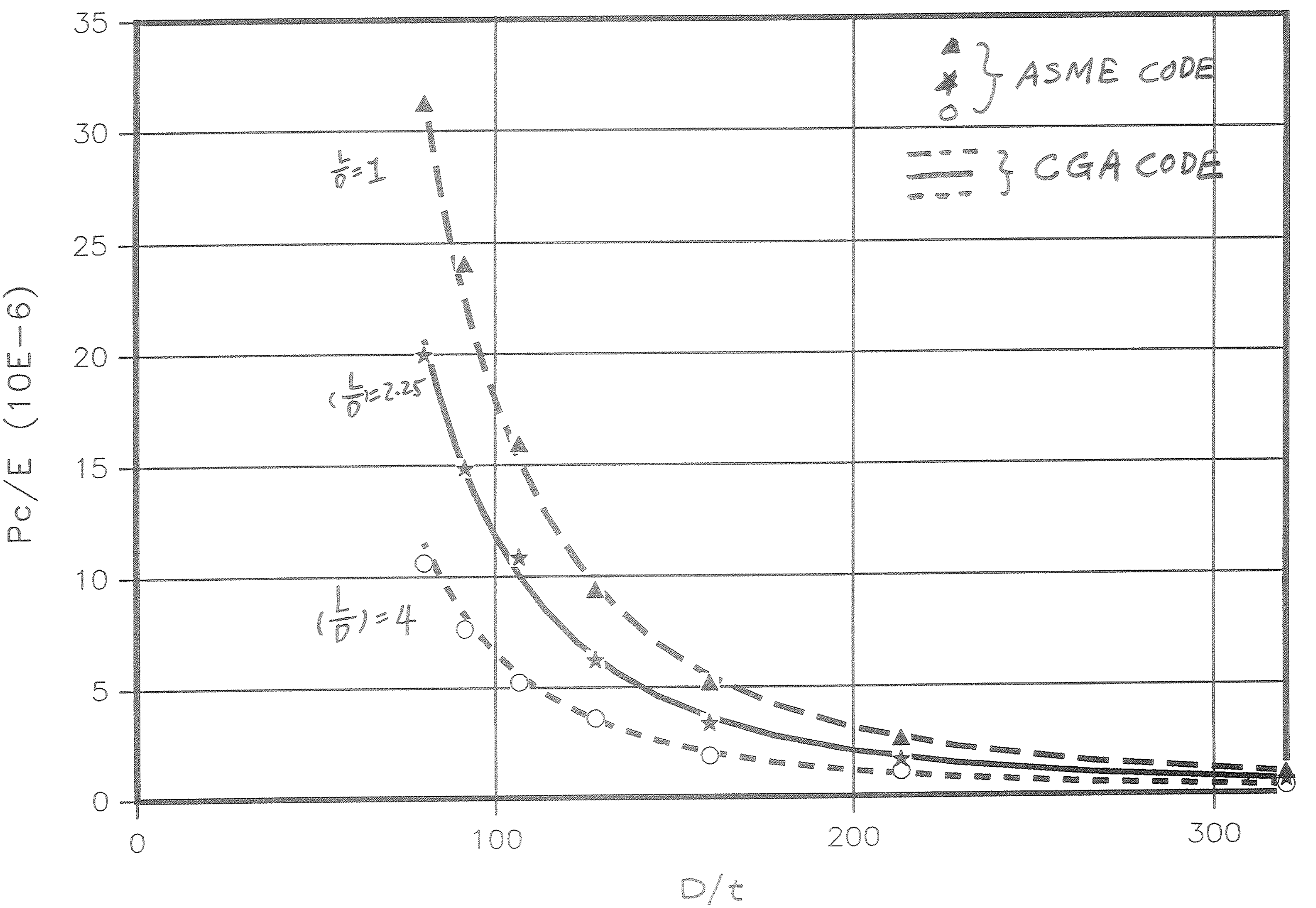
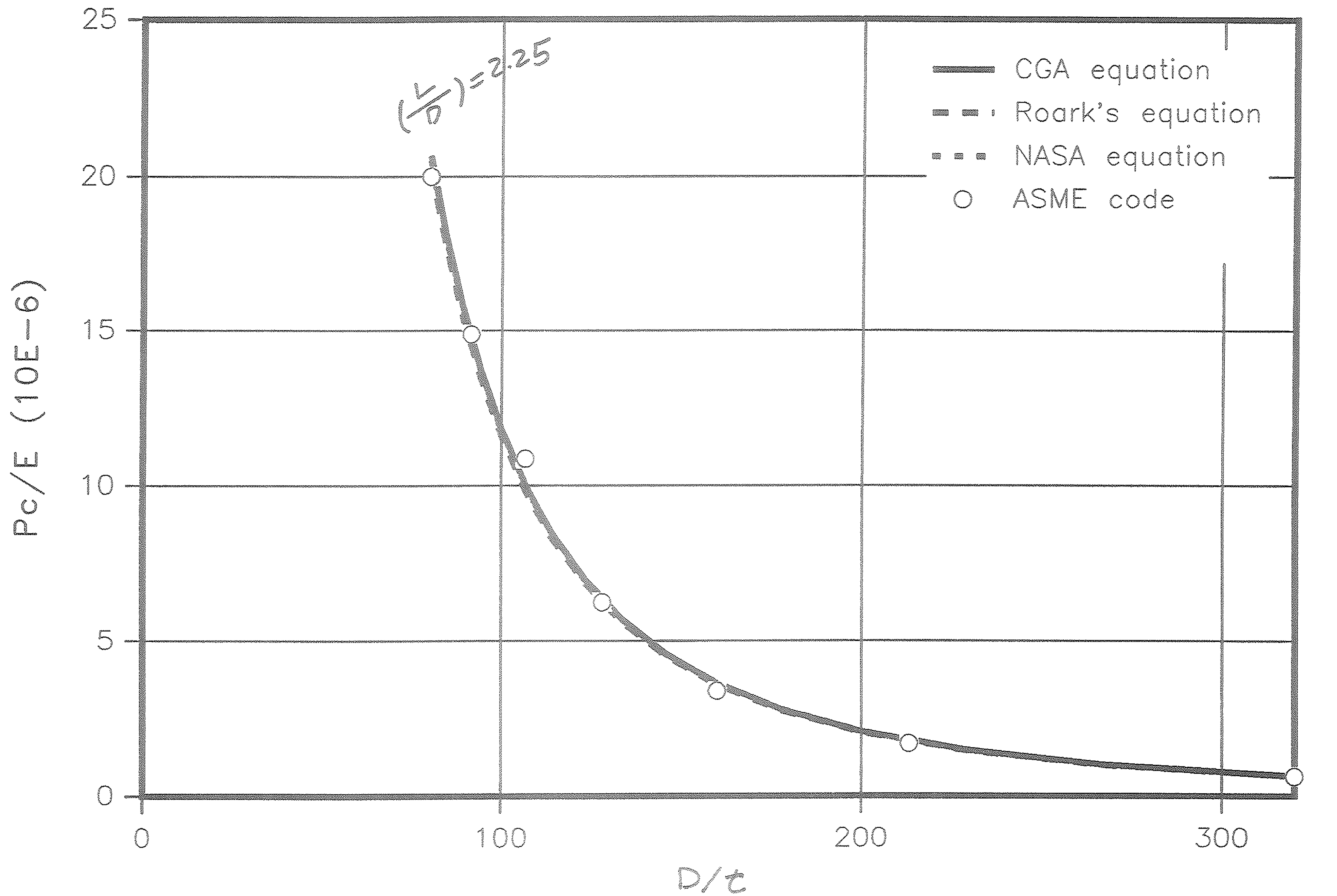


Fig-2

Comparison between ASME code and other equations for the cylindrical shell with an external pressure



Appendix

TO: CGA FAX (703)979-0900

ATTENTION: Technical Director

From: Ron Fast and Ang Lee

Fermi National Accelerator Laboratory, MS-219
P.O.Box 500, Batavia, IL60510
Tel: (708)840-3381,(708)840-3085
Fax: (708)840-4343

Subject: Safty Factor

The CGA Standard for Insulated Cargo Tank Specification for Cryogenic Liquids (CGA-341-1987) was used as a guide during the development of the engineering standard for vacuum vessels at Fermi National Accelerator Laboratory. The final Fermilab engineering standard requires that all vacuum vessels with a vacuum volume of more than 50 cubic feet be designed for at least a safety factor of two on collapse.

Vacuum vessels, although they fall outside the scope of the ASME Pressure Vessel Code, can be designed in accordance with the Code, Section VIII, Div 1, UG-28. The Code methodology contains a built-in safety factor of three on collapse.

We are designing a very large insulating vacuum vessel for a superconducting solenoid to be used in a high-energy physics detector. The dimensions of this aluminum vacuum shell are L =360", D = 160", L/D = 2.25. We are in the process of deciding on a collapse safety factor for the shell and would prefer to use SF = 2, if we can justify this choice.

Can you give me some insights into the reasons CGA chose a safety factor of two for CGA-341?

Thank you very much.

FAX FROM BILL BARLEN

TECHNICAL DIRECTOR
Compressed Gas Association
Phone: 703-979-0900
Fax: 703.979.0134

TO: Ron Fast

AT FAX #: 708-840-3867 DATE: 2-13-92

RESPONDING TO YOUR FAX OF 2-12

HARD question. We will try to get you an answer, just wanted you to Know I am trying to get you an answer(s) Will take a while - safety factors or (confidence levels) are based on experience of experts more so than math formulas. I'll be in touch.

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THIS IS IN ANSWER TO YOUR REQUEST FOR TECHNICAL INFORMATION AND IS BASED ON CGA PAMPHLETS AND/OR MY PERSONAL EXPERIENCE (OVER 30 YEARS) IN THE INDUSTRY. IF YOU ARE NOT A CGA MEMBER AND NEED A MORE COMPLETE ANSWER OR BETTER DOCUMENTATION I WILL TRY TO RECOMMEND A CONSULTANT WITH EXPERIENCE IN THE SPECIALIZED FIELD INVOLVED.

CGA OFFICE RECORDS = L4 ID # ________ Docket File________ TDFAX