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HAZARDOUS CHEMICAL CONTAINER FEASIBILITY/CONCEPT DESIGN STUDY.(U)
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16. Abstract

The purpose of this effort was to: (1) determine the feasibility of developing a hazardous chemical container for use in offloading hazardous chemicals from endangered vessels at sea, and (2) provide conceptual design for such portable containers.

This effort resulted in the development of several feasible concepts for the containment of pumpable liquid hazardous chemicals with a specific gravity of up to 1.9. However, while determining the technical feasibility of developing a portable, flexible hazardous chemical container, this effort also points out the various developmental risks of each concept. Continuation of this effort, to further define the associated risks, has been deferred pending the results of other container efforts within this project area.

17. Key Words hazardous chemicals, portable containers, flexible containers, offloading chemical tankers, floating containers, towable containers		18. Distribution Statement This document is available to the public through the National Technical Information Service, Springfield, VA 22161	
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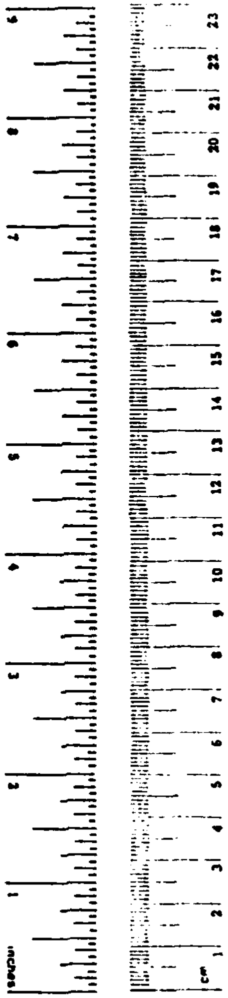
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

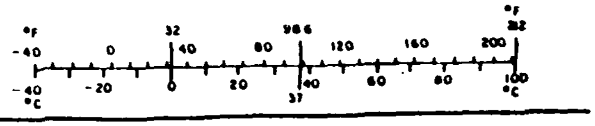
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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SECTION I--INTRODUCTION

As part of its system for offloading damaged oil tankers and barges, the U.S. Coast Guard is including floating flexible rubberized fabric containers as a means for storing and transporting oil. In developing offloading systems for damaged chemical tankers and barges, the availability of this same type of container would be advantageous. The ideal situation would be to use the same container for both oil and chemicals. However, the chemicals are often heavier than water and often damage the materials presently used for flexible oil containers. An early review of the chemicals on the U.S. Coast Guard List of Hazardous Chemicals indicated that only 42 percent of the chemicals can be carried in present oil containers, Reference 1. If flotation is added, it was predicted that 60 percent of the chemicals could be carried. To increase the percentage of chemicals carried, the container must have not only added flotation but improved materials.

A project goal of containing at least 90 percent of the chemicals can be attained if container materials and buoyancy features can be developed for all of the listed chemicals with a specific gravity of 1.4 or less. If the container materials cannot tolerate all of these chemicals, then the 90 percent goal is to be attained by increasing the flotation capability to carry some of the heavier chemicals that are compatible with the container materials.

The U.S. Coast Guard contracted Goodyear Aerospace Corporation (GAC) to conduct a hazardous chemical container feasibility/concept design study to determine the feasibility of developing and using portable containers to offload hazardous chemicals at sea and to provide conceptual design for such portable containers, Reference 2. The intent of the study is to evaluate the feasibility of developing the portable containers by investigating the potential specific gravity capability and the types of materials that can be used with the chemicals on the U.S. Coast Guard List, Reference 1.

The requirement for carrying denser chemicals leads to increased loads on the fabric components. A factor of 2 increase in fabric strengths and seam strengths are required over presently built containers to carry chemicals with a specific gravity of 1.9. Attaining these seam strengths requires engineering development. Another approach is to use seamless construction techniques. Compatibility of the different potential container materials with the different chemicals over a 200-hour period is based on available data which are limited for some of the combinations. Thus the goal may be exceeded or not attained after more complete compatibility tests are conducted in the future. Container concepts are to be operated with a minimum of new equipment and training for using the stronger system with its large buoyancy provisions.

The container design requirements for the different chemicals are presented in Figure 1. The chemicals are listed in two groups by increasing values for their specific gravities. All but three of the top group of chemicals can be carried by present flexible containers. These three chemicals can be carried by adding flotation and using stronger fabric of the same materials for improved container designs. The other larger group of chemicals require container designs that use new materials. The last portion of chemicals in this group require container designs that have flotation systems and stronger fabrics of the new materials. The structural requirements become more severe as the specific gravity values of the chemicals increase.

The approach used to conduct the program is presented in Figure 2. Task 1 was the largest task, and the results are presented in Section II-A through F. Task 2 is a comparative analysis of the viable container concepts, and the results are presented in Section II-G and H. Task 3 studied other than completely flexible container concepts, and the results are presented in Section II-I.

Hazardous Chemical	Specific Gravity	Container Design Requirements
Hexane	.659	Met by
Cyclohexane	.779	Present
Isopropyl Alcohol	.785	Container
Ethyl Alcohol	.79	Designs
Methyl Alcohol	.792	(Medium
Hydrocarbon Fuels	.7 - .8	Nitrile/
Turpentine	.86	Nylon
Copper Naphthenate	.093 - 1.05	Fabrics) Flotation
Caustic Soda (Solution)	1.5	Plus and Increased
Copper Fluoroborate	1.54	Strength Fabrics
Acetone	0.791	
Methyl Ethyl Ketone	0.806	Container
Acrylonitrile	0.8075	
Toluene	0.867	
Benzene	0.879	Designs Require
Xylene m,p,o	0.864, 0.861, 0.88	
Ammonia (28% aq.)	0.899	New Materials
Ethyl Acetate	0.902	
Styrene	0.906	
Ethyl Acrylate	0.923	● High Nitrile/Nylon
Vinyl Acetate	0.934	
Methyl Acrylate	0.956	
Xylenol	1.01	● Butyl/Polyester
Cresols	1.03 - 1.07	
Acetic Acid	1.051	Flotation
Phenol	1.058	● EPDM/Nylon Plus
Acetic Anhydride	1.08	and
Hydrochloric Acid	1.19	
Ethylene Dichloride	1.253	● Viton/Teflon Increased
Nitric Acid (conc.)	1.49	
Sulphuric Acid (Dilute)	1.84 (98%)	Strength Fabrics
Phosphoric Acid	1.892	● Teflon/Glass
Oleum	1.91 - 1.97	

FIGURE 1--CONTAINER DESIGN REQUIREMENTS FOR THE HAZARDOUS CHEMICALS

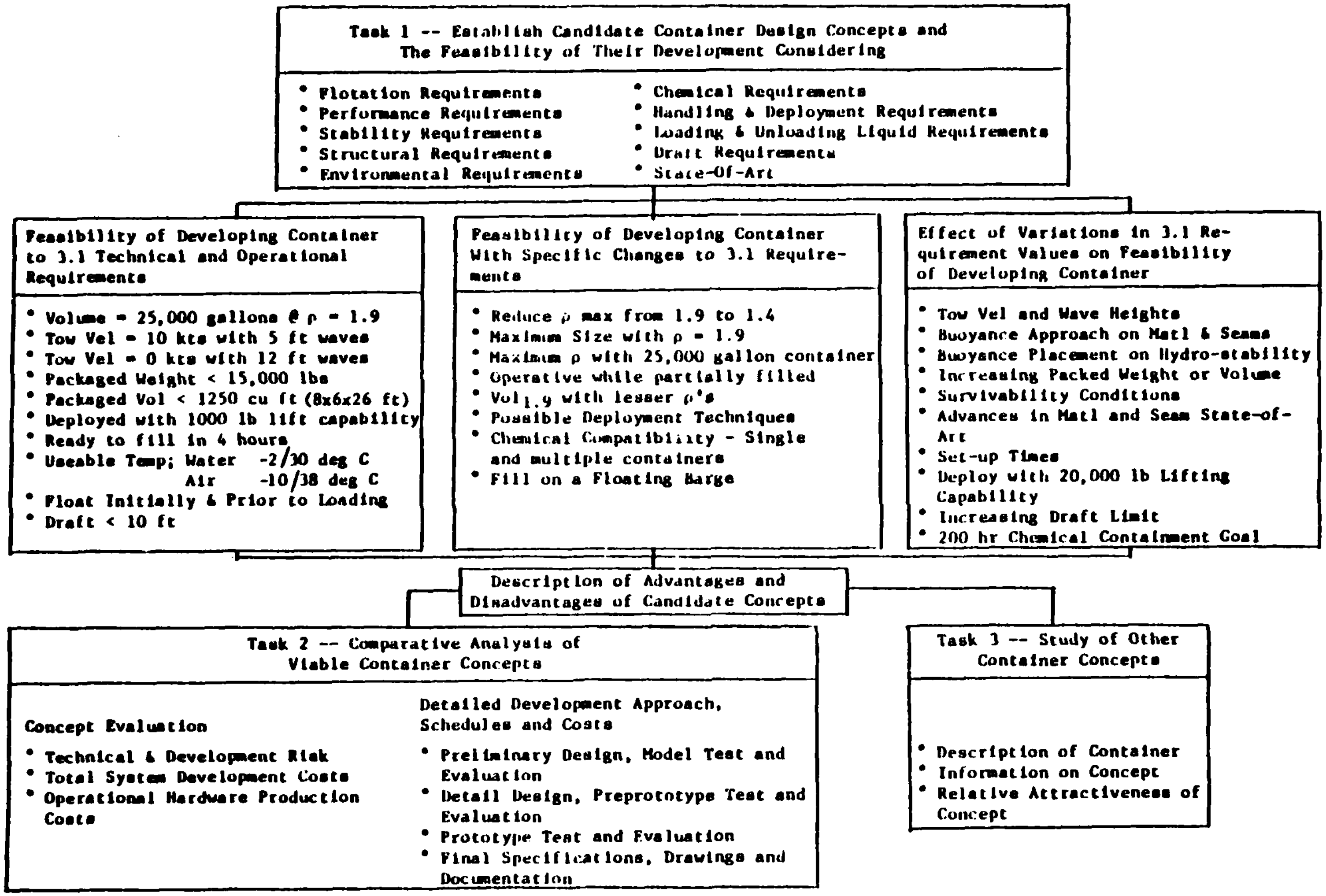


FIGURE 2--PROGRAM SCOPE AND APPROACH

SECTION II--STUDY RESULTS

A. General Characteristics of Containers

1. Conceptual Design Approaches Considered

Three conceptual design approaches were selected to determine the characteristics of the resulting chemical containers for comparison and evaluation. Approach 1 retained as many as possible of the operational features for present flexible containers that are designed for fluids with specific gravities of one or less. Separate flotation devices were added to provide adequate buoyancy.

Approach 2 evolved from investigating containers with common chemical and buoyancy chambers within the container's structure. More than one chamber is required since the chemical can flow to one end causing each chamber to rotate toward a spar buoy attitude. Methods to fill the many chambers of Approach 2 with a common hose or from a common point were investigated to retain as many as possible of the desirable operational features of present flexible containers.

The third conceptual design approach investigated consists of segmented containers that have chemical and buoyancy provisions within each segment. The segments are filled either separately using one hose or in multiples using several hoses.

The factors considered in selecting the three conceptual design approaches include operational factors, performance factors, and sizing requirements which are discussed in this subsection. Preliminary configurations resulting from the three approaches are presented in Figure 3.

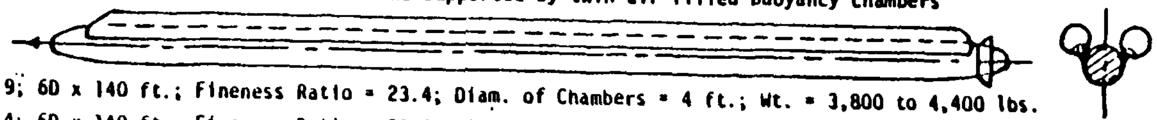
a. Operational Factors

Some of the operational factors considered for investigating the different container design concepts include:

1. The efforts required to train personnel and equipment needed for transporting, using, maintaining, refurbishing (including repacking), and storing each system concept.

CONCEPTUAL DESIGN CONCEPTS INVESTIGATED

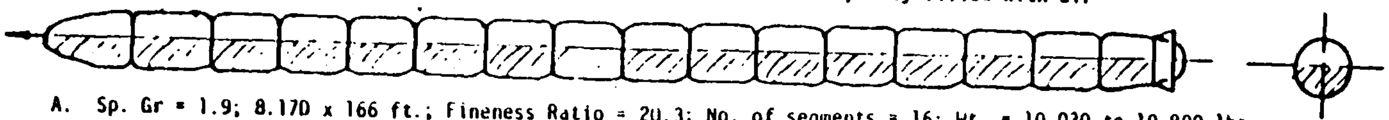
Approach 1--Single container filled with a chemical and supported by twin air filled buoyancy chambers



A. Sp. Gr = 1.9; 6D x 140 ft.; Fineness Ratio = 23.4; Diam. of Chambers = 4 ft.; Wt. = 3,800 to 4,400 lbs.

B. Sp. Gr = 1.4; 6D x 140 ft.; Fineness Ratio = 23.4; Diam. of Chambers = 3 ft.; Wt. = 2,800 to 3,400 lbs.

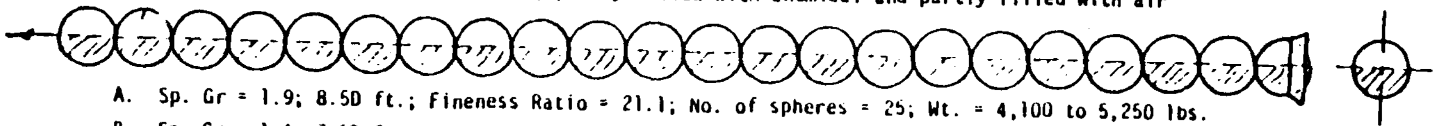
Approach 2--Segmented chemical container, partly filled with chemical and partly filled with air



A. Sp. Gr = 1.9; 8.17D x 166 ft.; Fineness Ratio = 20.3; No. of segments = 16; Wt. = 10,030 to 10,800 lbs.

B. Sp. Gr = 1.4; 7.0D x 166 ft.; Fineness Ratio = 23.8; No. of segments = 17; Wt. = 7,500 to 8,250 lbs.

Approach -- Chemical containers in series, partly filled with chemical and partly filled with air



A. Sp. Gr = 1.9; 8.5D ft.; Fineness Ratio = 21.1; No. of spheres = 25; Wt. = 4,100 to 5,250 lbs.

B. Sp. Gr = 1.4; 7.5D ft.; Fineness Ratio = 22 ; No. of spheres = 26; Wt. = 2,880 to 3,820 lbs.

FIGURE 3--CONTAINER CONFIGURATION APPROACHES

2. The efforts and equipment required to deploy each system concept for it to be ready to receive chemicals.

3. The efforts and equipment required to fill and provide buoyancy for each system and the relative degree that personnel are exposed to any of the chemicals.

4. The force required to tow the system at 10 kts and the efforts required to develop a stable system.

5. The efforts and equipment required to discharge each system and the relative degree that personnel are exposed to any of the chemicals.

6. The efforts required to retrieve the container after use.

7. The efforts required to refurbish the container after use including any equipment for repacking.

b. Performance Factors

Some of the performance factors considered for investigating the different container design concepts included:

1. The draft of the system with chemicals having specific gravities greater than one.

2. The volume of chemicals with specific gravities of more or less than 1.9 that can be contained by a system designed for 25,000 gallons of chemicals with a specific gravity of 1.9.

3. The tensile and seam strengths required of the fabrics.

4. The tear strengths required of the fabrics.

5. System weights.

6. System packed volumes.

c. Costs and Technical Risks

Some of the cost and technical risk factors considered for investigating the different concepts included:

1. The materials chosen for the system components.
2. The methods for constructing the systems.

2. Initial Sizing and Geometry of the Systems

A review of available information indicates that a cylindrical container with a shaped nose and a tail section with a fence for even separation of the flow is one candidate geometry, References 3, 4, and 5. The information in Reference 5 also indicates that the length (l) of the container should be from 23 to 25 times its diameter (D) to limit the amount of increase in drag per unit cross-sectional area of the container with increasing towing speeds, Figure 4. The nominal dimensions of the containers can be calculated by selecting a fineness ratio of 23 to 25, a fullness ratio of .85, and total volumes of either 25,000 gallons for containers with separate buoyancy chambers or 50,000 gallons for containers with integral buoyancy chambers. Container diameters versus container lengths and fineness ratios (l/D) for these two types of containers are presented in Figure 5. The nominal diameter of a container with a separate buoyancy chamber(s) is 6 feet, and the nominal diameter of a container with an integral buoyancy chamber(s) is 7.5 feet for fineness ratios of approximately 24.

The fullness ratio values were then calculated for the container cross-section when filled with chemicals with specific gravities from 1 to 1.9 for comparison with the assumed fullness ratio value of 0.85. The top of the container was assumed to be 3.25 feet under water, and the pressure in the container at that point was assumed to be 6.5 feet of water. The resulting cross-sectional shapes are presented in Figure 6. All shapes have a fullness ratio value greater than 0.85.

Towing drag forces were estimated considering the data presented in References 3, 4, and 5 for single cylindrical containers. The data presented in Reference 3 used the wetted area of the container as the reference for calculating the drag coefficient values. The values were presented versus the values of the parameter, Velocity, knots, length , feet (the modified Froude number or Taylor quotient). These data and the data presented in References 4 and 5 were

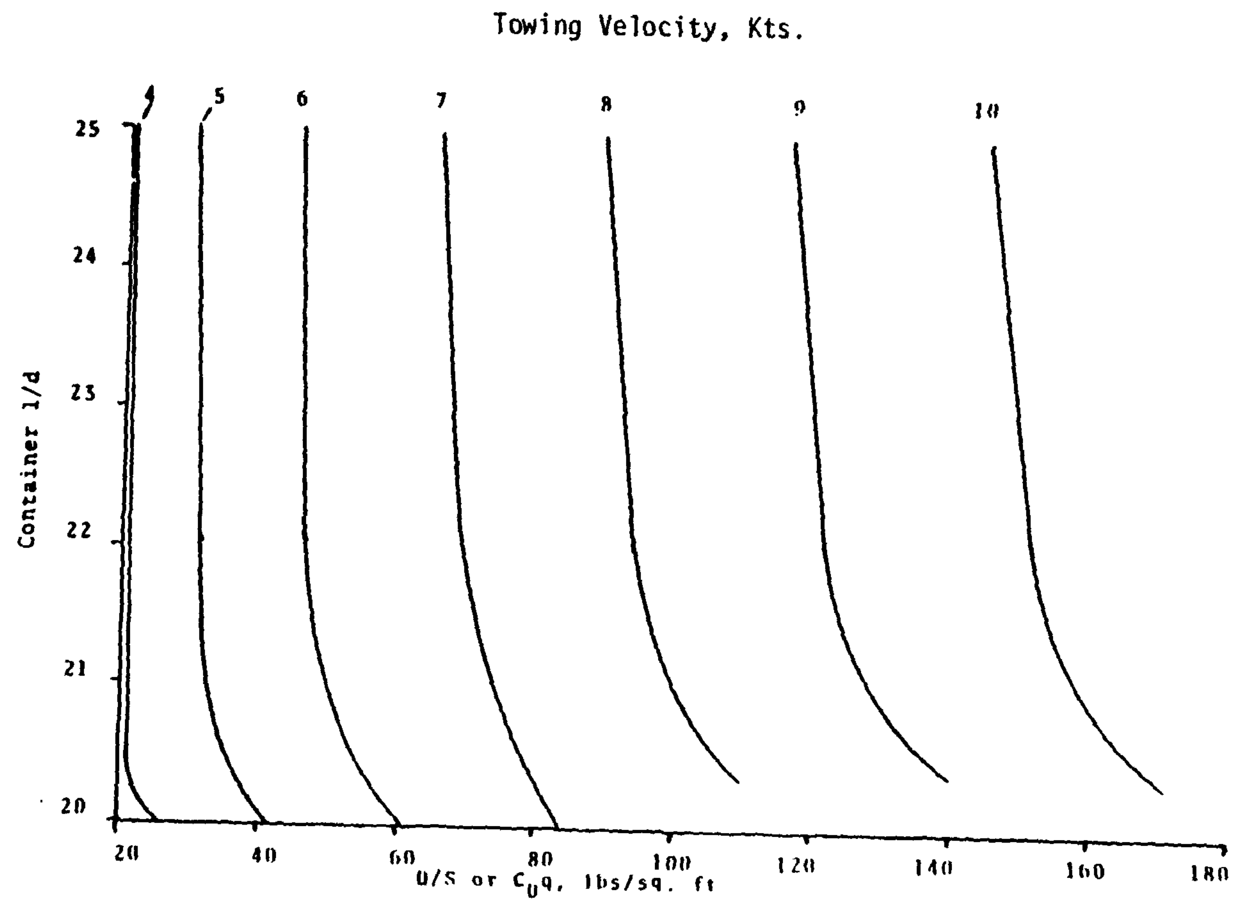


FIGURE 4--CIRCULAR CONTAINER DRAG/CROSS-SECTIONAL AREA VERSUS FINENESS RATIO

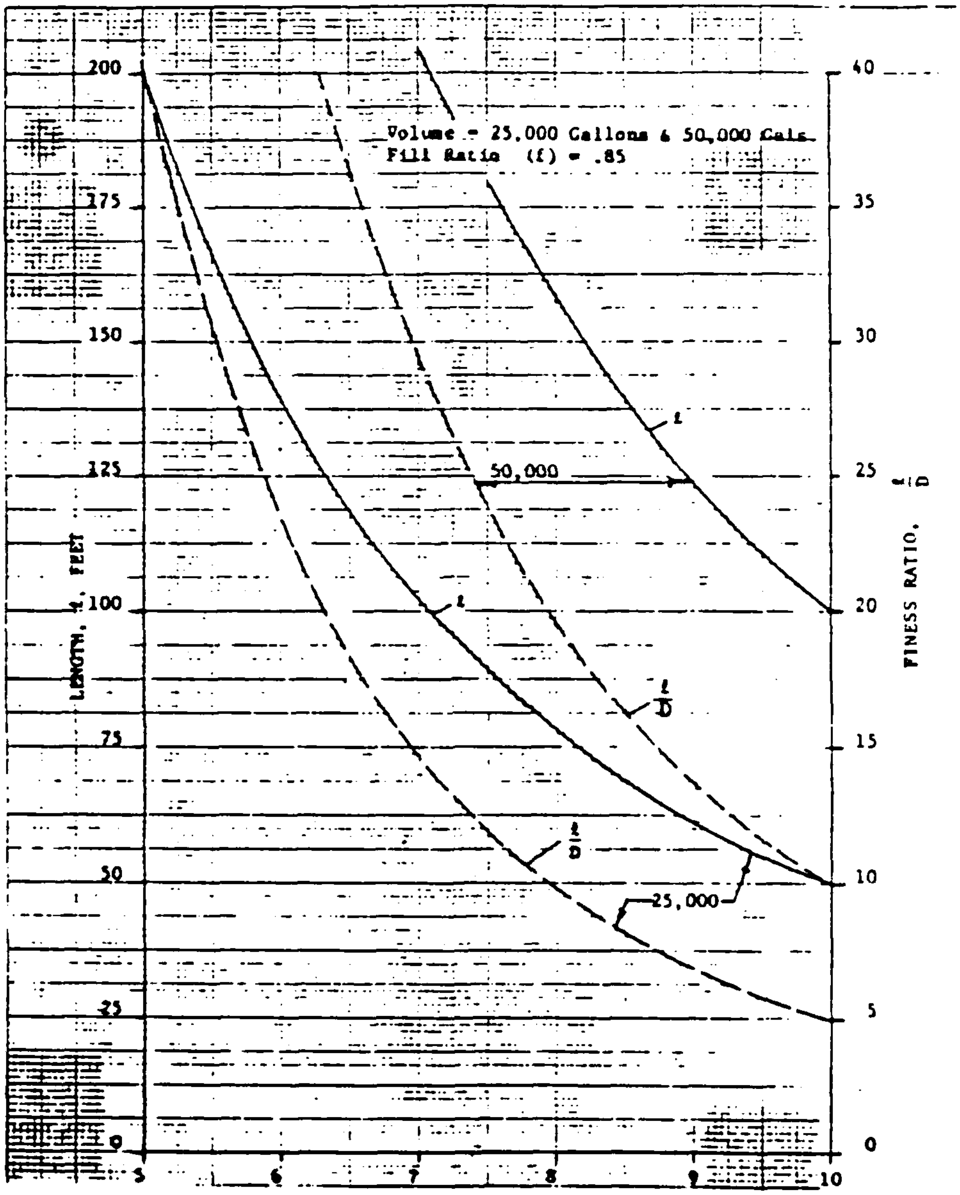


FIGURE 5--CONTAINER DIAMETER VERSUS LENGTHS AND FINENESS RATIOS FOR 25,000 AND 50,000 GALLON CONTAINERS

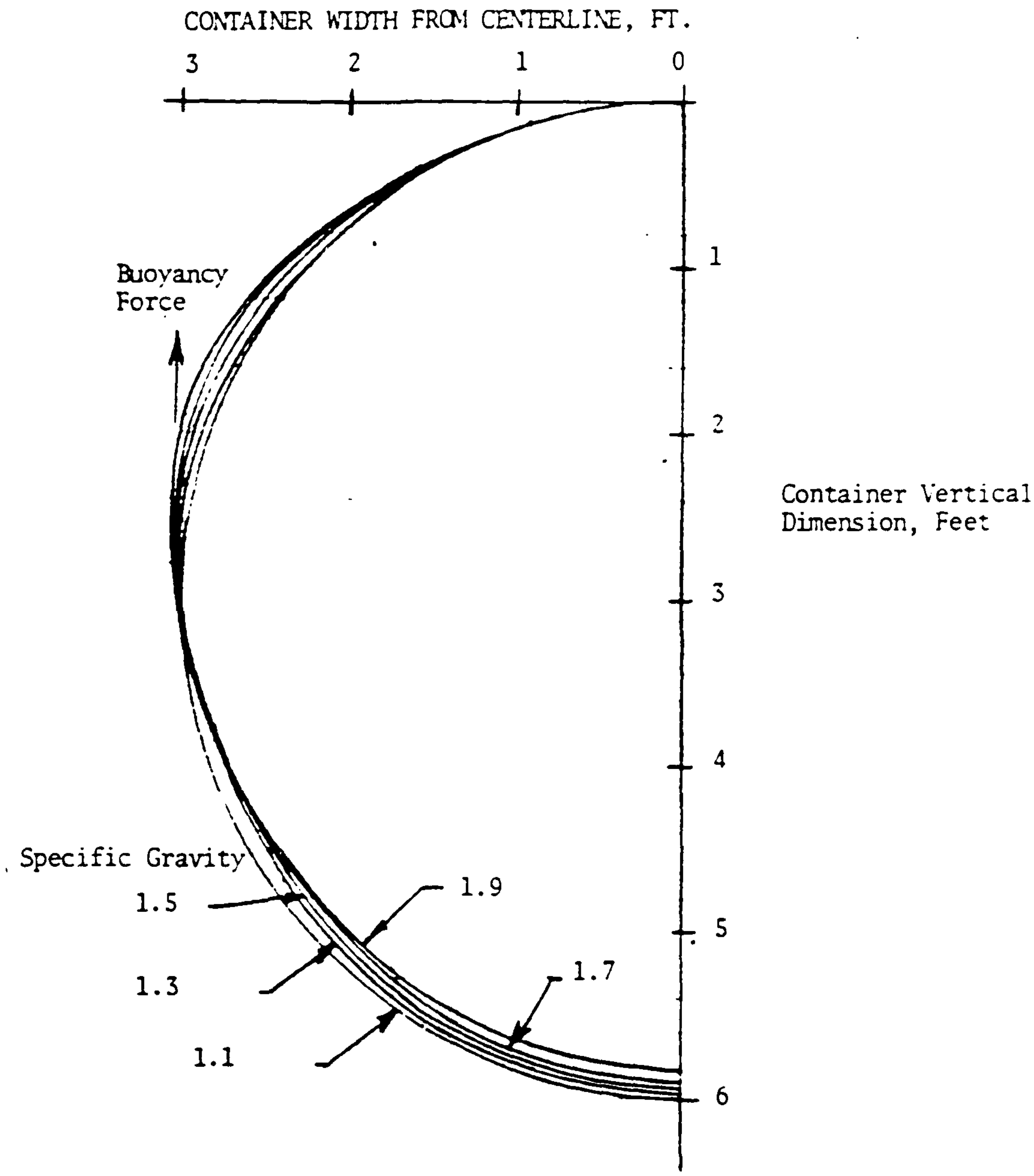


FIGURE 6--FULL CONTAINER CROSS-SECTIONS VERSUS CHEMICAL SPECIFIC GRAVITY VALUES OF 1.1 TO 1.9--APPROACH 1

used to calculate the values of drag coefficients based on each container's maximum cross-sectional area (including any fence projection). The resulting values are presented versus towing velocity in Figure 7. The test results for the stabilized nine-inch D and K models, Reference 3, and for the 1/2 scale ADAPTS container, Reference 4, have some correlation between the peak load values, especially at 4-6 knots.

The values from Reference 5, being average values, are less than the peak values presented from References 3 and 4. The relationship between peak and average towing forces can be established from the towing force versus time curves presented in Reference 3. The results indicate that peak towing forces are approximately 1.5 times the average force. Average force is normally used for calculating towing power requirements. Considering this relationship, the peak towing force values for the Reference 5 data were calculated using a factor of 1.5 times the presented average force values. The results then can be compared with the other data from References 3 and 4. Correlation between the values from all three references then becomes more reasonable at the greater towing velocities, Figure 7. Based on the values presented, a peak drag coefficient value of 0.765 was selected for cylindrical containers operating at 10 knots.

3. Structural Requirements

The structural requirements are based on a dynamic amplification factor in conjunction with a design factor.

a. Dynamic Amplification Factor

When the container is subjected to wave action or is being towed in a seaway, the fluid inside the container is set into motion. The dynamic amplification factor is a measure of the pressures that the fabric must resist in containing the fluid under these conditions. In Reference 3, the pressures are related directly to the wave height with the observation that the dynamic pressures seldom exceed twice the static pressure due to the height of the wave. In Reference 6, a dynamic amplification factor of 3.5 is suggested for the ADAPTS container for towing velocities greater than five knots. This is denoted by the symbol α in the equation of Figure 8. The value comes from Figure 9 where $p_{max} = 5.2$ psi.

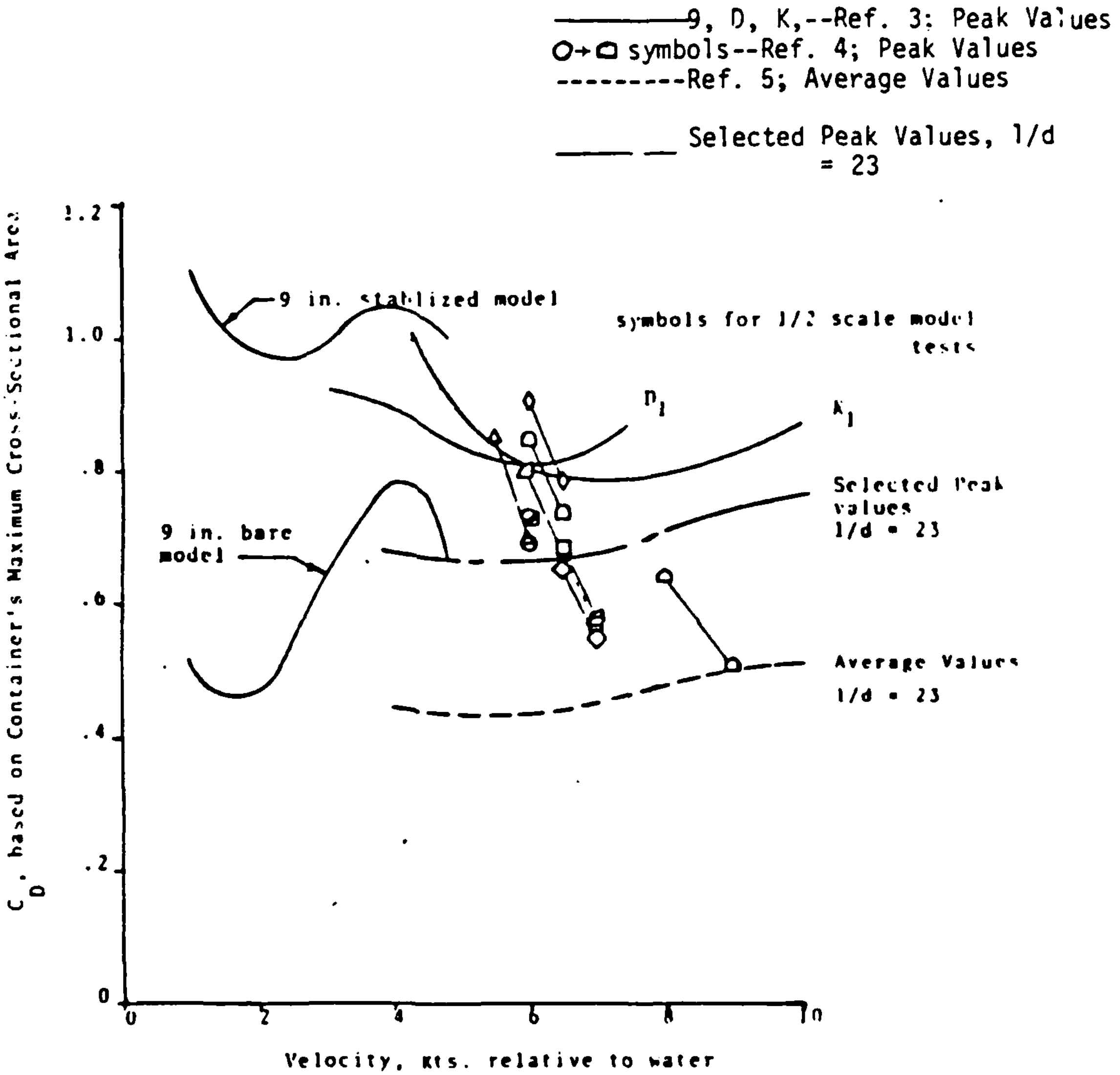
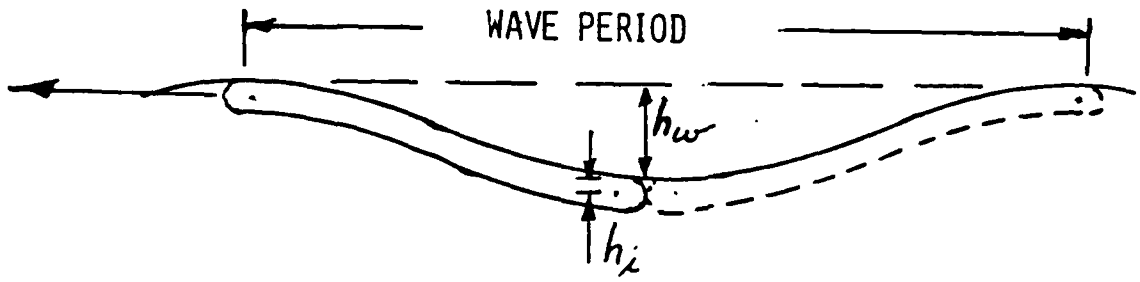


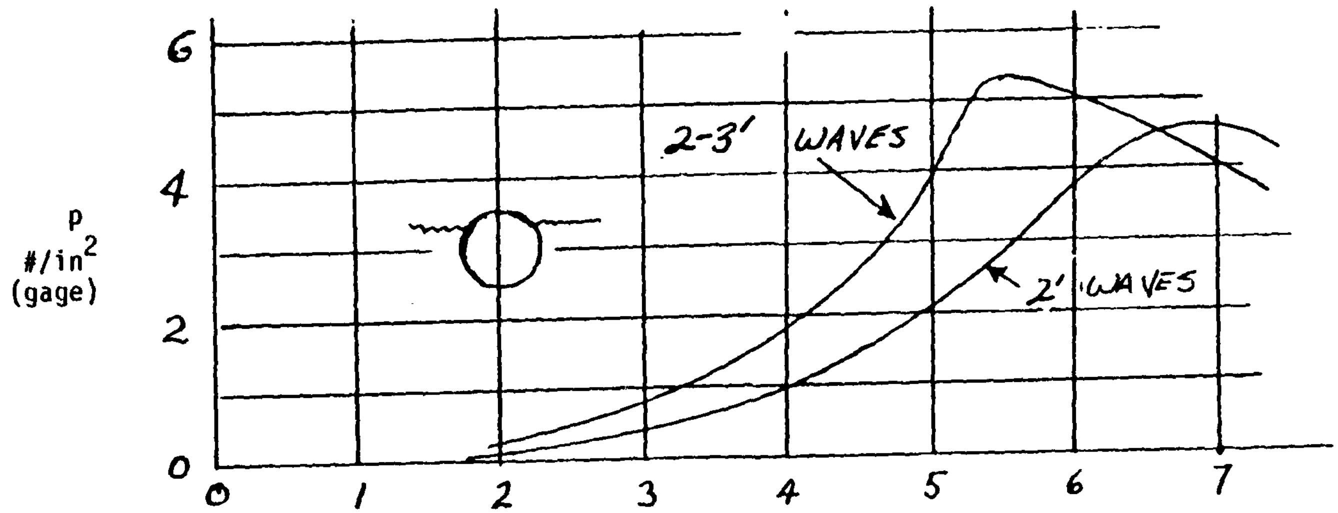
FIGURE 7--DRAG COEFFICIENTS OF CIRCULAR CONTAINERS VERSUS VELOCITY

p_d = pressure due to dynamics, psi
ρ = density of contained liquid, lb/ft^3
α = dynamic amplification factor
h_w = wave height, feet

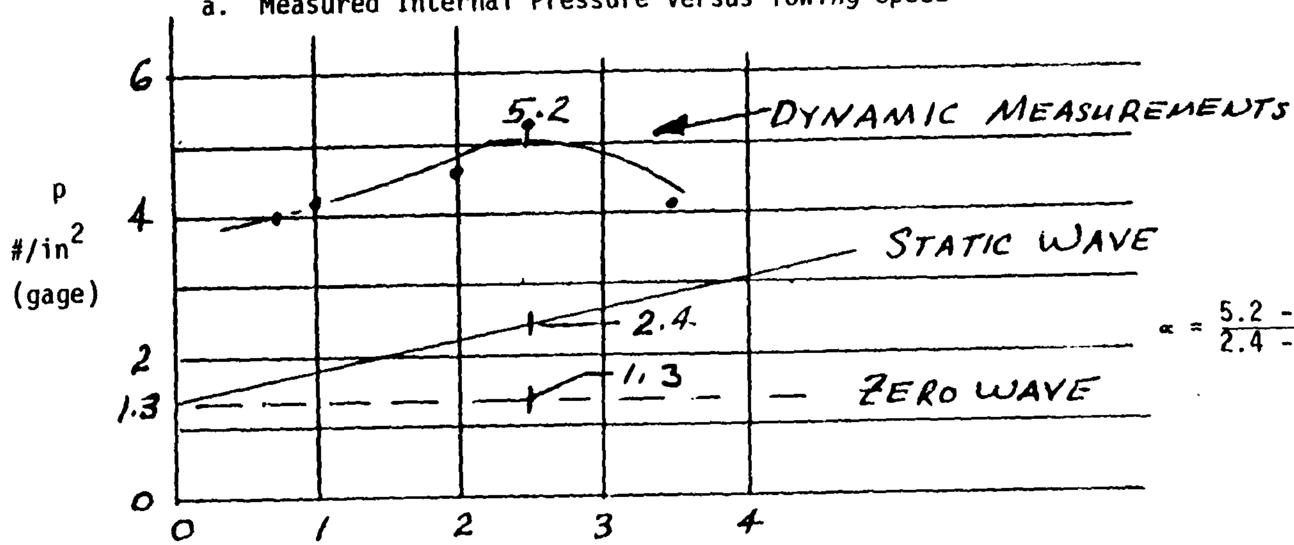


$$p_d = \frac{\rho}{144} (\alpha h_w + h_i)$$

FIGURE 8--DYANAMIC AMPLIFICATION FACTOR DEFINITION



a. Measured Internal Pressure versus Towing Speed



$$\alpha = \frac{5.2 - 1.3}{2.4 - 1.3} = 3.5$$

b. Measured Internal Pressure versus Wave Height--Towing Velocity > 5 kts

FIGURE 9--ANALYSIS OF TEST RESULTS FOR DYNAMIC AMPLIFICATION FACTOR

It is expected that the dynamic amplification factor depends upon a number of operational and design variables such as:

Operational	Design
Sea State	Container Shape and Size
Specific Gravity of Contained Fluid	Fabric Elongation
Fill Fraction	
Towing Speed	

Available information does not indicate how the dynamic amplification factor might change with these variables. The mechanism for generating these surge pressures seems to begin with the high pressures acting on the nose of the container as it starts through a wave. This high pressure squeezes the fluid in the container and starts a surge wave traveling down the length of the container. When the surge wave reaches the aft end of the container, it must be stopped, thereby generating large pressures across the fabric.

To the extent that the phenomenon resembles an acoustic wave, a dynamic amplification factor of two would represent complete reflection of the surge wave, a worst case condition for acoustic type waves except in a resonance condition.

The maximum limit internal surge pressure is expressed as a fraction of wave height and dynamic amplification factor in Reference 3 as:

$$\Delta p = \propto \rho H$$

Where:

Δp = maximum differential surge pressure

$\propto$ = dynamic amplification factor

ρ = density of contained liquid

H = wave height

The corresponding limit hoop stress at the aft end of the container is simply:

$$\sigma = pR$$

Where:

σ = limit hoop stress

R = maximum radius at aft end of container

The specified maximum wave heights are 5 feet during 10 knot tow and 12 feet with zero tow velocity. Based on References 6 and 3, the corresponding amplification factors are 3.5 and 2, respectively. The latter case governs since 2 x 12 > 3.5 x 5. The stresses and fabric strength requirements are based on a limit internal surge pressure of:

$$\Delta p = 2 \times 12\ \rho = 24\ \rho \text{ psf.}$$

The corresponding maximum allowable wave height for which the container may be towed faster than 5 knots is:

$$h_A = \left(\frac{2}{3.5}\right)(12) = 6.9 \text{ ft.}$$

b. Design Factors

Design factors must be applied to the calculated maximum limit loads and stresses in order to specify the ultimate room temperature, quick-break tensile strength requirements for the textile components of the container system. A composite design factor includes material strength degradations based on the desired operational environments along with overload factors and a basic factor of safety. The values selected are for elastomer-coated, woven nylon cloth and are considered representative of the material to be used.

The composite design factor is defined as:

$$D.F. = \frac{(1 + \varepsilon)F.S.}{jecuta} \tag{1}$$

Where:

D.F. = composite design factor

$1 + \varepsilon$ = factor to account for stretch of the nominal dimensions at the working strain, $\varepsilon \sim$ in/in.

F.S. = basic design factor of safety

j = joint or seam efficiency, percent

e = strength retention for salt water and chemical action, percent

c = creep rupture, percent

u = strength retention for ultraviolet exposure, percent

t = strength at operating temperature, percent

a = strength retention for abrasion, percent

Factor of Safety (F.S.)

This is the ratio of the failure load or stress to the imposed load or stress. It is required as a safeguard against possible increases in the design loads and stress producing factors. The selected value for this application is:

$$F.S. = 1.5 \tag{2}$$

Stretch Factor ($1 + \varepsilon$)

For convenience, the stresses are calculated based on the nominal dimensions of the container. Allowance for increased stresses due to the significant elongation of the nylon fabric and increases in container size is made by taking a conservative value of strain, ε, at the maximum limit stress level. The stress-strain properties are different in the warp and fill directions and each is nonlinear having the typical S-shape curves for nylon. Test results of candidate fabrics are used when available, otherwise the typical curve of Figure 10 is used. At a maximum limit stress of 25 percent of ultimate strength, a strain of 11 percent is indicated. Thus:

$$1 + \varepsilon = 1.11 \tag{3}$$

Joint Efficiency (j)

The strength of the longitudinal seams and joints at the openings, such as the bead attachment at the tow connection, from past experience has proven to be at least 90 percent efficient. Where sewing is used as a backup for bonded seams, the sewing also provides a 90 percent efficient joint. Hence:

$$j = 0.90 \tag{4}$$

Effect of Salt Water Immersion and Chemical Action (e)

GAC test data are available for determining strength degradation of coated fabrics when tested after 7, 14, and 30 days of immersion in a 3 percent by weight

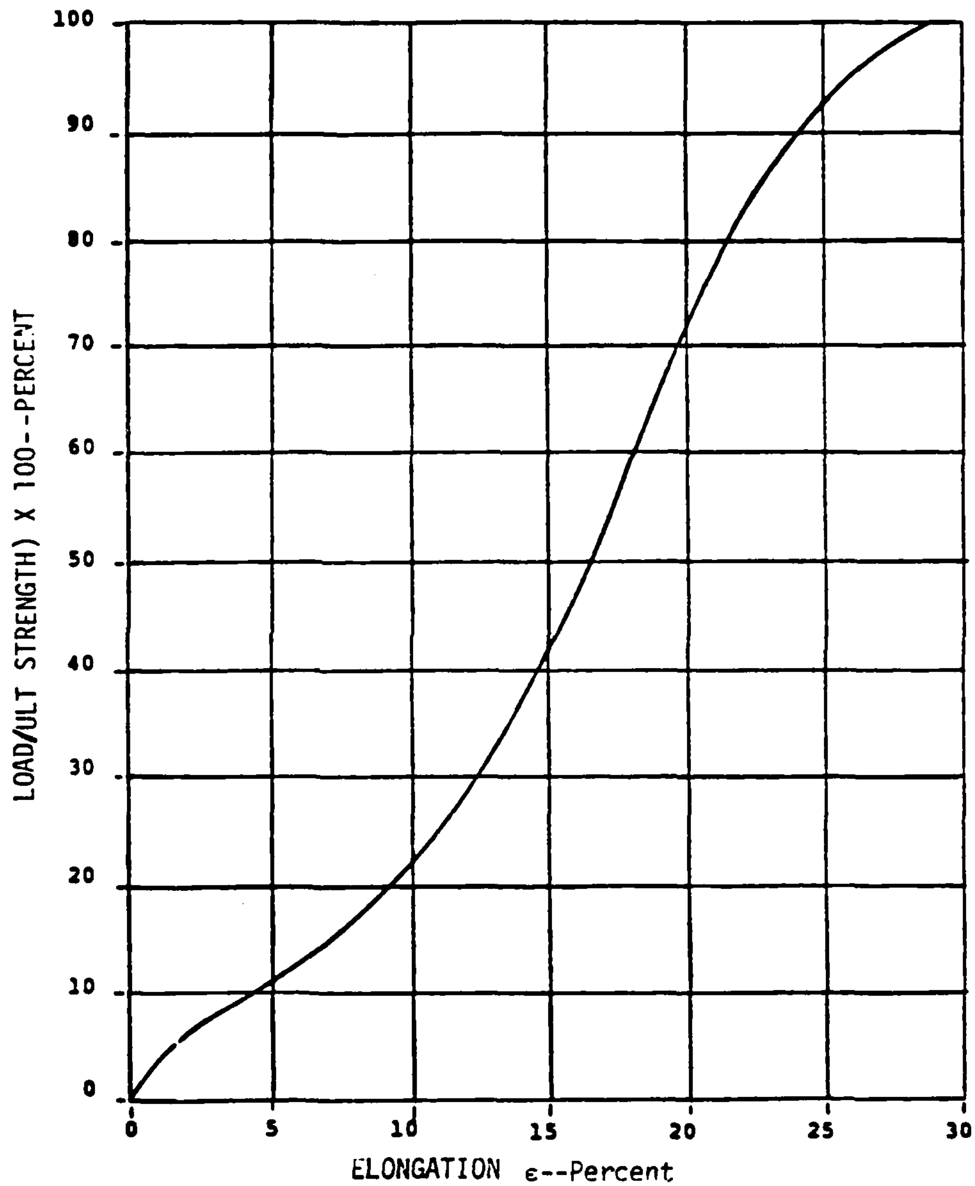


FIGURE 10--TYPICAL LOAD ELONGATION PROPERTIES FOR NYLON FABRIC

solution of NaCl in distilled water. Data for some typical high tensile strength, basket weave nylon fabric tested are shown in Table I.

TABLE 1--EFFECT OF SALT WATER IMMERSION ON THE TENSILE STRENGTH OF COATED NYLON FABRIC

Goodyear Code	Baseline Tensile Strength (lbs/in)		Salt Water Tensile Strength (lbs/in)					
			After 7 Days		After 14 Days		After 30 Days	
	Warp	Fill	Warp	Fill	Warp	Fill	Warp	Fill
XA28A495-22	1085	917	958	786	874	749	865	744
XA28A496-23	1033	965	841	894	816	911	821	817
XA28A495-24	1084	1034	958	786	874	749	865	744
XA28A497-25	1039	588	894	494	885	521	856	536

Based on the above table, the salt water strength retention factor is:

$$e = 0.75 \tag{5}$$

Similar data will be used to determine e due to fuel and chemical containment.

Creep Rupture (c)

One of the principal structural design requirements for the Goodyear Airships is the ability of the fabric to sustain long-term pressure stresses. Considerable creep rupture data have been generated to confirm service life in excess of five years. A preliminary design relationship for coated nylon fabric taken from this data base is given by:

$$c = 0.73 - 0.0652 \log t \qquad (t\sim\text{days})$$

Consider a life of five years with eight, 2-week missions per year. This gives a total of 560 days. However, the time during which the maximum design sea state will occur is much less. For design purposes it was assumed that this maximum stress will be applied only over 10 percent of the time of the total, i.e., 56 days. Therefore:

$$c = 0.73 = 0.0652 \log 56 = 0.62 \tag{6}$$

Ultraviolet Exposure (u) and Abrasion (a)

No degradation of the strength of the coated fabric was applied for these factors since the coating must be adequate to preclude exposure of the cloth yarns to both sunlight and surface abrasion. Therefore:

$$a = u = 1 \tag{7}$$

Strength at Operating Temperature (t)

Fabric temperatures greater than 100°F during operational sea state conditions are not possible. Therefore:

$$t = 1 \tag{8}$$

The composite design factor is given by substituting the values of equations (2) through (8) into equation (1):

$$D.F. = \frac{(1.11)(1.5)}{(0.9)(0.75)(0.62)} = 4$$

c. Fabric Strength Requirements

The calculation of the room-temperature, quick-break tensile strength values (F_{tu}) of the fabric for the container in waves 12 feet high is based on:

$$F_{tu} = DF \propto \rho \; HR$$

Where:

DF = The composite Design Factor = 4

$\propto$ = The dynamic Amplification Factor = 2

ρ = The density of the fluid = .036111(Sp. Gr.) lbs/cu in.

H = Wave height = 144 inches

R = Maximum radius of container, inches

Substituting:

$$F_{tu} = 4 \times 2 \times .036111\,(\text{Sp. Gr.}) \times 144 \times R$$
$$= 41.6\,(\text{Sp. Gr.}) \times R, \text{ lbs/in. or}$$
$$= 20.8\,(\text{Sp. Gr.}) \times D, \text{ lbs/in.}$$

For the range of interest, the container diameters are 6 to 8.5 feet, and chemical specific gravities are 1.0 to 1.9. The minimum and maximum F_{tu} values are as follows:

$$F_{tu} \text{ Min} = 20.8 \times 1.0 \times 72 = 1{,}498 \text{ lbs/ in.}$$

$$F_{tu} \text{ Max} = 20.8 \times 1.9 \times 102 = 4{,}031 \text{ lbs/in.}$$

The values for the range of container diameters and specific gravities are presented in Figure 11.

The selection of fabric must consider not only its ultimate strength but also its tear strength. Fuel tank fabrics are woven considering both capabilities to be important. Weaves have been developed to improve the tear strengths to several times that for the same tensile strength, square woven fabric where individual ends are woven over perpendicular single ends. One family of weaves used is the basket weave where two or four ends are woven at a time over two or four perpendicular ends. Tear strength is improved because the groups of two or four basket weave ends tend to slide together during tear and must be broken as a unit as compared to breaking single ends during tear of square woven fabric. Other approaches include selecting larger yarns for weaving the cloth or double weaving the cloth.

The actual selection of the weave of the cloth for good tensile and tear properties will be part of a preliminary design effort for developing efficient seams considering both seam tensile strength and the tear strength of the resulting fabric.

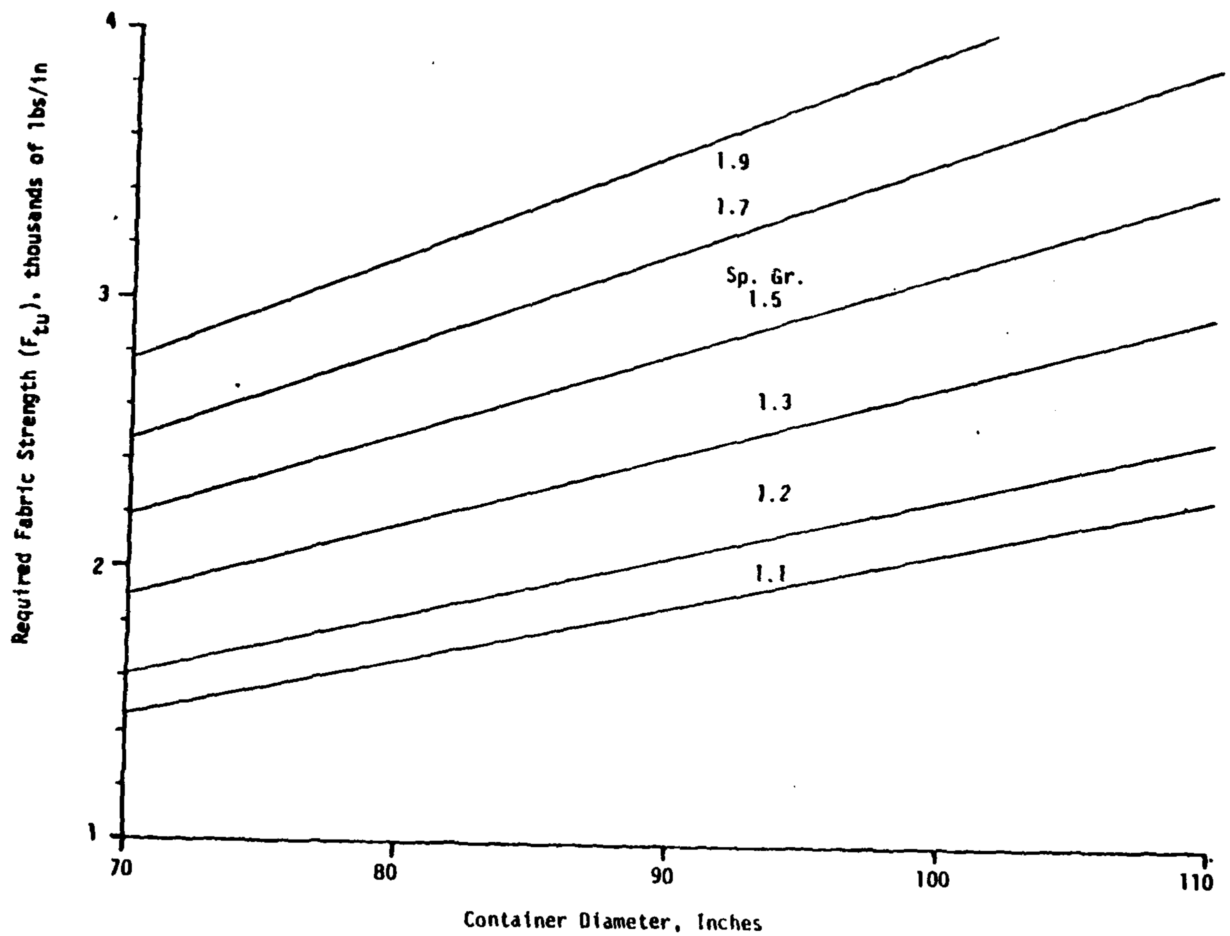
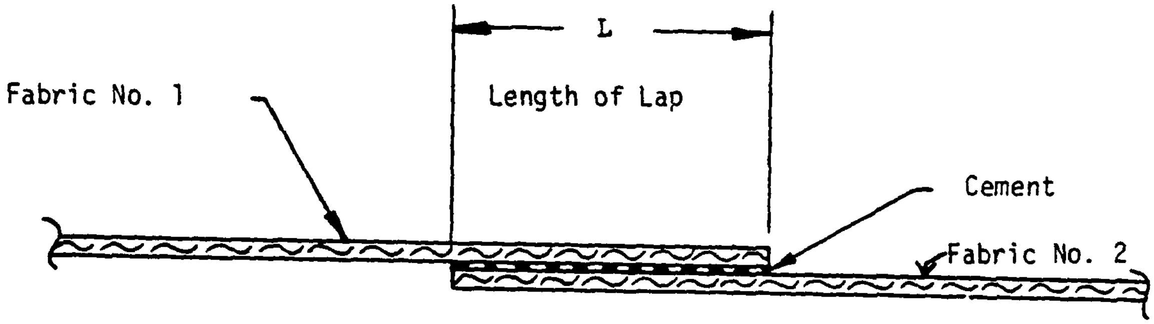


FIGURE 11--REQUIRED ROOM-TEMPERATURE, QUICK-BREAK, FABRIC TENSILE STRENGTH VALUES (F_{tu}) VERSUS CONTAINER DIAMETER FOR WAVES 12 FEET HIGH AND CHEMICALS WITH SP. GR. = 1.1 to 1.9

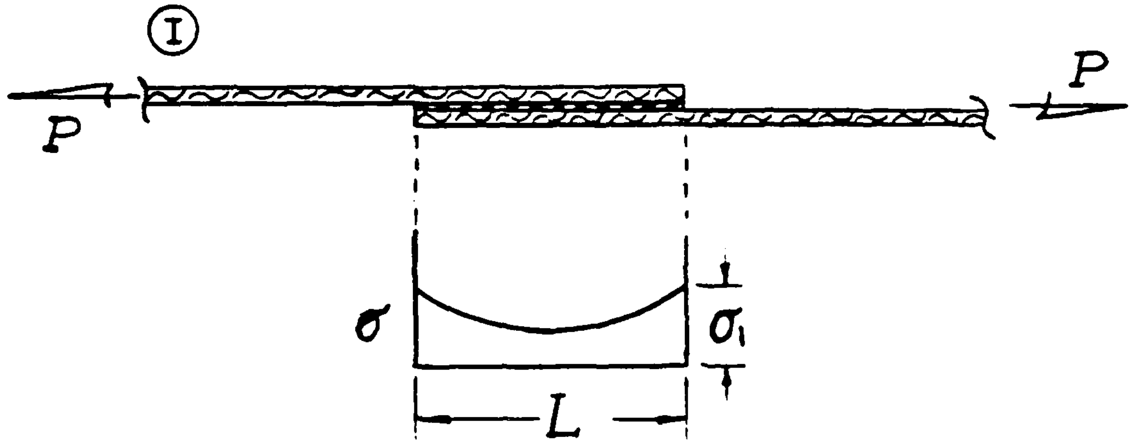
4. Seam Strength State-of-the-Art

The principal design goal for seams is to maximize the performance of a seam for a particular application. A coated fabric is chosen that meets the requirements of the application, and the seams are normally designed to be as strong as the fabric to utilize its strength. With lightweight fabrics, seams are readily attainable that equal the fabric strength. With the use of very high-strength fabrics, a design problem arises; that is, can a seam be built to equal the fabric's load carrying ability?

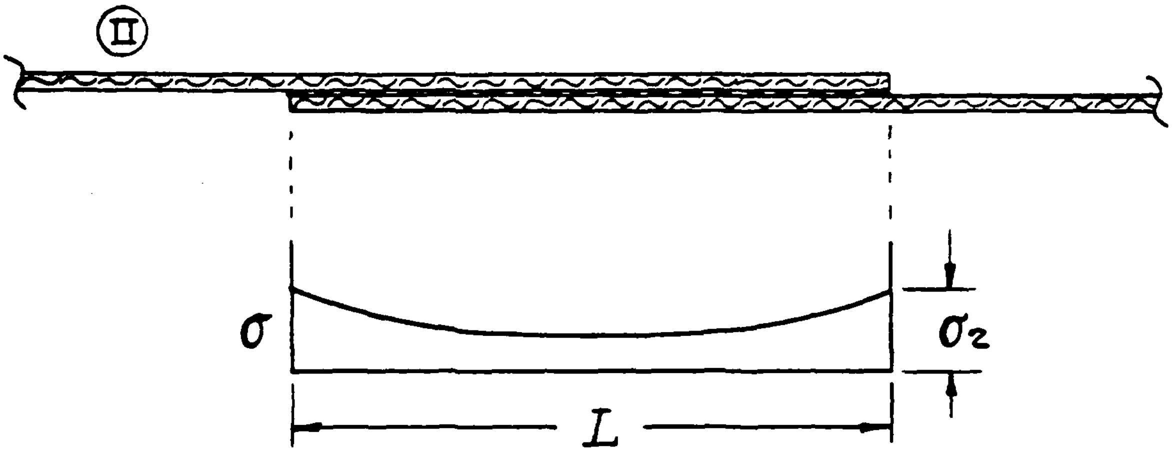
The lap seam illustrated below is the most widely used seam. For most applications it develops sufficient strength and it is easy to build. It is made by lapping the two pieces of fabric, using an adhesive, and vulcanizing the pieces together. The seam transfers the load from one fabric to the other by the shear strength of the elastomer between the fabrics.



The shorter the lap, or the less elastomer in shear, the less the seam strength will be. However, the converse of this is not true. There is a definite length of lap for which the seam will carry the maximum loads. Any lap length beyond this will not add to the load carrying capabilities of the seam. This is because the elastomer tries to take most of the load at the ends of the laps; and consequently, this is where the maximum shear stresses and resultant elongations occur. When the elastomer can no longer take the forces in these regions, the seam will fail. It doesn't matter how far apart the ends of the laps are placed; they still try to carry most of the load. (See the sketch on the next page.)

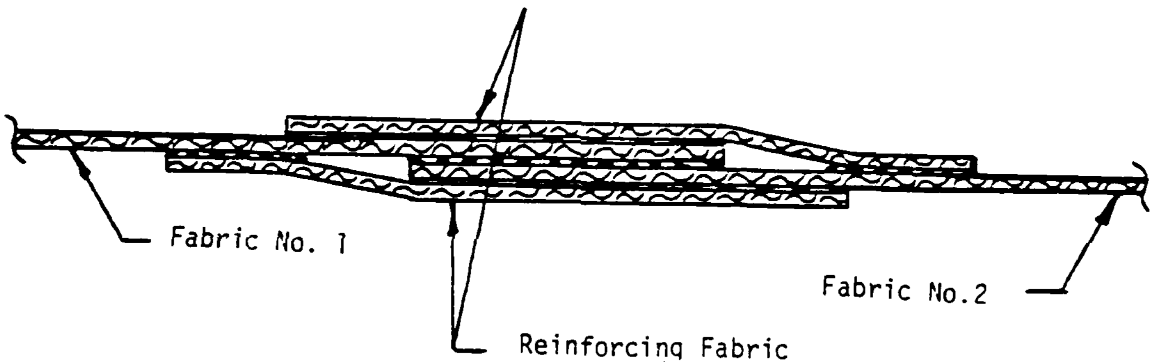


$$\sigma_1 = \sigma_2$$

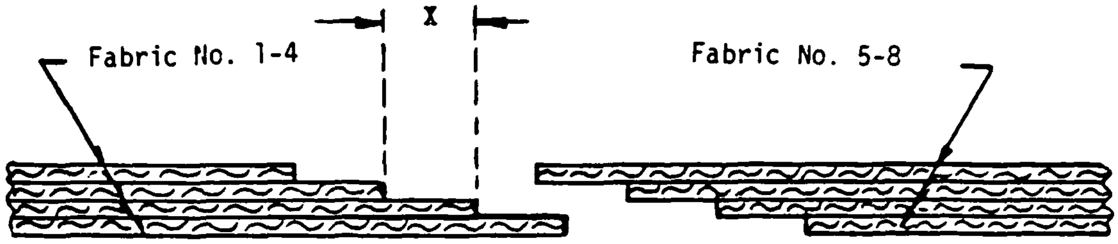


Inherent in the design of a lap seam is the fact that the two fabrics to be seamed are not in the same plane, in the immediate area of the seam. When the lap seam is loaded, a couple is formed causing the seam to rotate about its center. The seam bends until static equilibrium is reached. This bending creates tensile forces in the elastomer tending to peel the seam apart. The tendency to peel is the main cause of present lap seam failure because the ability for lap seams to resist the tensile forces is much less than their ability to resist shear loads.

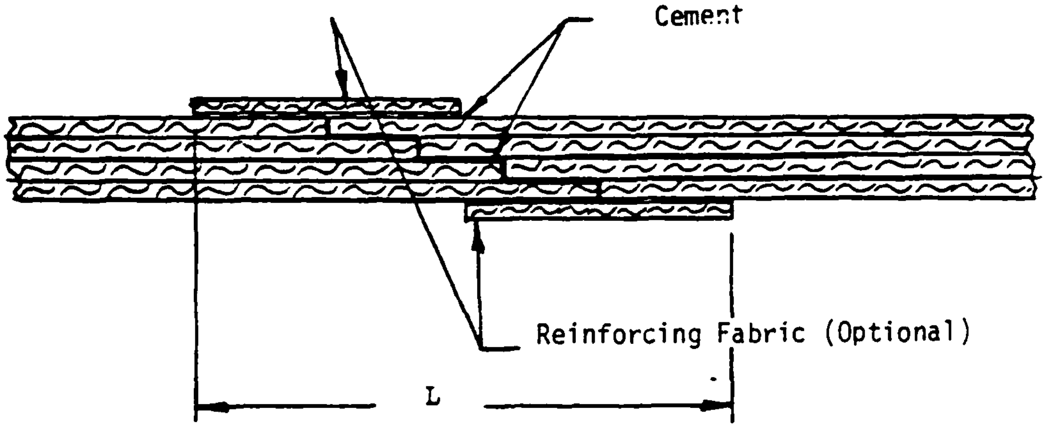
Peeling can be counteracted by adding a reinforcing tape layer over each edge of the lap seam to eliminate the couple. The added layers can also spread the load acting somewhat like a multiple ply lap.



The best seam to use with multiple ply fabric is by stepping off the plies and making a series of lap seams with each ply (see sketch on the next page). Because these seams are stepped off, they are usually wider and more difficult to make than simple lap seams. They can be made very strong, depending on the number of plies and the length of the steps.



X = Length of Step Off



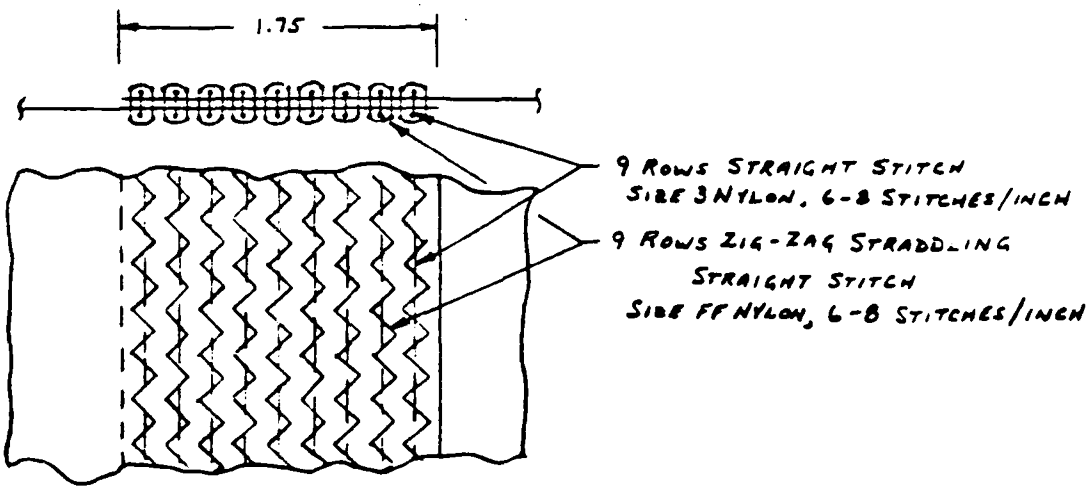
Length of Seam

Rubberized fabric containers are generally constructed by bonding the panels of rubberized fabric together with adhesives. One function of using an adhesive seam, as contrasted to a sewn seam, is to prevent leakage of air or liquid from the container. In addition to providing an air or liquid-tight seam, the adhesive seam can provide structural integrity for the container by transmitting loads between the panels. As the strength of the fabric and severity of the environment are increased, the type of seams used changes from room temperature vulcanized (RTV) to heat vulcanized, to heat vulcanized and sewn.

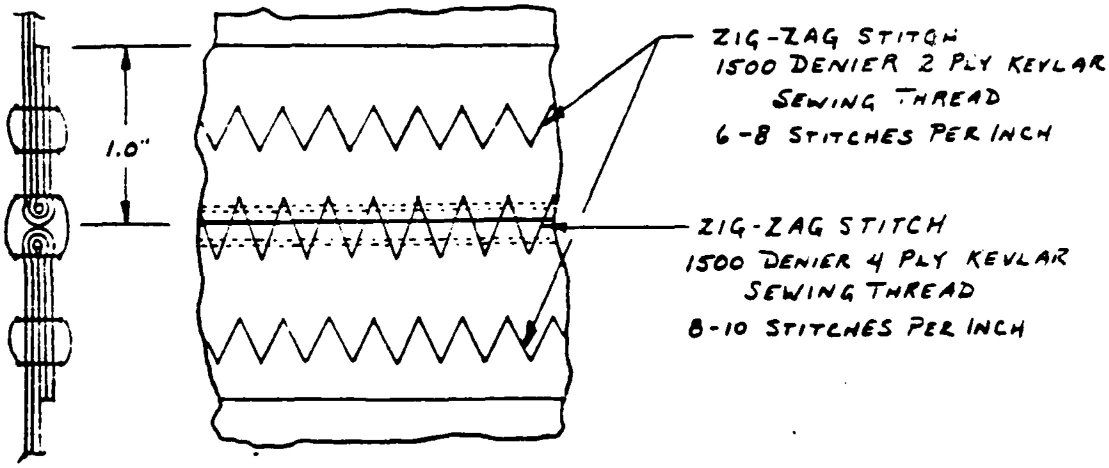
An example of a low fabric strength container with RTV seams would be an inflatable life raft. Typically, life raft fabric has a strength of 200 to 300 lbs/in. The RTV adhesive consists of compounded elastomer dissolved in solvents to which is added a chemical which promotes a certain amount of vulcanization of the elastomer at room temperature. While no hard and fast limit can be placed on the load bearing capabilities of RTV seams, industry experience relegates their use to low loads and environments free of fuels and chemicals which attack or swell the elastomer.

Rubberized fabric containers for fuel with volumes of up to 100,000 gallons are typically made with heat vulcanized seaming. This means that the adhesive joint is cured by the application of heat (240°F to 320°F) and pressure (30 psi to 200 psi). Rubberized fabric fuel containers are typically made from fabrics having quick break strength of 400 to 600 lbs/inch. The seams between fabric panels must develop the strength of the fabric when immersed in fuel. Heat vulcanized seams have this capability. It should be noted that one customer of such tanks, the U. S. Marine Corps, requires that most of the seams on its tanks be vulcanized and sewn. The value of 600 lbs/inch does not represent the ultimate strength obtainable in a heat vulcanized, unsewn seam. However, somewhere between 600 and 1,000 lbs/inch, depending on the fabric construction and the environment, the utility of heat vulcanized, unsewn seams disappears; and sewing is added to make seams sufficiently strong enough to develop the strength of the fabric.

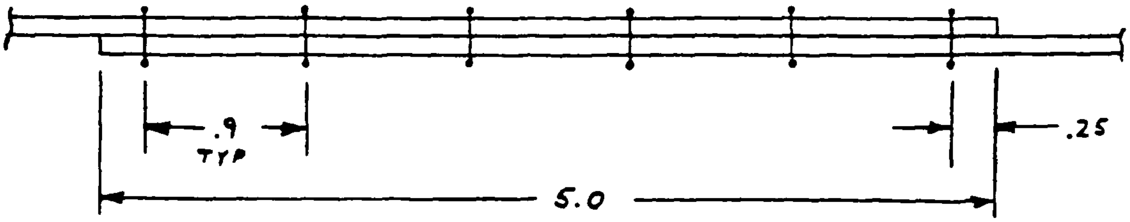
Goodyear Aerospace Corporation has been involved in fabricating inflatables that require high-strength, sewn seams. One of the early programs (1964) was the design and development of the Holloman Sled Decelerator. The decelerator was a Ballute configuration incorporating 1,040 lbs/inch nylon fabric. Through a series of seam development tests, an average seam strength of 928 lbs/inch was attained, which corresponds to a sewn seam efficiency of 89 percent. The seam design for the Holloman decelerator was as shown on the next page.



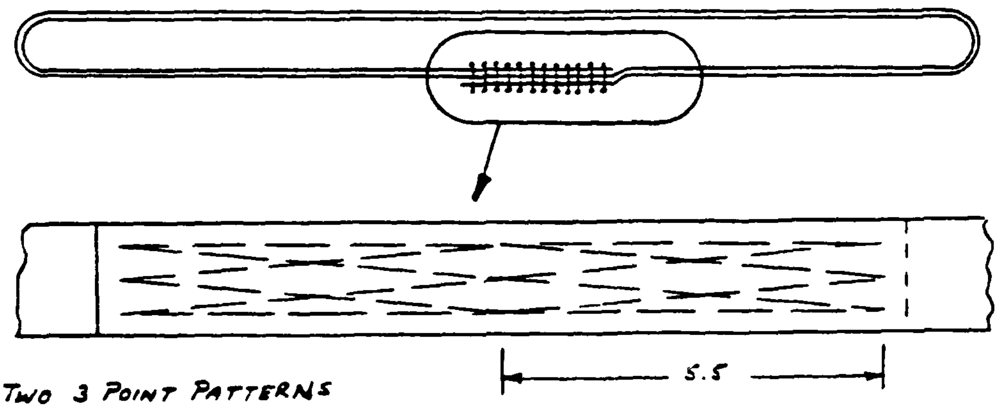
A more recent development of a high-strength sewn seam involved the Early Stabilization System for the B-1 Escape Module. The fabric components of the Early Stabilization System were fabricated from Kevlar cloth having an ultimate strength of 5,300 x 3,200 lbs/inch (Reference 7). An 80 percent efficient seam was developed for this fabric using a somewhat unconventional design. The seam configuration is depicted below:



Under a subcontract to Rohr Industries, Inc., Goodyear Aerospace Corporation conducted a test program to evaluate high-strength materials and seams after exposure to various environments for potential use on a 2,000 ton surface effect ship (Reference 8). Although no attempt was made to optimize the sewn seam, a seam strength of approximately 1,600 lbs/inch was obtained which represented a seam efficiency of about 53 percent. The seam is shown below and as can be seen, it is a very simple seam and can be made stronger with some modifications.

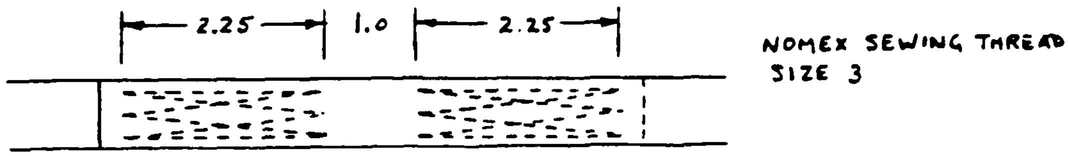


Goodyear Aerospace Corporation has considerable experience in designing seams for webbings and ribbons which can be applied to the hazardous material container. For example, a 15,000 lb. webbing (1 1/8 inches wide) was used on the Viking Decelerator System as a bridle. Each bridle leg consisted of four plies of webbing which was obtained by making a continuous double wrap and incorporating one splice as shown below (Reference 9).



TWO 3 POINT PATTERNS
KEVLAR SEWING THREAD - 1500 DENIER (2 PLY)
4-6 STITCHES PER INCH

The ADDPEP Ballute configuration, designed and built by Goodyear Aerospace Corporation, incorporated Nomex webbing. One of the seam designs developed on ADDPEP (Reference 10) employed a "relief" area as shown below to aid in distributing the load and improving the efficiency. This design resulted in a seam efficiency of 97 percent.



Although high-strength, sewn seams as required for hazardous material containers are within the present state-of-the-art, developmental testing of samples is required to attain the designs for these strengths. The seam strength for a given design will vary with different fabric weaves. The starting point in designing a seam begins with the seam strength required. Then, knowing the sewing thread strength available, the number of rows of sewing and stitches per inch necessary to attain the required strength can be established. Other variables include: type of seams, ie, simple lap versus felled seams, the spacing between rows of sewing and the type of stitch such as straight versus zig-zag stitch. Normally a seam which is theoretically capable of meeting the strength requirement is designed and seam specimens are fabricated and tensile tested. Visual observation of the testing is critical since the way in which the seam fails can indicate what adjustments should be made to improve its efficiency. To obtain the strength required for the hazardous material container, it may be necessary to employ a high-modulus, high-strength thread (such as Kevlar) for the center rows of sewing and a lower-modulus thread (nylon or polyester) for the outer rows of sewing to better distribute the load and improve the seam efficiency. It is certain that the final seam design will be the result of an iterative process of testing sample seams.

5. <u>Construction State-of-the-Art</u>

Structural chemical containers can be fabricated with state-of-the-art techniques using cured fabric, uncured fabric, or filaments wound onto uncured gum.

When woven cured fabric is used, flat panels can be cut and joined to form the final shape. The panels are joined using lap seams sewn together, adding uncured gum to both sides, and curing the gum using heat and pressure. Normally, this can be accomplished using a press with heated plattens or placing the total system in an autoclave (a heated pressure vessel). When uncured woven fabric is used, the panels are lapped and joined by sewing them together, adding uncured gum to both sides, and curing the fabric and the gum in an autoclave. The selection of woven fabric allows the use of flat patterns joined together instead of requiring a male mold of the container (mandrel) for constructing the system. Curing systems made of woven fabric joined together can also be accomplished without the use of a mandrel. A typical approach is to roll the fabric system onto a large drum and cure it in an autoclave.

When uncured cord fabric is used, it is applied one ply at a time at a given angle onto a mandrel. The proper wrap angles are selected to carry the pressure and drag loads. Each ply consists of cords in gum with the cords running in only one direction. The cords are positioned along side each other covering the total mandrel surface. The only seams within a ply are at the laps where individual strips of cord fabric begin and end. The laps can be staggered for efficiency since the widths and the starting point of each cord fabric strip can be adjusted while forming a ply. The next ply of cord fabric is applied over and across the prior ply at the opposite sign wrap angle. With this construction seam lines are eliminated, and the required fabric strengths can be created by choosing the proper cord fabrics. A typical approach for curing the system is to cover its mandrel with a vacuum blanket and use an autoclave.

When filaments are used, they are wound onto uncured gum covering a mandrel. Specific wrap angle and patterns are associated with selected filament-wound shapes. The filaments are essentially continuous and run to fittings incorporated in each end of the container segments. When a cylindrical portion is added to the central portion of a filament-wound shape, additional wraps in the hoop direction are added to carry the greater hoop loads. Seams are eliminated with this construction approach, and the required fabric strengths can be created by selecting the proper filament size, spacing, and number of wraps. A typical approach for curing the system is covering it on its mandrel with a vacuum blanket and using an autoclave.

Liner materials are normally cured fabrics. The construction technique for the liner is to cut flat patterns and join the patterns together using techniques compatible with the materials and the chemicals. Some liner materials can be joined together using cemented lap seams and curing the cemented seams using heat and pressure techniques similar to those used for the structural fabrics. Other liner materials are joined together in lap seams by fusing the coating of the materials together using heat and pressure techniques that require demonstration of the state-of-the-art.

Compatibility of Candidate Materials with the Hazardous Chemicals on the U.S. Coast Guard List

The compatibility of potential fabric materials for containers with the hazardous chemicals listed by the Coast Guard was investigated by reviewing available data. The effects of these chemicals on Goodyear's in-line tank and diaphragm fabrics were organized into a matrix which is shown as Table 2. An N rating is no, a Y rating is yes, a PN rating is a probable no, and a PY rating is a probable yes. The ratings are based not only on the suitability of the coating compound and cloth, but on the coating to cloth adhesive system and the availability of systems for seaming. The fabrics are rated yes or no where Goodyear has specific knowledge and experience with the fabric and chemical. The probable yes and no ratings are based on experience with similar chemicals.

Several of the materials on the Coast Guard list are strong acid oxidizing agents [ie, oleum, nitric acid (conc)]. None of the Goodyear fabrics are suitable for service with chemicals in this class. The fabric coatings having potential for handling these chemicals are fluorocarbons. The most likely fluorocarbon fabric coatings are Viton elastomer and Teflon thermoplastic--both products of E. I. DuPont DeNemours and Company (Inc.). These materials are sold in bulk or in the form of finished coated fabrics.

The information in Table 3 shows the effect of the various chemicals on the Coast Guard list on fluorocarbon coated fabrics produced by the Fabrics and Finishes Department of DuPont as reported by DuPont. The Viton coated fabrics are used primarily in applications where load bearing seams are avoided, so there is little background to evaluate their suitability for large flexible containers. There is enough background on these fabrics to consider them for use as liners for flexible containers constructed from other fabrics which are known to be suitable from the structural standpoint. Viton coated fabrics are available from DuPont where the cloth is Teflon or glass. The Teflon is very low in strength and the glass is subject to mechanical damage by folding and flexing during packaging. Viton fabric with these two cloths are judged to be suitable candidates for liners only on the basis of the cloth characteristics, regardless of seaming considerations.

TABLE 2--GOODYEAR-PRODUCED TANK, SEAL AND DIAPHRAGM FABRICS INVESTIGATED

Elastomer Coating	Nitrile (Medium)	Nitrile (High)	Urethane	SBR	Butyl	Chloroprene	EPDM	Natural
Cloth	Nylon	Nylon	Nylon	Nylon	Polyester	Nylon	Nylon	Polypropylene
Goodyear Code	H370	H402	TV600	G309	B601	A378	B301	D901
U.S. CG Haz. Chemical				Rating				
Acetic Acid	N	N	N	N	PY_2	N	N	N
Acetic Anhydride	N	N	N	N	Y_3	N	N	N
Acetone	N	N	N	N	Y	N	Y_3	N
Acrylonitrile	N_3	PN_3	PN_3	N_3	N_3	PN_5	N_3	N_3
Ammonia (28% aq)	N_3	PN_3	N	PN_3	N	PY_3	Y_3	N_3
Benzene	N	PY	Y	N	N	N	N	N
Caustic Soda (Solution)	Y	Y	N	N	N	N	Y	Y_3
Copper Fluoroborate	Y	Y	Y	Y	Y	Y	Y	Y
Copper Naphthenate	Y	Y	Y	N	N	PY	N	N
Cresols	N	PY_3	N	N	N	N	N	N
Cyclohexane	Y	Y	Y	N	N	N	N	N
Ethyl Acetate	N	PN	N	N	Y	N	PY_3	PN
Ethyl Acrylate	N	PN	PY	PN	PY_3	N	PY_3	PN
Ethyl Alcohol	Y	Y	Y	Y	Y	Y	Y	Y
Ethylene Dichloride	N	PY	N	N	PY_3	N	PY_3	N
Hexane	Y	Y	Y	N	N	Y	N	N
Hydrochloric Acid	N	N	N	N	Y_4	N	N	N
Isopropyl Alcohol	Y	Y	Y	Y	Y	Y	Y	Y
Methyl Acrylate	PN	PN	PY	PN	Y_3	PN	Y_3	PN
Methyl Alcohol	Y	Y	N	N	Y	Y	Y	Y
Methyl Ethyl Ketone	N	N	N	N	Y_3	N	Y_3	N
Nitric Acid (Conc.)	N	N	N	N_3	PN	N	N	N
Oleum	N	N	N	N	N	N	N	N
Phenol	N_3	N_3	N_3	N_3	PY_6	N_3	PY_6	PN
Phosphoric Acid	N	N	N	N	Y	N	N	N
Styrene	N_3	PN_3	PN_3	N_3	N_3	N_3	PN_3	N_3
Sulfuric Acid (Dilute)	N	N	N	N	Y	N	N	N
Toluene	N	Y	Y	N	N	N	N	N
Turpentine	Y	Y	Y	N	N	N	N	N
Vinyl Acetate	N	Y	PN	N_3	Y_3	PN	PN	N
Xylene	N	Y	Y	N	N	N	N	N
Xylenol	N_7	N_7	N_7	N_7	PY_7	N_7	N_7	N_7
Hydrocarbon Fuels	Y	Y	Y	N	N	N	N	N
Fresh & Sea Water	Y	Y	Y	Y	Y	Y	Y	Y

Table 2 (con't)

NOTES: Ratings with no subscript refer to note 1 and ratings with subscript numbers refer to the corresponding notes 2 through 8.

1. Ratings are based on Goodyear information and assume sewn & vulcanized seams with 200 hr exposure.

2. Data shows fabric satisfactory for 75% acetic acid, no data for glacial acetic acid.

3. This rating is based on information in trade literature, rather than on Goodyear test results.

4. Trade literature indicates this construction satisfactory for all concentrations. Goodyear data shows fabric to be satisfactory for 38% hydrochloric acid, no Goodyear data for higher strength acid.

5. Some trade literature indicates neoprene nylon fabric may be serviceable in acrylonitrile.

6. Trade literature is contradictory on phenol, some sources claiming butyl and EPDM to be satisfactory. No information on the effect on the base cloths is available.

7. Information on Xylenol's effect on coated fabrics and elastomers is nonexistent. On the basis of chemical similarity, it is believed that it would behave like phenol.

8. Goodyear rates its high acrylonitrile content nitrile rubber coated fabric H402 suitable for use in xylene and toluene. It would be satisfactory for benzene under the conditions on note 1. Most trade literature on nitrile rubber is based on medium acrylonitrile rubber which is not suitable for 100% aromatic service.

TABLE 3--DuPONT-PRODUCED FLUOROCARBON COATED DIAPHRAGM FABRICS INVESTIGATED

Coating	Viton	Viton	Viton	Teflon	Teflon-Viton
Cloth	Teflon	Dacron	Glass	Glass	Nomex
DuPont Code	VT-0007	VD-0008	VG-0001	TG-4140	VX-9301
U.S. Coast Guard Haz. Chemical	Rating				
Acetic Acid	N	N	N	Y_4	Y
Acetic Anhydride	N	N	N	Y	Y
Acetone	N	N	N	Y	Y
Acrylonitrile	N_2	N_2	N_2	Y_2	Y_2
Ammonia (28% aq)	Y	Y	Y	Y_2	Y_2
Benzene	Y	Y	Y	Y_2	Y_2
Caustic Soda (Solution)	N	N	N	Y_4	Y
Copper Fluoroborate	Y	Y	Y	Y	Y
Copper Napatrenate	Y	Y	Y	Y	Y
Cresols	PY	PY	PY	Y_2	Y_2
Cyclohexane	Y	Y	Y	Y	Y
Ethyl Acetate	N	N	N	Y	Y
Ethyl Acrylate	N_2	N_2	N_2	Y_2	Y_2
Ethyl Alcohol	Y	Y	Y	Y	Y
Ethylene Dichloride	Y	Y	Y	Y_2	Y_2
Hexane	Y	Y	Y	Y	Y
Hydrochloric Acid	Y	Y	Y_4	Y_4	Y
Isopropyl Alcohol	Y	Y	Y	Y	Y
Methyl Acrylate	N_2	N_2	N_2	Y_2	Y_2
Methyl Alcohol	Y	Y	Y	Y	Y
Methyl Ethyl Ketone	N	N	N	Y	Y
Nitric Acid (Conc)	Y	Y	Y_4	Y_4	Y
Oleum	Y	Y	Y_4	Y_4	Y
Phenol	Y	Y	Y	Y	Y
Phosphoric Acid	Y	Y	Y_4	Y_4	Y
Styrene	Y	Y	Y	Y_2	Y_2
Sulfuric Acid (Dilute)	Y	Y	Y	Y	Y
Toluene	Y	Y	Y	Y_2	Y_2
Turpentine	Y	Y	Y	Y_2	Y_2
Vinyl Acetate	N_2	N_2	N_2	Y_2	Y_2
Xylene	Y	Y	Y	Y	Y
Xylenol	Y_3	Y_3	Y_3	Y_3	Y_3
Hydrocarbon Fuels	Y	Y	Y	Y	Y
Fresh & Sea Water	Y	Y	Y	Y	Y

Table 3 (con't)

NOTES: Ratings with no subscripts refer to note 1 and ratings with subscript numbers refer to the corresponding notes 2 through 4.

1. Ratings are based on DuPont information and are for suitability of coated fabric itself. No seam data are available.

2. This rating is based on information in trade literature other than that published by DuPont.

3. Information on xylenol's effect on coated fabrics and elastomers is nonexistent. On the basis of chemical similarity, it is believed that it would behave like phenol.

4. Glass fabric will lose strength after exposure to strong acids and bases. The magnitude of the loss in 200 hrs. when protected by a fluorocarbon coating is unknown.

The Teflon-glass coated fabrics produced by DuPont under the trade name Armalon are used primarily as release sheets where high temperatures are involved or where sticky products are handled. The materials can be seamed by heating to 700°F. There is no background on the use of these fabrics as containers for liquid chemicals (ie, will the seam leak). On a theoretical basis they would be candidates to investigate as liners used with tanks constructed of other materials.

One DuPont fabric listed is a combination of Teflon, Viton, and Nomex. This material is probably not useful as a primary tank fabric due to its weight.

The information in Table 2 for Goodyear produced tank, seal, and diaphragm fabrics was reviewed to arrive at a recommendation of fabrics for transporting the greatest number of chemicals in the fewest containers. The results of this review are given in Table 4. The totals indicate that four to 14 chemicals can be carried by a container made of one of the Goodyear fabrics. When the Y + PY ratings are considered, the number of chemicals a single container can carry is from four to a probable 17.

The number of chemicals that can be carried using separate containers, each made from one of the eight different Goodyear fabrics, was then determined. The results are presented in the right hand columns based on Y and Y + PY ratings, respectively. The results indicate that the maximum number of chemicals that can be carried using eight different containers is 24 chemicals considering only Y ratings and 30 chemicals considering Y + PY ratings.

The number of chemicals that can be carried using only two containers, each made of a different Goodyear fabric, was then determined. The best selection is to use one container made of nitrile rubber (high acrylonitrile content) nylon cloth fabric, and one container made of butyl rubber polyester cloth fabric. By choosing the proper container, 22 of the chemicals can be contained using Goodyear fabrics with Y ratings or 29 chemicals can probably be contained using Goodyear fabrics with Y and PY ratings. The chemicals not accommodated include: nitric acid (conc.), oleum, styrene, acrylonitrile, and ammonia (28% aq.). The first four of these five chemicals cannot be accommodated by any of the fabrics listed in Table 4.

TABLE 4--SELECTION OF GOODYEAR-PRODUCED TANK, SEAL AND DIAPHRAGM FABRICS

Elastomer Coating	Nitrile (Medium)	Nitrile (High)	Urethane	SBR	Butyl	Chloroprene	EPDM	Natural	Materials with Y Ratings No.	Materials with Y + PY Ratings No.
Cloth	Nylon	Nylon	Nylon	Nylon	Polyester	Nylon	Nylon	Polypropylene		
Goodyear Code	H370	H402	TV600	G309	B601	A378	B301	D901		
U.S. CG Haz. Chemical	Rating									
Acetic Acid	N	N	N	N	PY_2	N	N	N	0	1
Acetic Anhydride	N	N	N	N	Y_3	N	N	N	1	1
Acetone	N	N	N	N	Y	N	Y_3	N	2	2
Acrylonitrile	N_3	PN_3	PN_3	N_3	N_3	PN_5	N_3	N_3	0	0
Ammonia (28% aq)	N_3	PN_3	N	PN_3	N	PY_3	Y_3	N_3	1	2
Benzene	N	PY	Y	N	N	N	N	N	1	2
Caustic Soda (Solution)	Y	Y	N	N	N	N	Y	Y_3	4	4
Copper Fluoroborate	Y	Y	Y	Y	Y	Y	Y	Y	8	8
Copper Naphthenate	Y	Y	Y	N	N	PY	N	N	3	3
Cresols	N	PY_3	N	N	N	N	N	N	0	1
Cyclohexane	Y	Y	Y	N	N	N	N	N	3	3
Ethyl Acetate	N	PN	N	N	Y	N	PY_3	PN	1	2
Ethyl Acrylate	N	PN	PY	PN	PY_3	N	PY_3	PN	0	3
Ethyl Alcohol	Y	Y	Y	Y	Y	Y	Y	Y	8	8
Ethylene Dichloride	N	PY	N	N	PY_3	N	PY_3	N	0	3
Hexane	Y	Y	Y	N	N	Y	N	N	4	4
Hydrochloric Acid	N	N	N	N	Y_4	N	N	N	1	1
Isopropyl Alcohol	Y	Y	Y	Y	Y	Y	Y	Y	8	8
Methyl Acrylate	PN	PN	PY	PN	Y_3	PN	Y_3	PN	2	3
Methyl Alcohol	Y	Y	N	N	Y	Y	Y	Y	6	6
Methyl Ethyl Ketone	N	N	N	N	Y_3	N	Y_3	N	2	2
Nitric Acid (Conc.)	N	N	N	N_3	PN	N	N	N	0	0
Oleum	N	N	N	N	N	N	N	N	0	0
Phenol	N_3	N_3	N_3	N_3	PY_6	N_3	PY_6	PN	0	2
Phosphoric Acid	N	N	N	N	Y	N	N	N	1	1
Styrene	N_3	PN_3	PN_3	N_3	N_3	N_3	PN_3	N_3	0	0
Sulfuric Acid (Dilute)	N	N	N	N	Y	N	N	N	1	1
Toluene	N	Y	Y	N	N	N	N	N	2	2
Turpentine	Y	Y	Y	N	N	N	N	N	3	3
Vinyl Acetate	N	Y	PN	N_3	Y_3	PN	PN	N	2	2
Xylene	N	Y	Y	N	N	N	N	N	2	2
Xylenol	N_7	N_7	N_7	N_7	PY_7	N_7	N_7	N_7	0	1
Hydrocarbon Fuels	Y	Y	Y	N	N	N	N	N	3	3
Fresh & Sea Water	Y	Y	Y	Y	Y	Y	Y	Y	8	8
Chem. with Y ratings	11	14	12	4	13	4	8	6	No. of Chem. all Matl. Ys: 24	No. of Chem. all Matl. Y+PY: 30
Chem. with (Y+PY) ratings	11	17	14	4	17	6	12	6		

The latter chemical, ammonia (28% aq.) requires a third container made from EPDM nylon cloth fabric. Since this is the only chemical which cannot be carried by using the other two containers, further compatibility testing should be done between this chemical and the fabrics of the other two containers. Nitrile rubber is rated from unsatisfactory to fair with ammonium hydroxide in most trade literature. However, limited hard data exists as to its effect on the high acryonitrile nitrile rubbers which may have satisfactory resistance. Ammonia (28% aq.) can be handled by butyl rubber, but there is a reluctance to recommend a butyl-polyester tank due to the loss in tensile strength of polyester cloth when immersed in alkaline solutions. However, ammonia (28% aq.) is not as strongly alkaline as a material, such as sodium hydroxide is and on which there are more data. Further considering the use of a Teflon liner, a limited exposure period, and the fact that aqueous ammonia will evaporate may make feasible the use of a butyl polyester tank with a Teflon liner for ammonia (28% aq.).

Considering the first three fabrics listed in Table 5 in the same manner results in Y ratings for 23 chemicals and Y + PY ratings for 24 chemicals using one container made from any one of the first three fabrics. Having containers made from each of the fabrics doesn't increase the number of chemicals that can be carried because all three fabrics have no (N) ratings for the same chemicals.

The ratings for the last two fabrics indicate they can contain all 34 chemicals. However, seaming techniques for containing liquid chemicals using these fabrics in a flexible container may require development.

Combinations of two different materials to make single containers were then considered; ie, a tank structure of one material and a liner of another material. One combination will be a butyl polyester fabric from Table 4 for the container's structure with a Viton Teflon cloth fabric from Table 5 for the liner. If the Viton Teflon cloth fabric liner is removable or considered expendable with some chemicals, then this combination has Y ratings for 29 chemicals and Y + PY ratings for 32 chemicals. Other combinations using only the first three fabrics of Table 5, and any of the fabrics from Table 4 result in a fewer number of chemicals that can be carried by a single container. The Viton-coated liner will be damaged by some of the materials that the butyl polyester cloth fabric can contain by itself. The chemicals that will damage the Viton-coated liner but not the butyl

TABLE 5--SELECTION OF DUPONT-PRODUCED FLUOROCARBON COATED DIAPHRAGM FABRICS

Coating	Viton	Viton	Viton	Teflon	Teflon	Materials with Y Ratings	Materials with Y+PY Ratings
Cloth	Teflon	Dacron	Glass	Glass	Nomex		
DuPont Code	VT-0007	VD-0008	VG-0001	TG-4140	VX-9301	No.	No.
U.S. Coast Guard Hazardous Chemical	Rating						
Acetic Acid	N	N	N	Y_4	Y	2	2
Acetic Anhydride	N	N	N	Y	Y	2	2
Acetone	N	N	N	Y	Y	2	2
Acrylonitrile	N_2	N_2	N_2	Y_2	Y_2	2	2
Ammonia (28% aq)	Y	Y	Y	Y_2	Y_2	5	5
Benzene	Y	Y	Y	Y_2	Y_2	5	5
Caustic Soda (Solution)	N	N	N	Y_4	Y	2	2
Copper Fluoroborate	Y	Y	Y	Y	Y	5	5
Copper Napatrenate	Y	Y	Y	Y	Y	5	5
Cresols	PY	PY	PY	Y_2	Y_2	2	5
Cyclohexane	Y	Y	Y	Y	Y	5	5
Ethyl Acetate	N	N	N	Y	Y	2	2
Ethyl Acrylate	N_2	N_2	N_2	Y_2	Y_2	2	2
Ethyl Alcohol	Y	Y	Y	Y	Y	5	5
Ethylene Dichloride	Y	Y	Y	Y_2	Y_2	5	5
Hexane	Y	Y	Y	Y	Y	5	5
Hydrochloric Acid	Y	Y	Y_4	Y_4	Y	5	5
Isopropyl Alcohol	Y	Y	Y	Y	Y	5	5
Methyl Acrylate	N_2	N_2	N_2	Y_2	Y_2	2	2
Methyl Alcohol	Y	Y	Y	Y	Y	5	5
Methyl Ethyl Ketone	N	N	N	Y	Y	2	2
Nitric Acid (Conc)	Y	Y	Y_4	Y_4	Y	5	5
Oleum	Y	Y	Y_4	Y_4	Y	5	5
Phenol	Y	Y	Y	Y	Y	5	5
Phosphoric Acid	Y	Y	Y_4	Y_4	Y	5	5
Styrene	Y	Y	Y	Y_2	Y_2	5	5
Sulfuric Acid (Dilute)	Y	Y	Y	Y	Y	5	5
Toluene	Y	Y	Y	Y_2	Y_2	5	5
Turpentine	Y	Y	Y	Y_2	Y_2	5	5
Vinyl Acetate	N_2	N_2	N_2	Y_2	Y_2	2	2
Xylene	Y	Y	Y	Y	Y	5	5
Xylenol	Y_3	Y_3	Y_3	Y_3	Y_3	5	5
Hydrocarbon Fuels	Y	Y	Y	Y	Y	5	5
Fresh & Sea Water	Y	Y	Y	Y	Y	5	5
Chem. with Y Ratings	23	23	23	34	34	No. of Chem. All Matls. Y	No. of Chem. All Matls. Y+PY
Chem. with (Y + PY) Ratings	24	24	24	34	34	34	34

include: acetic acid, acetic anhydride, acetone, methyl ethyl ketone, and vinyl acetate. Thus, the liner will have to be removed, or it will have to be considered expendable. The cost of a Viton coated liner may rule out the latter approach.

When the last two fabrics of Table 5 are considered for use as a liner, then the container made from the butyl polyester fabric listed in Table 4 can be upgraded to carry strong acids. The butyl polyester fabric itself cannot withstand continuous immersion in nitric acid (conc.) and oleum, which are both acid oxidizing agents. The use of a Teflon fabric liner can reduce to an acceptable amount the exposure of the butyl polyester cloth fabric container to these acids. Exposure is considered to be associated with spills during filling or discharge and minor pinholes in the liner. It will not be necessary to remove the Teflon fabric liner because it is resistant to all chemicals.

A candidate combination is a Teflon cloth fabric liner within a butyl polyester cloth fabric container. It is not known how suitable a Teflon glass cloth fabric will be for styrene and acrylonitrile; however, it is probably as good as any other combination.

Teflon resists all the chemicals on the Coast Guard list, but the butyl polyester tank with the Teflon glass lining can be used only for chemicals for which the butyl polyester structural envelope has a considerable degree of resistance. The assumption is that exterior spills or minor seepage through the inner Teflon liner might cause some of the chemical to contact the butyl polyester tank.

From this chemical compatibility analysis, the candidate container materials for individual containers are presented in Table 6.

TABLE 6--NUMBER OF CHEMICALS PROBABLY CARRIED
BY INDIVIDUAL CONTAINERS AND COMBINATIONS OF CONTAINERS

Container Materials	Probable No. of Chemicals Carried by Individual Container & by Combination of Containers		
a. Nitrile (H)--Nylon	17	(a + b)	
b. Butyl--Polyester	17	29	(a + b + c)
c. EPDM--Nylon	12		30
Container and Liner Materials	**By Combination of Containers**		
d. Nitrile (H)--Nylon	(d + e)	34	
e. Butyl-Polyester with Teflon-Glass Cloth Liner			

Note: All chemicals probably can be carried when 1) a Nitrile Rubber (H) nylon cloth fabric container is used for the aliphatic and aromatic hydrocarbons and for the caustic (sodium hydroxide); and 2) a butyl polyester cloth fabric container is upgraded by a Teflon-glass cloth fabric liner and is used for ketones and acids. If the state-of-the-art is not sufficiently developed for fabricating a Teflon-glass cloth fabric liner, then Viton Teflon cloth fabric can be considered as the backup material for a liner.

The recommendations of having two containers, one constructed from nitrile rubber (high acrylonitrile content) with nylon cloth and one constructed from butyl rubber with polyester cloth and a flourocarbon fabric liner is based on state-of-the-art knowledge of currently produced coated fabrics and containers. It must be recognized that many of the chemicals on the list have never been transferred and stored in rubberized fabric containers, and that a test program must be run to verify the suitability of the recommended containers for these chemicals.

C. Feasibility of Developing a Container to 3.1 Requirements

1. Investigation of Three Design Approaches for Candidate Design Concepts

The characteristics of containers that generally meet the technical requirements were further investigated to better define candidate design concepts relative to both the technical and the operational requirements.

TABLE 7--LIST OF 3.1 TECHNICAL AND OPERATIONAL REQUIREMENTS

The following list of requirements applies in defining and determining the feasibility of various container concepts. The container shall:

1. Have a capacity of at least 25,000 gallons for liquid chemicals weighing 1.9 times the weight of water.
2. Be towable fully loaded in seas with significant wave heights of 5.0 feet at speeds relative to the water of 10 knots.
3. Survive, in any load condition, in seas with significant wave heights of 12 feet (no towing conditions).
4. Have a packaged weight less than 15,000 pounds.
5. Be packageable in a space of less than 1,250 cubic feet, nominally 8 feet by 6 feet by 26 feet.
6. Be deployable from a ship with less than 1,000-pound lifting capability.
7. Be ready to receive chemicals in less than four hours after arrival at site.
8. Be usable in water temperatures between -2°C and 30°C and in air temperatures between -10°C and 38°C.
9. Float when initially deployed and prior to loading of chemicals.
10. Have a draft of less than 10 feet in the fully loaded condition.

Variables affecting the operational factors, weights, number of chemicals carried, technical risks, and cost were included in the investigation of the design concepts. The variables chosen for investigating each of the three different design approaches during Task 1 efforts included:

Approach 1

1. Single fill/discharge point for the chemicals and single or twin fill points for each separate buoyancy cylinder.

2. One, two, three, or four compartments for containing the chemicals.

3. Separate volumes for buoyancy--one cylinder or twin cylinders.

4. Two types of fabric for the structure.

5. Several possible fabrication techniques for constructing and curing the fabric structure.

6. Two types of material for making a liner.

7. Possible fabrication techniques for constructing a liner.

8. Possible locations of foam pads or strips for initial flotation and attitude control.

9. Possible choices and locations of hoses, supporting hardware, towing point, and stabilizing fence.

Approach 2

1. Single fill/discharge point for the chemicals to the multiple container compartments, single or multiple fill/discharge points for the volumes of air for buoyancy.

2. Multiple compartments for carrying the chemicals.

3. Integral chemical and buoyancy chambers.

4. Two types of fabric for the structure and consideration of hard structure for the bulkheads between compartments.

5. Several possible fabrication techniques for constructing and curing the individual container compartments.

6. Two types of materials for making a liner.

7. Possible fabrication techniques for constructing a liner.

8. Possible locations of foam pads and devices for initial flotation and attitude control for filling/discharging chemicals.

9. Possible choices and locations of hoses, compartment connections, supporting hardware, towing point, and stabilizing fence.

Approach 3

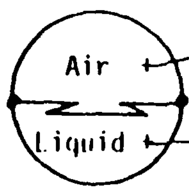
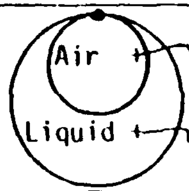
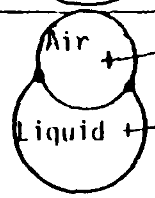
1. Multiple fill/discharge points and single fill/discharge points can be provided for the chemicals to the multiple container segments--multiple fill/discharge points for the volumes of air for buoyancy.
2. Multiple segments for carrying the chemicals.
3. Integral chemical and buoyancy segments.
4. Two types of fabric for the structure and a central cable for transmitting towing loads.
5. Several possible fabrication techniques for constructing and curing the container segments.
6. Two types of materials for making a liner.
7. Possible fabrication techniques for constructing a liner.
8. Possible locations of foam pads and devices for initial flotation and attitude control for filling/discharging chemicals.
9. Possible choices and locations of hoses, segment connections, supporting hardware, towing point, and stabilizing fence.

Initially, several internal membrane locations were investigated for integral air chambers for all approaches. The internal membrane locations and related factors are presented in Table 8.

In the first concept the membrane divider has sufficient fullness so it is always in contact with the liquid. Under this condition the operating pressure of the air is transferred directly to the liquid, and the liquid pressure is always equal or greater than the air pressure. Thus, if the container pitches, the liquid will flow toward the low point resulting in increasing liquid pressure; and the liquid will displace the membrane toward the air at the lesser pressures allowing more liquid to flow. Thus, the membrane serves no purpose in controlling the flow of liquid toward one end during pitching of the container.

The second concept has a structural membrane forming a complete air cylinder within the container to limit the flow of the chemicals during pitching of the container in waves. To retain its shape when the container is pitching requires the air pressure in the flotation cylinder to be greater than the maximum pressure of chemicals. Thus, the operating air pressure is large. One major disadvantage

TABLE 8--INTERNAL MEMBRANE CONCEPTS INVESTIGATED

Concept	Pressures	Membrane Location	Membrane Length	Structural Load f(PR) Membrane	Structural Load f(PR) Container	Constrains Liquid in Pitch	Membrane Continuously Exposed to Chem.
1. 	P_o $P_o + \rho h_T$	Attached Midpoints on Sides	$\approx .5\pi D_c$	Min.	$f(P_o + \rho h_t)$ $f(D_c/2)$	No	Yes
2. 	$P_o > \rho h_t$ $< P_o$	Attached at top	$.707\pi D_c$	$f(P_o)$ $f\left(\frac{.707D_c}{2}\right)$	$f(\approx P_o)$ $f(D_c/2)$ $f(\approx 2P_o)$ if over filled	Yes < Capacity No > Capacity	Yes
3. 	$P_o > \rho h_t$ $< P_o$	Attached Above Midpoint on both sides	$< .5\pi D_c$	$f(.P_o)$ $f\left(\frac{.707D_c}{2}\right)$	$f(\approx P_o)$ $f(D_c/2)$ $f(\approx 2P_o)$ if over filled	Yes < Capacity No > Capacity	Yes

of this concept is associated with any inadvertent over filling of the container with chemical. Under this condition all of the membrane will rest against the liquid, and the large operating air pressure will be added to the liquid pressure; thus the liquid pressure against the container under wave actions will be approximately twice the design pressure.

The third concept uses a structural membrane and the top portion of the container to form an air cylinder with somewhat of a circular cross section. The operating air pressure required is the same as that for Concept 2 for the cylinder to retain its shape and limit the flow of chemicals during pitching of the container in waves. The same problem arises as for Concept 2 when the container is slightly over filled with chemicals.

In all three of the above integral membrane buoyancy cylinder concepts, the following apply:

a) The fabrics of the cylinder must be compatible with direct exposure to the chemicals.

b) The fabrics of the cylinder and container must withstand chafing during wave actions.

c) The cylinders must be inflated to operating pressure prior to filling with chemicals.

d) A means must be provided to prevent over filling, or the design strength of the container fabric must be doubled.

e) Fabrics of greater strength are required with these larger containers than for smaller containers with exterior buoyancy.

f) More fabric material is required for these larger containers than for smaller containers with exterior buoyancy.

A variation to Concept 3 to obtain exterior buoyancy is to consider the membrane to be the upper instead of the lower surface of the air cylinder. With this variation, the membrane material is not in continuous contact with the chemicals and less coating is required. However, the pressure in the air cylinder can still be transferred to the chemical and to the container if the container is over filled with liquids.

Based on the limited benefit of using less material for the membrane in Concept 3 than for an external cylinder and the many disadvantages of its integral and coupled buoyancy chamber, it was decided to use external and decoupled buoyancy chambers for investigating container concepts using design Approach 1. The use of bulkheads or segments in containers was investigated for concepts following design Approaches 2 and 3.

2. Investigation of Approach 1

a. General

This approach in its simplest form has single fill/discharge locations for the chemicals and for air buoyancy cylinders. Providing single fill locations is considered desirable to minimize the exposure of personnel to any of the hazardous chemicals.

The results from investigating the use of a separate single flotation cylinder for a container with a capacity of 25,000 gallons indicated that it will exceed the draft limit of 10 feet when fully loaded with the heaviest chemical, Figure 12. The draft limit can be met by using separate twin air cylinders, Figure 13. A greater number of air cylinders can reduce the draft further; however, total buoyancy cylinder weight increases with increases in the number of cylinders because the fabric area increases for a given volume of air. Therefore, container design concepts with twin cylinders were investigated in more detail.

b. Typical Design Concept

A typical design concept using Approach 1 was generated to better define the characteristics of the container. The nose, center, and tail portions of the container are illustrated in Figure 14. The locations of the attachments between the buoyancy cylinders and the container and some details are presented in Figures 15 and 16. Some details of the nose section are presented in Figure 17. The nose section contains the fill/drain valve and is neutrally buoyant. An internal ring in the nose carries the container load that ends in a hoop bead in the container fabric, Figure 17. A segmented clamp ring is located over the bead to retain its position on the ring during packing and handling. A removable liquid tight bulkhead is provided for access to the inside of the container for refurbishment.

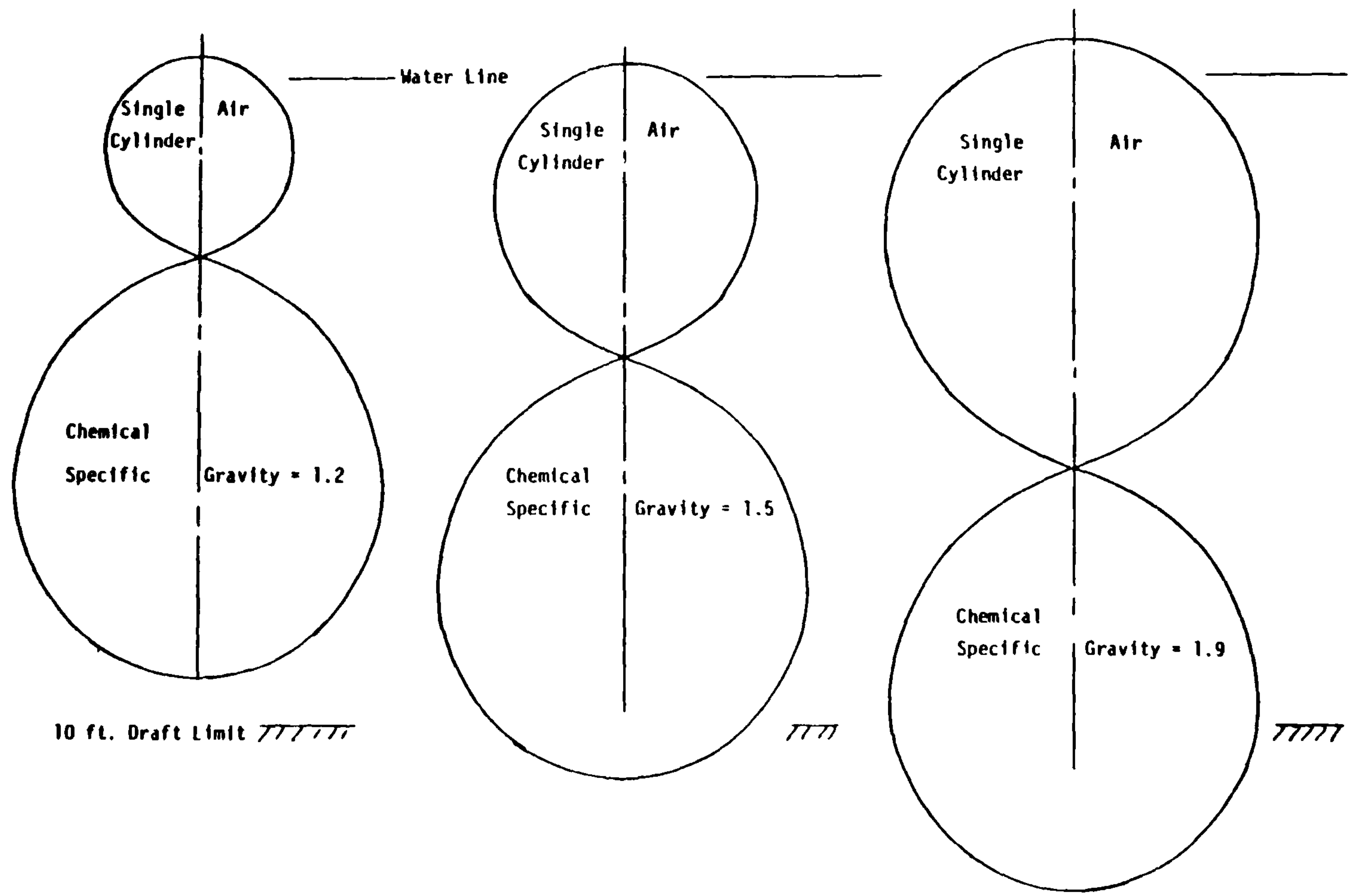


FIGURE 12-- EFFECT OF CHEMICAL SPECIFIC GRAVITY ON CONTAINER DRAFT--DESIGN APPROACH 1 WITH A SEPARATE SINGLE BUOYANCY CYLINDER

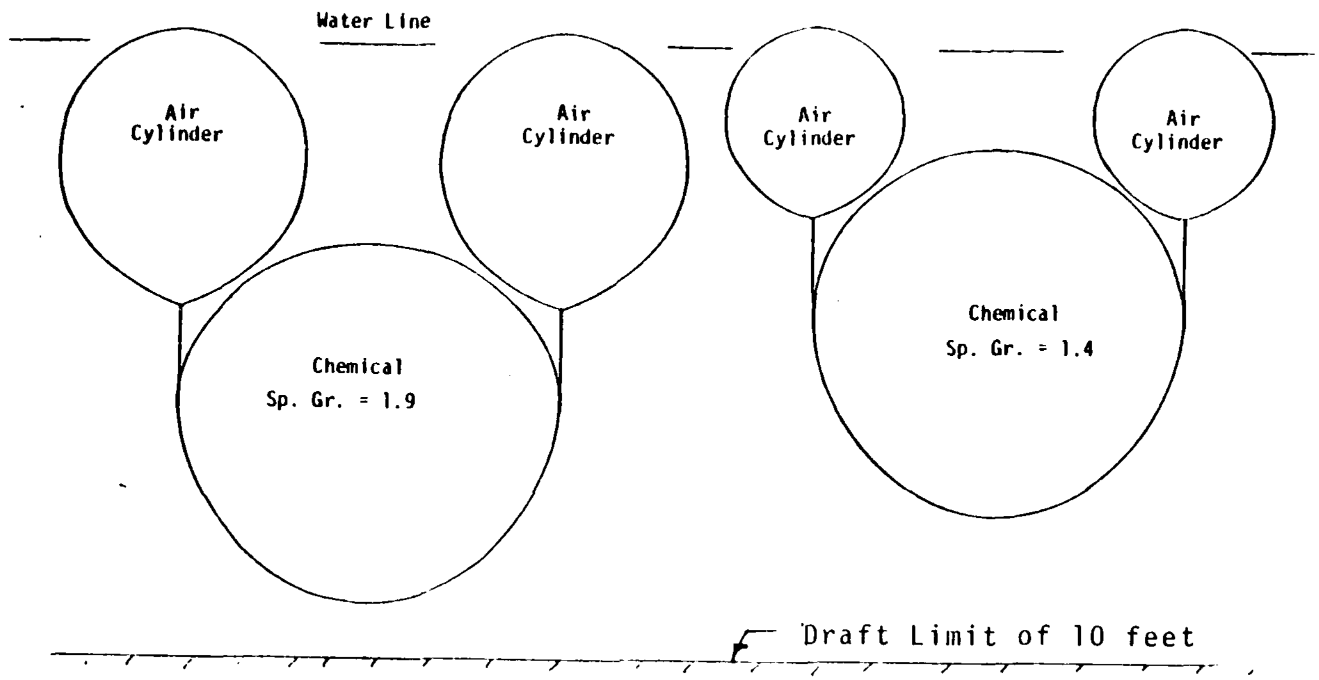


FIGURE 13--EFFECT OF CHEMICAL SPECIFIC GRAVITY ON CONTAINER DRAFT--DESIGN APPROACH 1 WITH SEPARATE TWIN BUOYANCY CYLINDERS

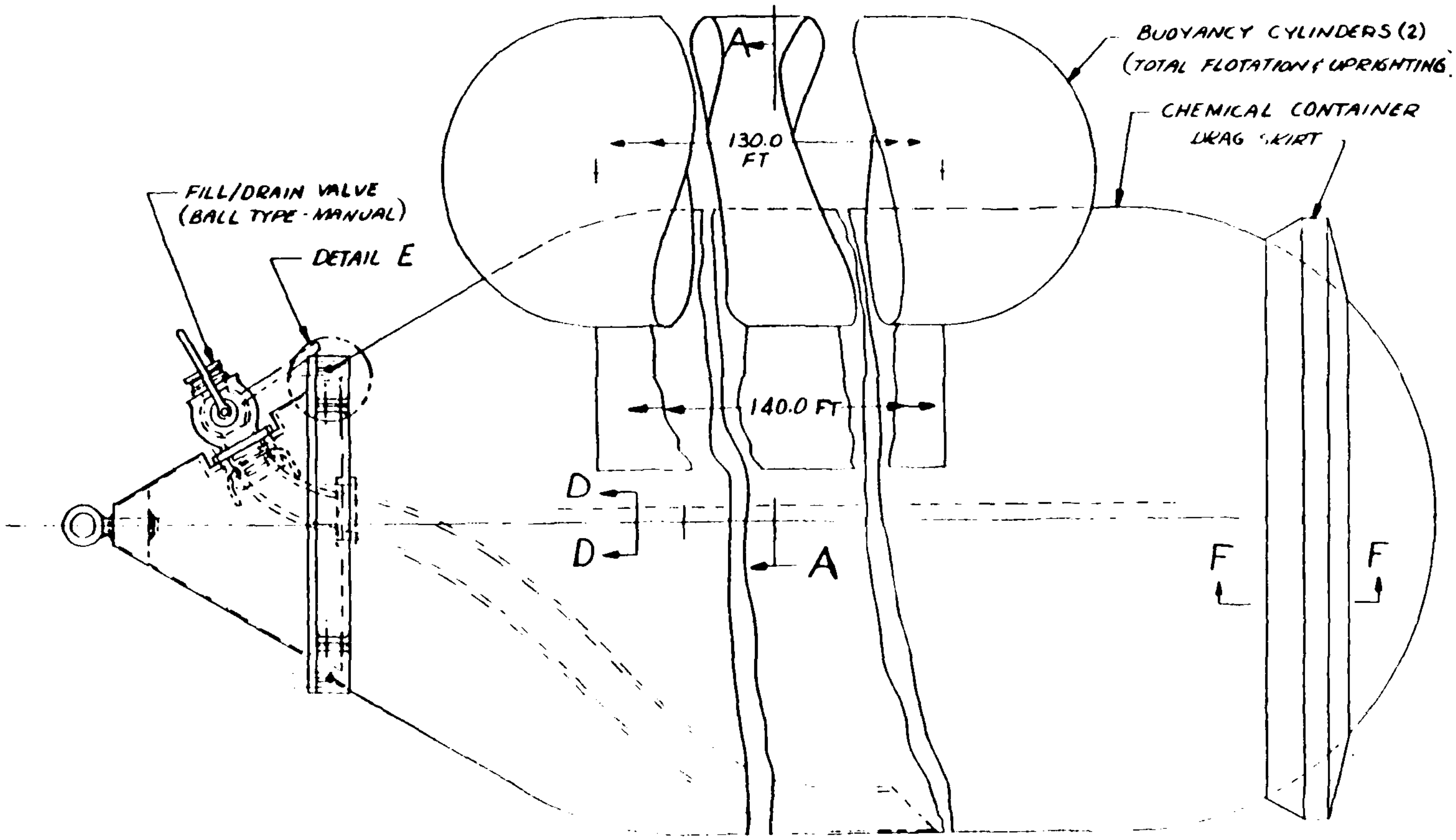


FIGURE 14--DESIGN APPROACH 1 CONTAINER CONCEPT
WITH SEPARATE TWIN BUOYANCY CYLINDERS

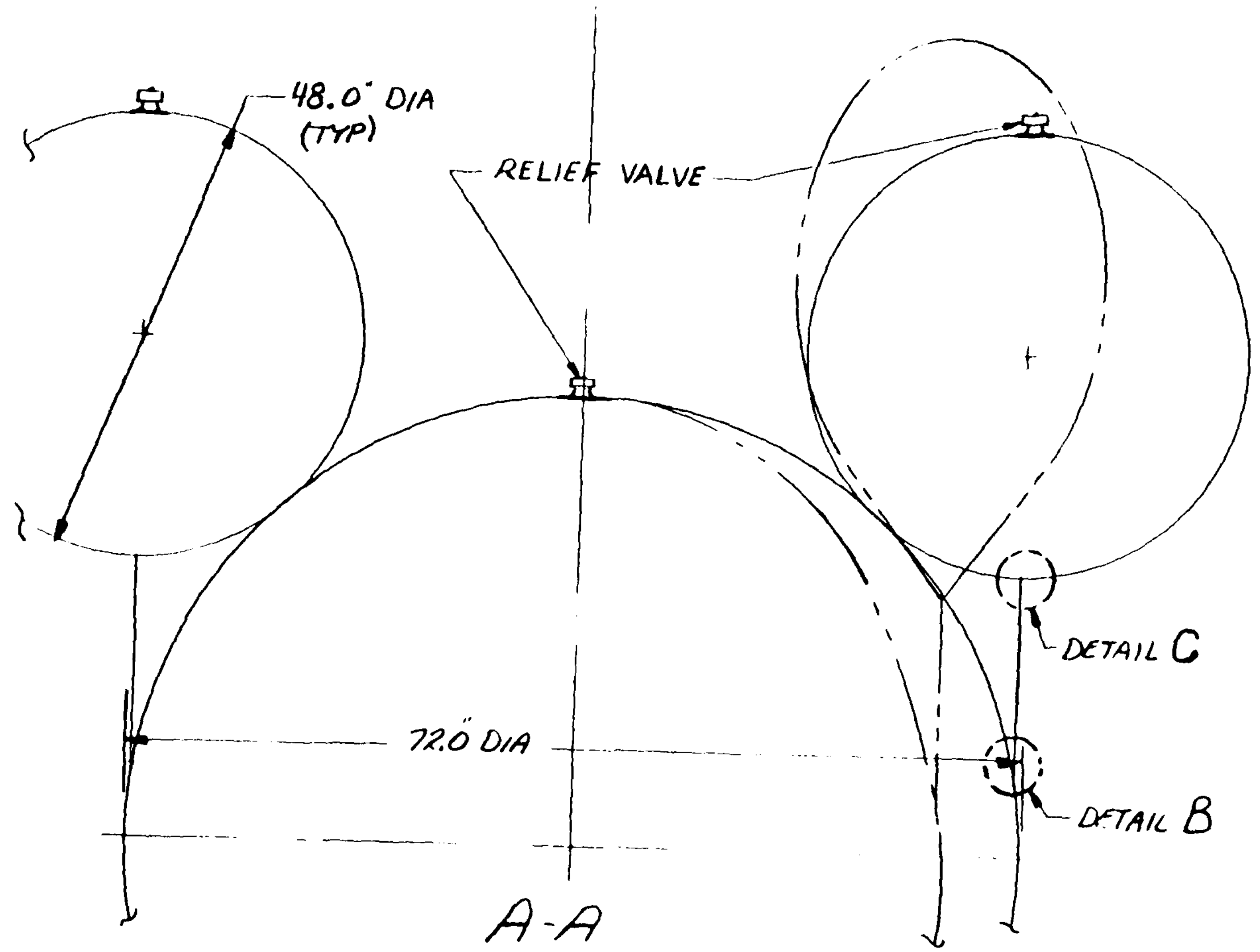


FIGURE 15--DESIGN APPROACH 1--BUOYANCY CYLINDER ATTACHEMENTS

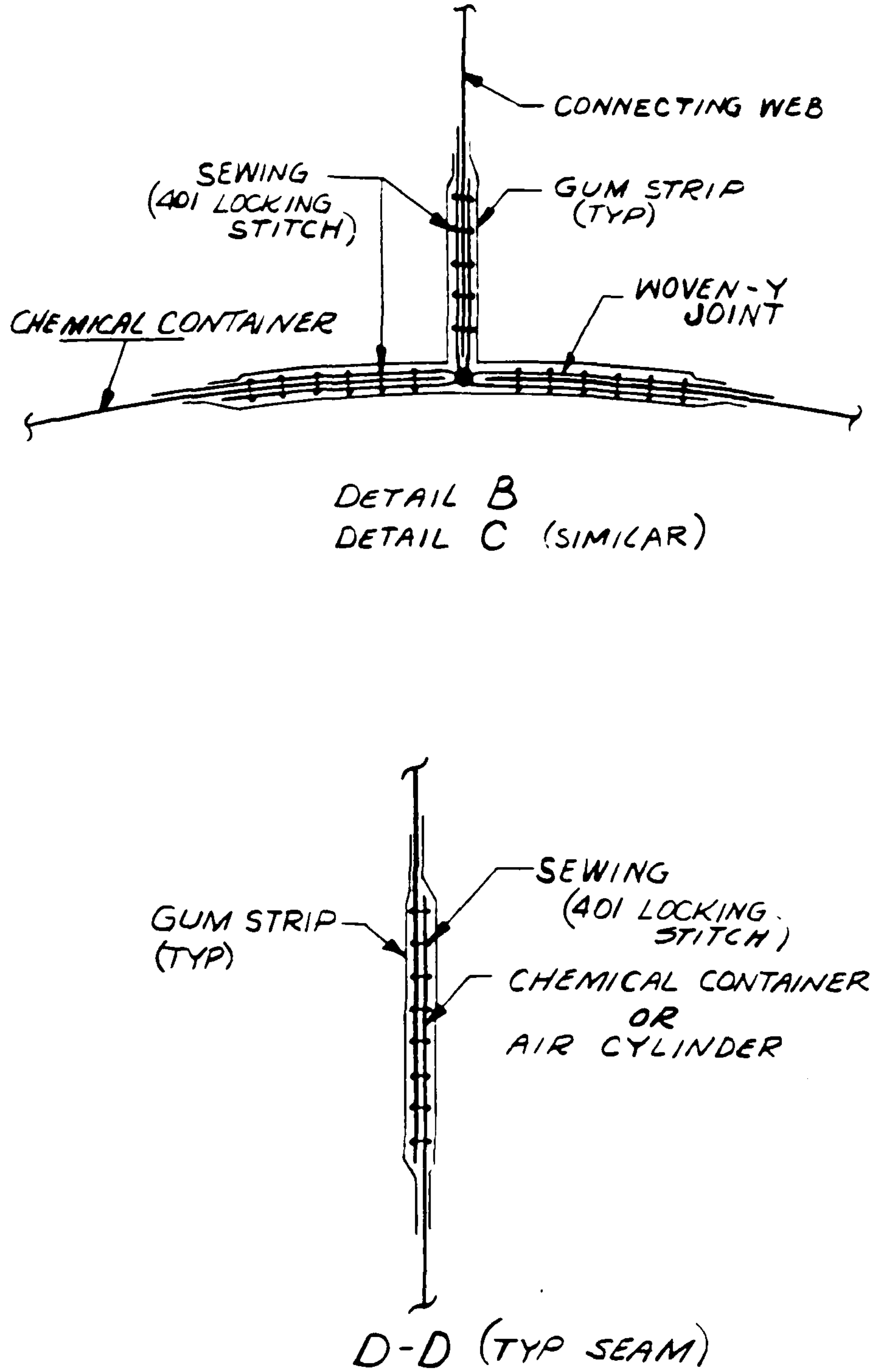


FIGURE 16--DESIGN APPROACH 1--BUOYANCY CYLINDER ATTACHMENT DETAILS

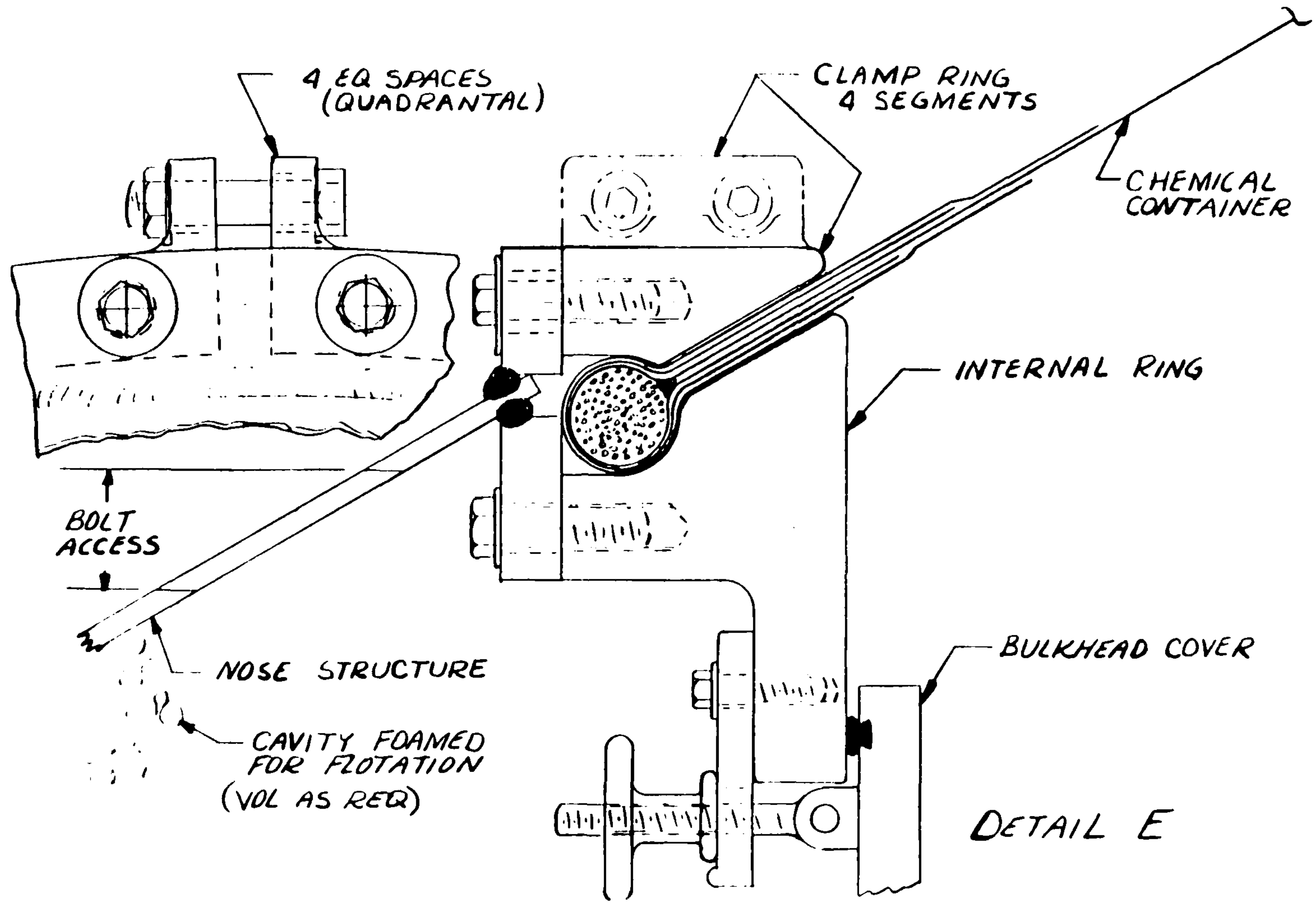


FIGURE 17--DESIGN APPROACH 1--CONTAINER NOSE DETAILS

The cylindrical section of the container includes the filling/discharge hose (s) and the attachment curtain between the container and the buoyancy cylinders. A woven "Y" joint is used to connect the curtain to the container and to the cylinder. The woven "Y" joint acts like a hinge and eliminates peeling forces on the seams, Figure 16.

The drag skirt or vortex fence is located on the rear of the container where the diameter becomes 80 percent, Figure 14. The drag skirt is filled with foam and laced to the container.

c. Towing Drag

The towing drag of the container system for Approach 1 is based on the drag of the chemical container plus the drags of the two flotation cylinders including an interference factor. The interference factor is included with the two flotation cylinders' drag coefficient because they are located near each other. The interference factor value is based on data for bombs located adjacent to each other under an aircraft wing, Reference 11. The value of the interference factor increases as the value of the ratio of the diameter of the bombs to the spacing between the bombs decreases when the values are less than one. Considering only the diameter of the flotation cylinder and the spacing between them, the value of the ratio becomes 0.58, which corresponds to an interference factor of 1.57 to be applied to the basic drag coefficient value of the cylinders. Total System Drag for Approach 1 is:

$$D_{Total} = D_{Chem.\ Container} + 2 \times 1.57\ D_{Buoyancy/Cylinders,\ each}$$

$$D_T = C_{D_{CC}} \times q \times S_{CC} + 2 \times 1.57\ C_{D_{BC}} \times q \times S_{BC} =$$

$$.765 \times 284 \times \frac{\pi}{4} (6^2) + 3.14 \times .765 \times 284 \times \frac{\pi}{4} (4^2) = 11{,}710 \text{ lbs. @ 10 kts.}$$

Where:

$$C_{D_{CC}} = .765 \text{ @ 10 kts for } 1/d \geq 23$$

$$q = 1/2\ \rho V^2 = \frac{64}{2 \times 32.2} (2.865)\ V^2_{knots} = 2.84\ (10)^2 = 284 \text{ PSF}$$

$$S_{CC} = \frac{\pi D^2}{4} \quad \text{where D of chemical container = 6 ft.}$$

$C_{D_{BC}}$ = .765 @ 10 kts for $l/d \geq 23$, flotation chamber

$S_{BC} = \frac{\pi D^2}{4}$ where D of buoyancy chamber = 4 ft.

d. Typical Fabric Strength Requirements

The operating pressure in the buoyancy cylinders is a function of the wave height plus that required to maintain a reasonable container cross section area. Since the chemical is initially free to flow to one end of the container during fill, the buoyancy cylinders must be filled to operating pressure prior to filling with heavy chemicals. Under these conditions the buoyancy cylinders will support all of the full portions of the container.

The tensions in the fabric in each air cylinder and in the fabric of the container are calculated by first defining their pressurized shapes under wave and static conditions, then applying a dynamic factor and a design factor as discussed in A-3 of this section. The method of structural analysis is presented in detail in Appendix A. The calculated shapes and the values of the major parameters are presented in Figure 18.

Tension in the fabric of each buoyancy cylinder can be calculated from

T/γ_0 = 33.46 sq. ft. and T = 64 x 33.5 lbs/ft. or T = 178.5 lbs/in.

Selecting an amplification factor of 2, the limit stress becomes:

$\sigma = \alpha T = 2 \times 178.5 = 357$ lb/in.

The corresponding required ultimate fabric strength (F_{tu}) incorporates the design factor of 4. A design factor of 4.8 instead of 4 was used to account for the woven "Y" joint; the ultimate fabric stress (F_{tu}) is:

$F_{tu} = (D.F.) \cdot \sigma = 4.8 \times 357 = 1,714$ lbs/in.

Tension in the fabric of the container can be calculated considering the radius of the container and the differential pressure due to the sum of the static pressure differential and the pressure differential due to the chemical's actions when the waves are 12 feet high. The static pressure from Figure 18 is

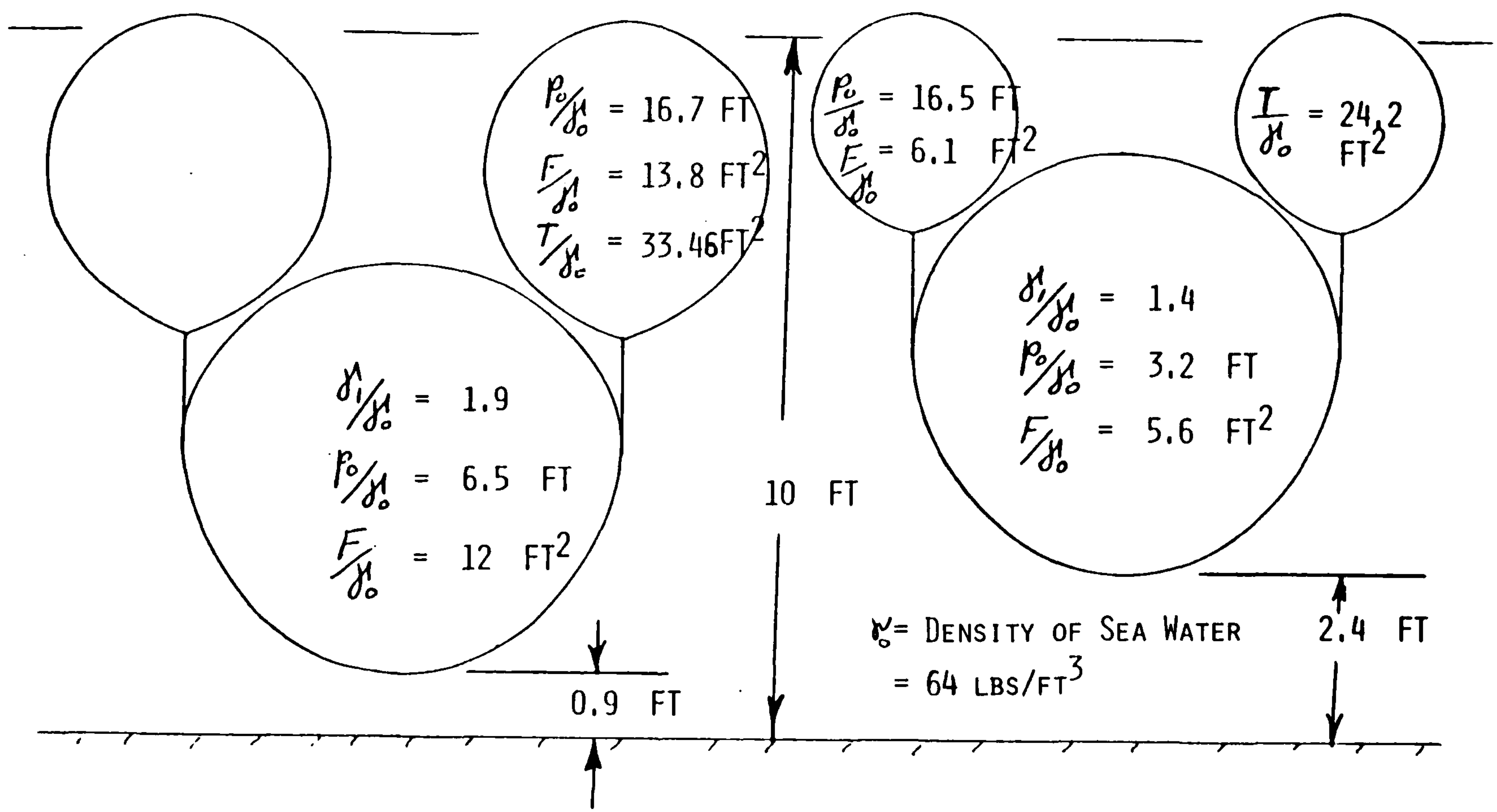


FIGURE 18--DESIGN APPROACH 1--CROSS-SECTIONAL SHAPES AND STRUCTURAL PARAMETERS

p_o/γ_o = 6.5 feet or 416 PSF. A differential pressure of one half of the static operating pressure (p_o) was chosen for the shape analysis, thus Δp_{static} = 208 PSF. The major pressure differential is associated with the container pitching in the waves and the differential head of the chemical is 12 feet. Thus, the calculated differential pressure due to dynamics including a dynamic factor of 2 is:

$$\Delta p_d = \alpha \rho H = 2 \times 1.9 \times 62.4 \times 12 = 2{,}845 \text{ PSF}$$

Thus, total $\Delta p = \Delta p_{static} + \Delta p_{dynamics}$ = 3,053 PSF

Considering a noninal radius (R) of 3 feet for this container, the limit stress is:

$$\sigma = (\Delta p)R = \frac{3{,}053 \times 3}{2} = 763.3 \text{ lbs/inch}$$

The corresponding required ultimate fabric strength (F_{tu}) is:

$$F_{tu} = DF \times \sigma = 4 \times 763.3 = 3{,}053 \text{ lbs/inch}$$

e. Container Weights and Packed Volumes

The weights of the containers were calculated for the major components of the system based on geometry, fabric strength requirements, and drag loads. The fabric weights were calculated based on the unit weights of the fabric to meet the strength requirements and the areas of fabric required. The results are presented in Table 9 for 25,000 gallon containers with and without liners. The weights are well within the 15,000 pound transport limit.

Packed volumes were calculated based on densities obtained by packing similar fabric materials. A packed density of 15 pounds per cubic feet was chosen as a typical value for heavy fabrics.

f. Deployment Sequence and Equipment

The major elements in the selected sequence for operating a design Approach 1 container concept include:

TABLE 9--WEIGHTS AND VOLUMES OF DESIGN APPROACH 1

CONTAINER CONCEPTS FOR CHEMICALS WITH A SPECIFIC GRAVITY = 1.9

Materials	Strength lbs/in	Cloth Wt. oz/sq yd.	Elastomer Code-Thickness	Fabric Wt. oz/sq yd.	Fabric Area sq/ft	Weight, lbs	Volume, cu. ft.
A. 1. Fabric (Nitrile-Nylon) Container 29,252 Gal.	2,400	48	M-906 25 mils	111	2,639	2,035	136
Twin Air Chambers 13,653 Gallons each	1,450	22 (RF-78)	M-906 15 mils	57	3,493	1,381	92
2. Hose (Nitrile-Nylon)						280	20
3. Nose and Tail Fence						350	23
4. Total						4,046	271
B. 1. Fabric (Butyl-Polyester) Container 29,252 Gallons	2,400	48	MA-948 25 mils	105	2,639	1,922	128
Twin Air Chambers 13,653 Gallons, Each	1,450	22	MA-948 15 mils	53	3,493	1,287	86
2. Hose (Butyl-Polyester)						270	20
3. Nose and Tail Fence						350	23
4. Total						3,829	257
C. Fabric (Viton-Teflon) Container liner 29,252 Gallons				VT-0007 30	2,639	550	37
D. Fabric (Teflon-Glass) Container liner 29,252 Gallons				TG-4140 20	2,639	376	25
B + C Totals						4,379	294
B + D Totals						4,205	282

a. Deploying the container from its pallet by flaking it into the water. Initial flotation and control of its attitude is provided by foam strips enclosed in the apex of the buoyancy cylinders.

b. Air is added to the twin buoyancy chambers until they are full and pressurized to operating pressure.

c. Chemical is added to fill the container.

d. Towing is then conducted.

e. The chemical is then pumped out of the container.

f. The air cylinders are deflated.

g. The container is then flaked onto the pallet for refurbishment, repacking, and reuse.

Deployment by faking the container from its pallet into the water is possible with a crane with a lift capacity of 1,000 lbs since the 140 feet long container can be packed onto a pallet using folds that result in lifting requirements of considerably less than 1,000 lbs.

Initial buoyancy is provided by flexible foam contained in sealed strips within the apex of each buoyancy cylinder, Figure 19. The buoyancy capability of the strips exceed the weight of the system in the water.

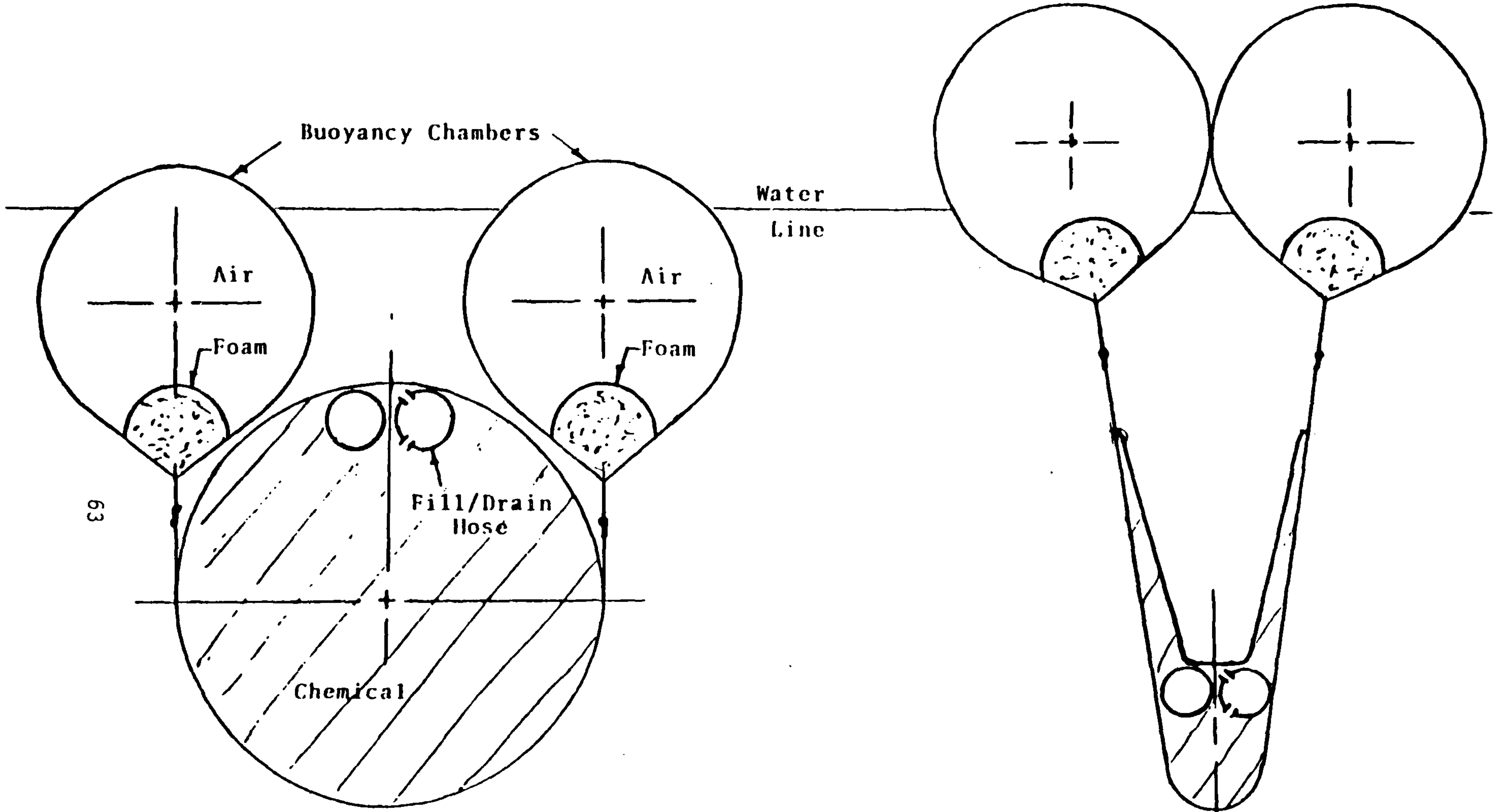
The twin buoyancy cylinders are sized to provide buoyancy with the container filled with a chemical with a specific gravity of 1.9 and pressurized to maintain its volume under wave heights of 12 feet, Figure 18. The operating pressure of the buoyancy cylinders is:

$$p_o = \rho_o(H + h_o) = 64(12 + 4.7) \text{ or } 1{,}069 \text{ PSF or } 7.42 \text{ psi.}$$

The work associated with filling the air cylinders to this operating pressure is pV where: p is the added pressure, 1,069 PSF; and V is the total volume of the air cylinders, 3,650 cu. ft. Thus, pV equals 3,901,850 lb-ft.

If the work is accomplished in one hour, the horsepower developed is:

$$\frac{3{,}901{,}850}{33{,}000 \times 60} \text{ or } 1.97.$$



a. Container Filled-Chemical Sp Gr = 1.9

b. Container nearly empty Chemical Sp Gr = 1.9

FIGURE 19--DESIGN APPROACH 1--BUOYANCY CYLINDERS WITH INTERNAL FOAM FOR INITIAL FLOTATION AND AIR FOR SUPPORTING THE HEAVY CHEMICALS

Compressor efficiency and line losses will require an inflation system with a greater horsepower rating. Because of the relatively low pressure and large volumes, a centrifugal blower system with one or two stages appears to be the most appropriate for inflating the cylinders.

g. Material and Construction Evaluation

Design Approach 1 leads to container concepts with very large structural components. To build large components at a reasonable cost requires that materials and construction techniques be selected that do not need large building mandrels and large autoclaves. This can be accomplished by using woven fabric (cured or uncured) that is cut into flat patterns and joined together using sewn lap seams with gum on both sides of the seams and curing the seams in a press or curing the total component while rolled onto a drum in an autoclave, Table 10.

Different types or conditions of materials were considered for costing the fabrication of Approach 1 concepts. The concepts are constructed from woven fabrics with the strengths and weights of those listed. Approach 1 is constructed of uncured fabric sewed together then cured. Approach 1A is constructed using two plies of uncured fabric overlapped one half of their width, taping the lap edges, and then curing the container as a unit. Approach 1B uses cured fabric with the coating peeled back locally for sewing. The edges are taped and sewn after adding adhesive. Adhesive is applied to the peeled back coating, edge tapes are added, and the seams are cured in either a press or the container is rolled onto a drum and cured in an autoclave.

Structural materials other than those first listed can be used with different state-of-the-art construction techniques; however, the relative cost of fabrication equipment (large mandrels and a large autoclave) needed with these other construction techniques made them noncompetitive for design Approach 1 container concepts, Table 10.

The liner materials selected are cured fabric. The Viton on Teflon fabric can be processed in a manner somewhat similar to that for the container structural fabric components. Flat patterns are cut and joined together using cemented lap seams, and the seams are cured by rolling the liner onto a drum and using an autoclave.

TABLE 10--DESIGN APPROACHES 1, 1A, and 1B--

EVALUATION OF SELECTED MATERIALS AND CONSTRUCTION TECHNIQUES

FOR CONTAINER CONCEPTS FOR CHEMICALS WITH A SPECIFIC GRAVITY = 1.9

Woven Fabric Construction				Fabrication State of Art**			Relative Equip. Req.***		
Selected Materials for Evaluation	Fabric Strength lb/in	Fabric Wt. oz/sq yd	Material Cost Ratio* Compared to Nitrile-Nylon 1450x1450 Fabrics	Sew & Bond	Layup	Filament Winding	Sewing	Layup	Filament Winding
A. Container Structure									
1. Nitrile-Nylon Chem. Sp. Grav. 1.9	2400	111	1.7	1	1	2	1	3	3
1.4	1880	91	1.2	1	1	2	1	3	3
2. Butyl-Polyester Chem. Sp. Grav. 1.9	2400	105	1.7	1	1	2	1	3	3
1.4	1880	85	1.2	1	1	2	1	3	3
B. Liner Fabric									
1. Viton-Teflon	VT-0007	30	6.5	2			1		
2. Teflon-Glass	TG-4140	20	1.33	2, 4 Sealing seams			UNK Sealing seams		
C. Flotation Chambers									
1. Nitrile-Nylon Chem. Sp. Grav. 1.9	1450	57	1	1	1	2	1	3	3
1.4	915	37	.85	1	1	2	1	3	3
2. Butyl-Polyester Chem. Sp. Grav. 1.9	1450	53	1	1	1	2	1	3	3
1.4	915	34	.85	1	1	2	1	3	3

Notes:

*Direct cost ratio to Nitrile-Nylon

**1. Production Method
2. Methods are Developed
3. Can be developed
4. Research Required

***1. Minor < $10K
2. Significant $10K--100K
3. Very Significant > $100K

The Teflon on Glass fabric can be cut into flat patterns and joined together using heat and pressure. However, the state-of-the-art for leak-proof, flexible seams requires demonstration.

3. Investigation of Approach 2

a. General

This approach uses single fill/discharge locations for a container with multiple bulkheads and integral air chambers. The single fill/discharge location is desirable from an operational and safety standpoint. The integral air chambers requires a somewhat larger diameter cylinder, 7.5 feet versus 6 feet for Approach 1, and meets the draft limit requirements of less than 10 feet when filled with 25,000 gallons of the heaviest chemical.

Bulkheads are required to prevent all of the chemical from flowing to one end of the container and causing the system to rotate to a spar buoy attitude. Air pressure is required to prevent compressing the air and sinking of the container in a rotated wave height of 12 feet plus the length of the air filled portion of the container approximately one half its length, ie. $\frac{172}{2}$ ft. The required operating pressure is thus 12 + 86 or 93 feet of water or 44 psi. Since this pressure is excessive for design, the operating air pressure requirements were calculated versus the number of equal length compartments in Approach 2. The operating air pressure requirements are reduced from 44 to 13 psi when the number of compartments are increased from one to five. Increasing the number to 16 reduces the operating air pressure requirements to approximately 8 psi, Figure 20.

b. Typical Design Concept

A typical design concept was generated using Approach 2 to better define the characteristics of the container. The nose, center, and tail portions are illustrated in Figure 21. Rigid bulkheads with rims are indicated for attaching the beads of the 14 center, nose, and tail compartments to form the complete container. More details of the rim on the rigid bulkhead, the beads in the ends of the fabric from each compartment, and the retaining tension band are presented in Figure 22.

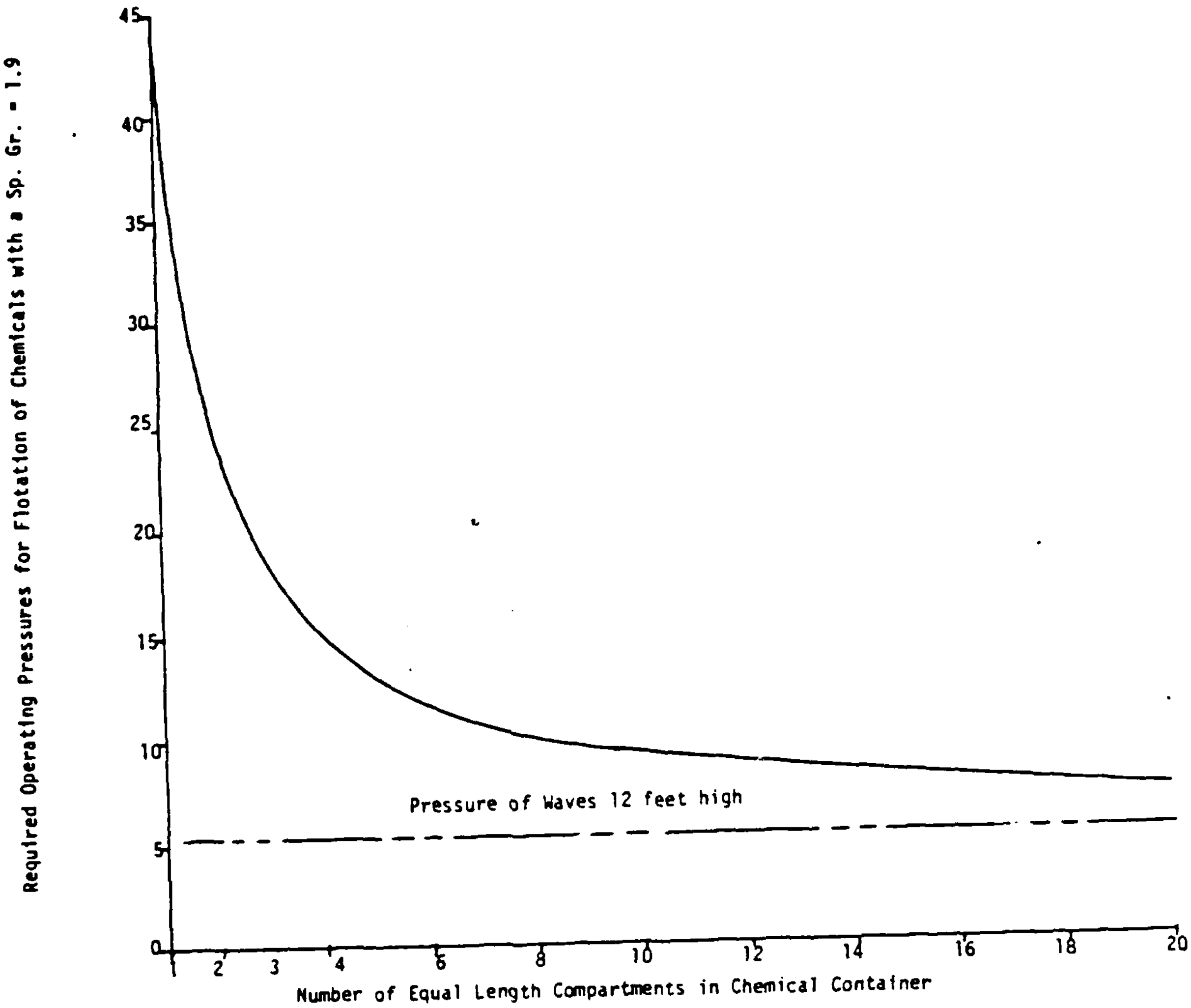


FIGURE 20--DESIGN APPROACH 2--WITH INTEGRAL AIR CHAMBERS--
OPERATING PRESSURES REQUIRED VERSUS NUMBER OF EQUAL LENGTH COMPARTMENTS
FOR FLOTATION OF 25,000 GALLONS OF CHEMICAL OF SPECIFIC
GRAVITY = 1.9 TO PREVENT SINKING OF ROTATED CONTAINER

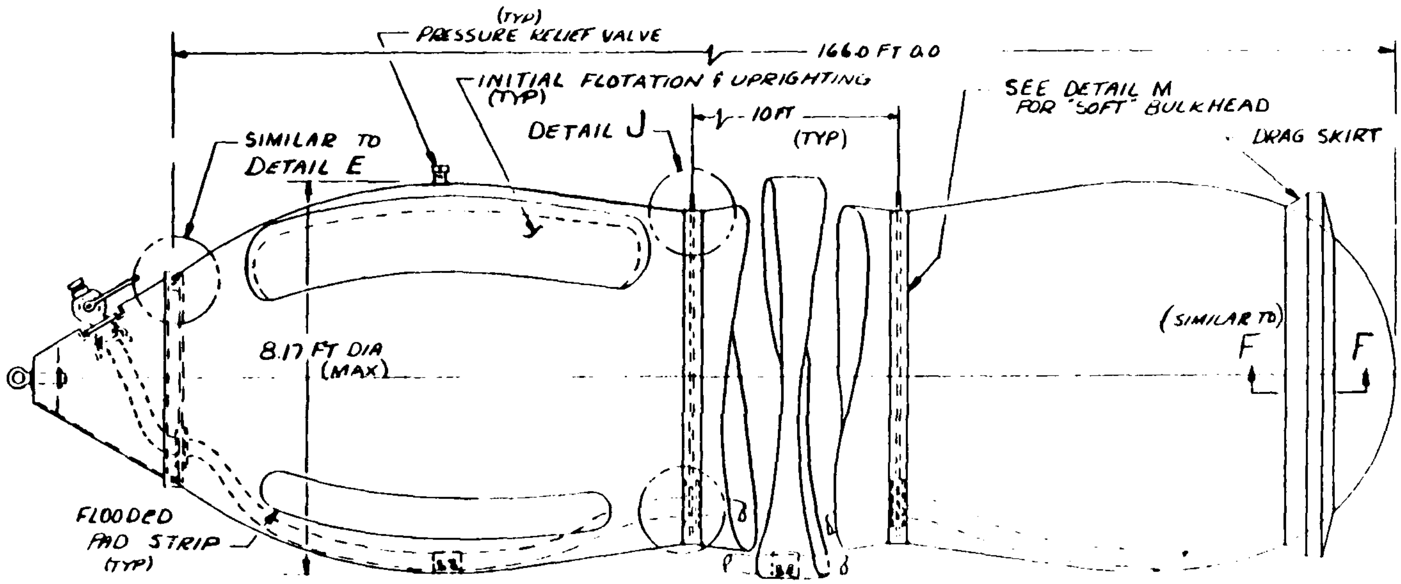


FIGURE 21--DESIGN APPROACH 2--CONTAINER CONCEPT WITH INTEGRAL AIR CHAMBERS IN MULTIPLE COMPARTMENTS--(SINGLE POINT FILLING/DISCHARGING)

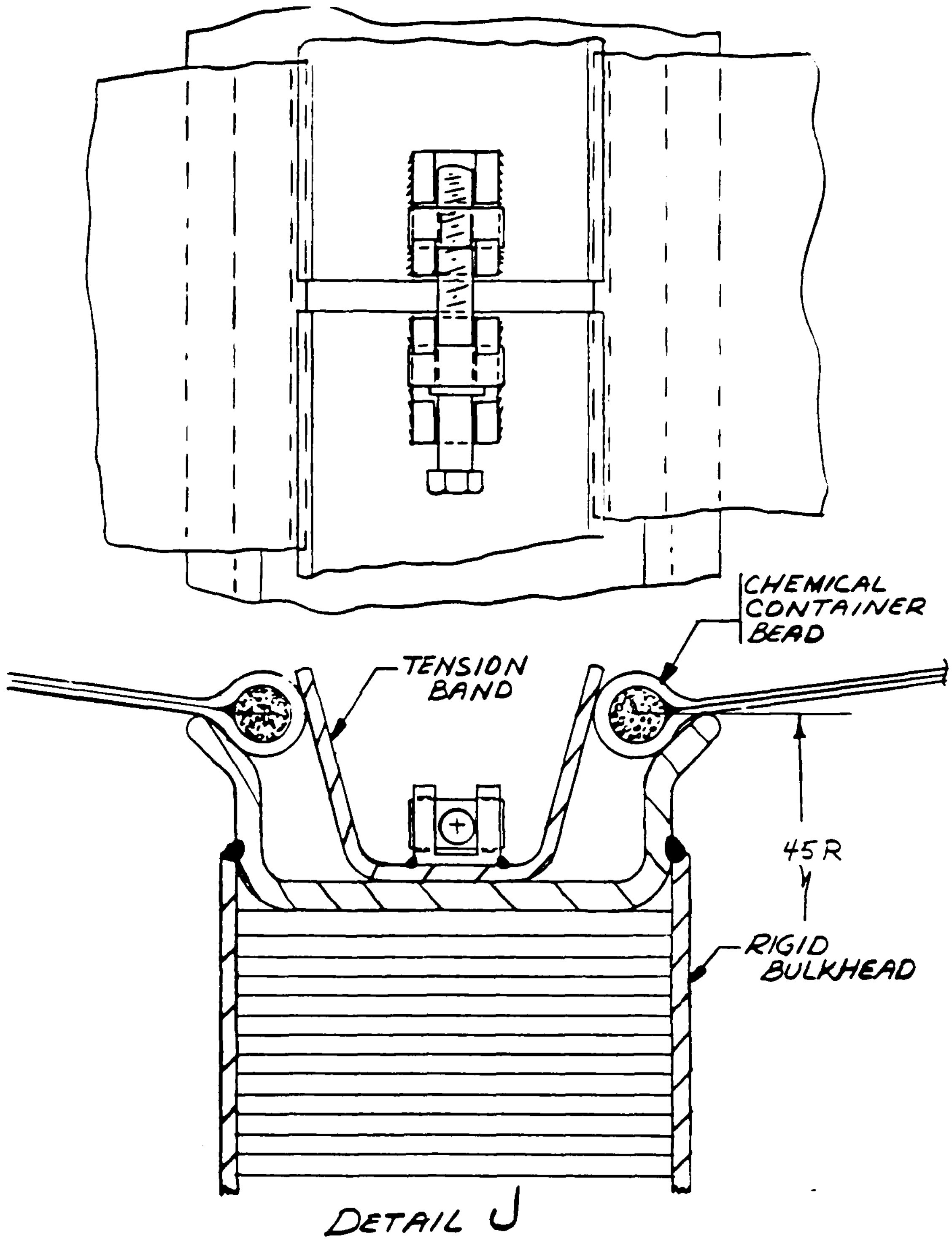


FIGURE 22--DESIGN APPROACH 2--RIGID BULKHEAD DETAILS FOR ATTACHING COMPARTMENTS TOGETHER

Valves are indicated in each of the rigid bulkheads to control the flow of chemical between compartments when a single filling/draining hose is used, Figures 22 and 23. The chemical valves are controlled from the top using an extended length stem. The air fitting and the pressure relief valve are located on the top surface.

The forward portion of the nose section is similar to that presented in Figures 14 and 17 for the concept resulting from Approach 1. The drag skirt is also located and attached to the rear compartment in a manner similar to that presented in Figure 14 for the Approach 1 design concept.

Enclosed strips of foam are located on the outside of the container to control the container's roll attitude for operating the valve handles. Initial buoyancy isn't required with rigid bulkheads because of their large displacements.

To reduce the weight of the bulkheads, a means of providing flexible fabric bulkheads instead of rigid bulkheads was also investigated. Methods of attaching the fabric bulkheads to the compartments and the compartments to each other are illustrated in Figure 24. The connection between the fabric bulkhead and the fabric surfaces of each compartment are by two of the three legs of a woven "Y" joint. The third leg ends with a bead for connecting the compartments together. A segmented clamp and a lacing arrangement are also illustrated. The fabric bulkheads are hemispheres and are free to invert to accept any pressure differential between compartments. In conjunction with the fabric bulkheads, an external arrangement of hoses was also investigated, Figure 25. The hoses connect to individual valves on a manifold and to individual compartments so each compartment can be filled independently. A single hose from the pump supplies the manifold. Details of the hose connection to each compartment is presented in Figure 26.

c. Towing Drag

The towing drag of the container configuration for Approach 2 was calculated to reflect the diameter and l/d for the conceptual design presented in Figure 21.

$$\text{Drag} = C_D \; q \; S$$

$$\text{Drag} = 1.161 \times .765 \times 284 \times 52.42$$

$$\text{Drag} = 13{,}223 \text{ lbs at } 10 \text{ kts}$$

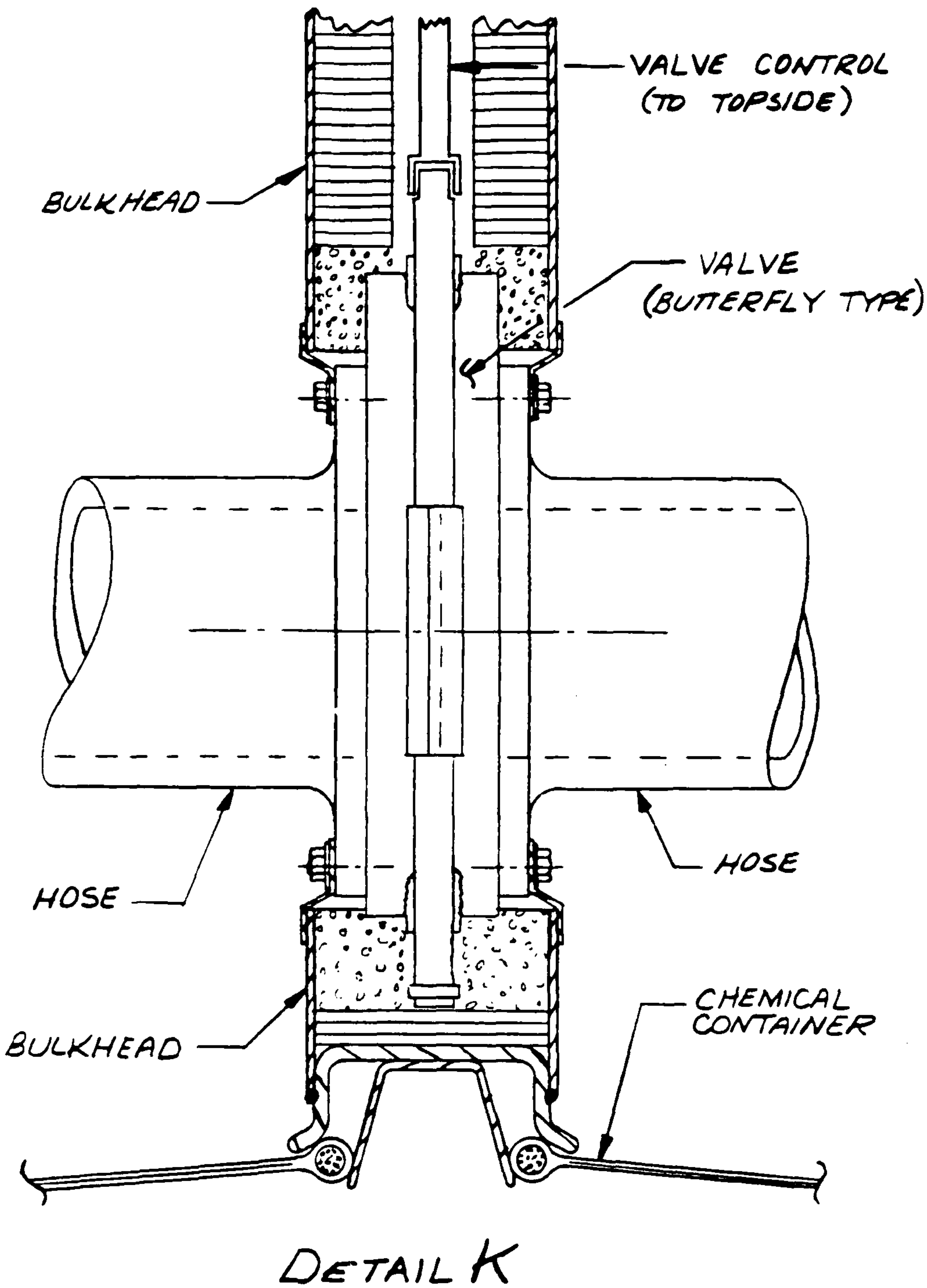


FIGURE 23--DESIGN APPROACH 2--VALVE IN RIGID BULKHEAD;
DETAILS FOR CONTROLLING CHEMICAL FLOW

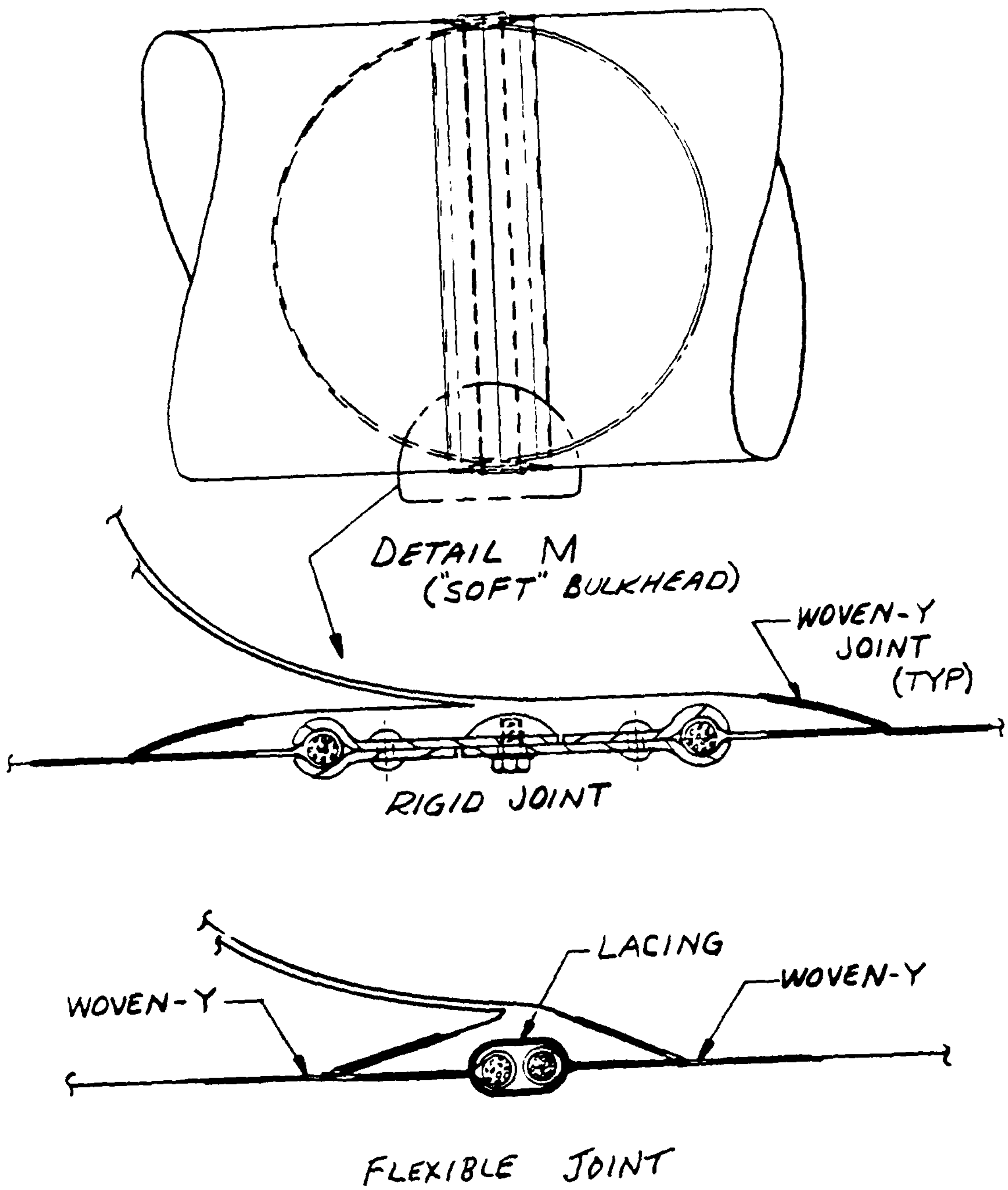


FIGURE 24--DESIGN APPROACH 2--DETAILS OF CONNECTIONS BETWEEN COMPARTMENTS AND WITH THE FABRIC BULKHEADS

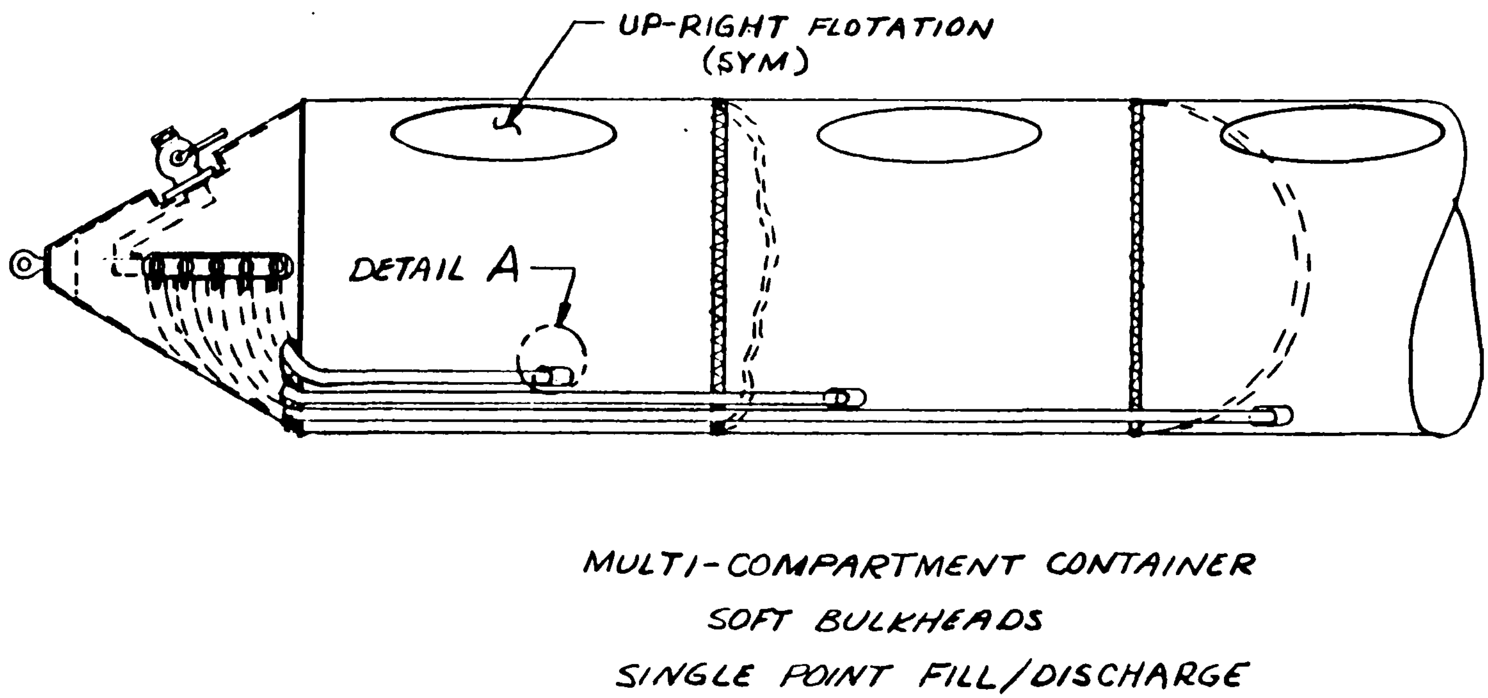


FIGURE 25--MODIFICATION TO DESIGN APPROACH 2--MULTIPLE EXTERNAL HOSES MANIFOLDED TO PUMP AND COMPARTMENTS

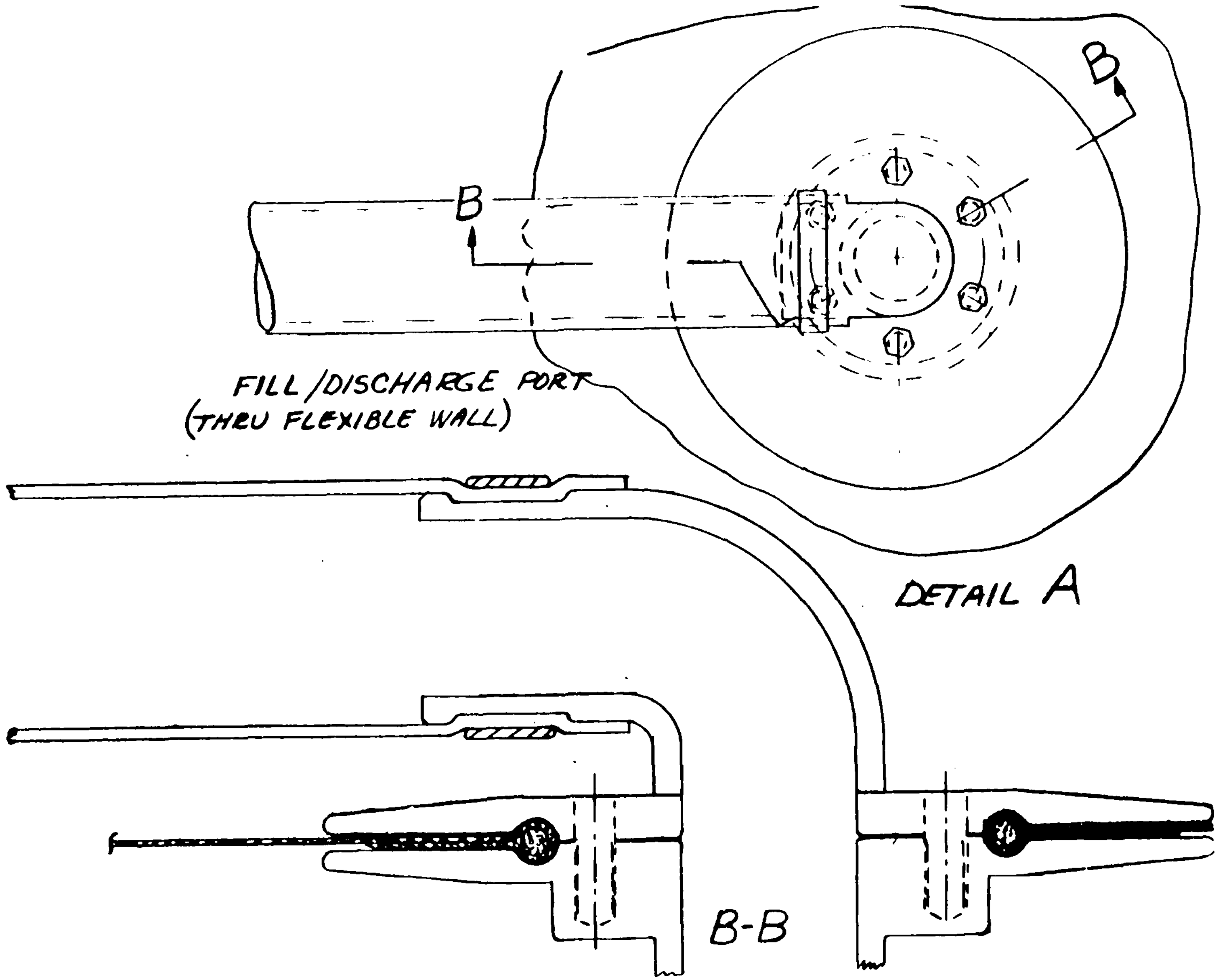


FIGURE 26--MODIFICATION TO DESIGN APPROACH 2--DETAILS OF HOSE CONNECTION TO EACH COMPARTMENT

Where:

C_D = maximum drag coefficient at 10 kts at an l/d of 20.3
= a factor x C_D for l/d of 23 = 1.161 x C_D for an l/d > 23.

$$q = (1/2)\rho V^2 = \frac{64}{2 \times 32.2}(2.865)V^2 = 2.84\ (10)^2 = 284 \text{ PSF}$$

$$S = \frac{\pi d^2}{4} = 52.42 \text{ sq. ft.; } d = 8.17 \text{ ft.}$$

d. Fabric Strength Requirements

The operating air pressure in the compartments must be equal or greater than the pressure from the 12 feet wave height plus the air pressure required to maintain the volume of the compartment when the compartments pitch. The values presented in Figure 20 indicate that a minimum pressure of 8 psi is required to prevent the container from sinking in waves when the compartments are pitched.

The approach for determining the operating pressure on the container fabric used for the stress analysis considers the air pressure to overcome the wave pressure times a factor of 1.5 for seating the bead on the rims to prevent leakage, and an amplification factor of 2 on the chemical height (5 feet) when the compartment is tilted 90°, Appendix B. The resulting operating pressure is $\frac{12 \times 64}{144} \times 1.5 + 2 \times 1.9 \times \frac{62.4}{144} \times 5 = 16.24$ psi. When this pressure is applied to the container surface, the limit design stress becomes $\sigma_B = 40.38 \times 16.42 = 663.7$ lb/inch in each of the plies, Appendix B. Applying the Design Factor (D.F.) of 4, the required ultimate fabric strength is $F_{tu} = \text{D.F.}\ \sigma_B = 4 \times 663.7 = 2{,}655$ lbs/inch. The calculated strengths and weights of the bulkheads and rim assemblies also are presented in Appendix B.

e. Container Weights and Packed Volumes

The weights were calculated for the major components of the system based on geometry, fabric strength requirements, and drag loads. The fabric weights were calculated from the weight per unit area and the area of fabric involved. The bulkheads and rim assemblies weights were calculated based on material thickness to carry the loads and the densities and areas of the materials, Appendix B. The results are presented in Table 11 for 25,000 gallon capacity

TABLE 11-WEIGHTS AND VOLUMES OF DESIGN APPROACH 2

CONTAINER CONCEPTS FOR CHEMICALS WITH A SPECIFIC GRAVITY = 1.9

Materials	Strength lbs/in	Cord Wt. oz/sq yd	Elastomer Code-Thickness	Fabric Wt. oz/sq yd.	Fabric Area sq/ft	Weight, lbs	Volume, cu. ft.
A. 1. Fabric (Nitrile-Nylon) Container 59,344 Gallons	2 plies 2,275	@ 2 @ 18 36	M-906 25 mils	104	4,261	3,080	205
2. Bulkheads 15 @ 266						3,990	190
3. Clamp Rings 15 @ 168						2,880	24
4. Hose and Valves						350	20
5. Nose and Tail Fence						350	23
6. Total						10,650	462
B. 1. Fabric (Butyl-Polyester) Container 59,344 Gallons	2 plies 2,275	@ 2 @ 18 36	MA948 25 mils	96	4,261	2,850	205
2. Bulkheads 15 @ 266						3,990	190
3. Clamp Rings 15 @ 168						2,880	24
4. Hose and Valves						350	20
5. Nose and Tail Fence						350	23
6. Total						10,420	462
C. Fabric (Viton-Teflon) Container liner 59,344 Gallons				VT-0007 30	4,261	890	60
D. Fabric (Teflon-Glass) Container liner 59,344 Gallons				TG-4140 20	4,261	590	40
B + C Totals						11,310	522
B + D Totals						11,010	502

containers with and without liners. The weights approach the 15,000 pound transport limit because of the weights of the metal parts. The use of fabric bulkheads will reduce the container weights to values similar to those for concepts using design Approach 1.

The packed volumes for the fabric parts were calculated on the basis of 15 pounds of fabric being packed in one cubic foot. The metal parts volume were calculated based on the geometric envelope they occupy. The calculated packed volumes are well within the limits.

f. Deployment Sequence and Equipment

The major elements in the selected sequence for operating a container concept using design Approach 2 include:

1) Deploying the container from its pallet by faking it into the water. Initial flotation and control of container attitude is provided by foam enclosed in external strips.

2) Filling requires a procedure that fills all compartments equally. One procedure for accomplishing this is to (a) fill all compartments with air using the internal continuous chemical hose and having the air flow through all of the chemical valves at the bulkheads and through the chemical inlet/outlets; (b) after all compartments are filled with air, the air line is disconnected and the chemical hose from the pump is connected; (c) chemical is pumped into the container increasing the air pressure; (d) the pumping rate is then controlled so that the chemical flow rate appears, from looking at the freeboard, similar to all compartments; (e) the air pressure in the stern compartment is reduced if required to increase the chemical flow rate into this compartment; (f) when the rear compartment appears to be properly filled, the chemical valve in the bulkhead is closed and the air pressure is increased to the design value using an air line connected to its air valve; (g) the same process is repeated for each compartment progressing forward from the stern; (h) if any compartment appears low in the water at design air pressure, it is over filled and the chemical can be made to flow to under filled compartments by reducing their air pressures and opening the valves between the high and low riding compartments; (i) finally, in the filled condition, all chemical and air valves are closed.

3) Towing is then conducted.

4) Discharging the chemical from the container is by opening all chemical valves and allowing the contained air to discharge the chemical through the internal continuous hose. Additional air must be added to completely empty the compartments. A suction pump can be used to collapse the system for retrieval of the system.

5) The container is then faked onto its pallet for refurbishment and/or reuse.

Deployment by faking the container from its pallet into the water is possible using a crane with a lifting capability of 1,000 lbs since the 166 feet long container can be packed onto a pallet using folds compatible with the crane's lifting capability.

Initial buoyancy is provided by flexible foam contained in sealed strips along the upper surface of the container.

The chemical compartment is sized so it can contain both the most dense chemical and the air required for buoyancy. The operating air pressure selected for design is based on the wave height times a factor of 1.5 for seating the beads in the rims of the rigid bulkheads. Thus, the design operating air pressure is 18 feet of water or 8 psi.

The work associated with filling the integral buoyancy chambers to this air pressure is PV where: P is the added pressure, 8 x 144 or 1,152 PSF; and V is the total volume of the container $\frac{59,344}{7.481} = 7,933$, cu ft. since the total system must be air filled and the beads seated before adding any chemical. Thus PV = 9,138,816 lb-ft. If work is accomplished in one hour, the horsepower developed is $\frac{9,138,816}{33,000 \times 60}$ or 4.62. Compressor efficiency, motor efficiency, and line losses will require a system with greater horsepower rating.

g. Material and Construction Evaluation

Design Approach 2 led to container concepts with rigid metal or flexible fabric bulkheads, 2 and 2A respectively. The container fabric structure consists of compartments, each 10 feet long, constructed on building mandrels by laying-up two plies of cord fabric at the proper bias angles. Beads are enclosed in the ends of the fabric for each compartment for attaching to the rigid bulkheads, or woven "Y" joints are attached to the compartment; and one leg is attached to the flexible bulkhead, and the other leg has a bead for attaching the compartments together. The layed-up cord fabric on its mandrel is wrapped in a vacuum blanket and cured in an autoclave.

The smaller size of the individual components for this container compared to those for container concepts resulting from design Approach 1 allows the use of reasonable size mandrels and autoclaves, Table 12. Thus, structural materials other than those first listed can be used with the other state-of-the-art construction techniques without additional costs for fabrication equipment.

The liner materials can be processed using a mandrel or in the same manner as presented for the liners of the Approach 1 concepts.

4. Investigation of Approach 3

a. General

This approach uses separate locations on each of the many segments of the chemical container for filling/discharging the chemical and the air for integral buoyancy. Multiple transfer locations have a disadvantage from an operational and safety standpoint, but they eliminate the need for internal hose/valve hardware that is associated with the basic concept for Approach 2. The dimensions of the spherical segments were established based on the desired chemical plus air volumes and the desired fineness ratio of the container. A diameter of 8.5 feet was selected for the 25 segments making up the container. With integral flotation, the draft of the container with the most dense chemical is less than 10 feet. Since the container consists of many segments, the operating air pressure required to prevent compressing the air is the sum of the pressures due to a wave height of 12 feet plus the pressure due to tilting the one half full, 7.2 feet long segments 90°. The operating air pressure is $12 + \frac{7.2}{2}$ or 15.6 feet of water or 6.93 psi, Figure 20.

TABLE 12--DESIGN APPROACH 2 AND 2A--EVALUATION OF SELECTED MATERIALS AND CONSTRUCTION TECHNIQUES FOR CONTAINER CONCEPTS FOR CHEMICALS WITH A SPECIFIC GRAVITY = 1.9

Two-ply Cord Fabric Construction				Fabrication State of Art**			Relative Equip Req.***		
Selected Materials for Evaluation	Fabric Strength lb/in	Fabric Wt. oz/sq yd	Material Cost Ratio* Compared to Nitrile-Nylon 1450x1450 Fabrics	Sewing-Bonding	Layup	Filament Winding	Sewing	Layup	Filament Winding
A. Container Structure									
1. Nitrile-Nylon Chem. Sp. Grav. 1.9	2 @ 2275	104	1.05	1	1	2	1	2	2
2. Butyl-Polyester Chem. Sp. Grav. 1.9	2 @ 2275	96	.97	1	1	2	1	2	2
B. Liner Fabric									
1. Viton-Teflon	VT-0007	30	6.5	2			1		
2. Teflon-Glass	TG-4140	20	1.33	2, 4 Sealing seams			UKN Sealing seams		

Notes:

*Direct Cost ratio to Nitrile-Nylon

**1. Production Method
2. Methods are Developed
3. Can be Developed
4. Research Required

*** 1. Minor < $10K
2. Significant $10K--$100K
3. Very Significant > $100K

b. Typical Design Concept

A typical design was generated using Approach 3 to better define the characteristics of the container. The nose, center, and tail portions are illustrated in Figure 27. The drag loads are carried by the stainless steel cables located at the centerline of each segment. Each segment is filament wound on a mandrel and the winding ends in metal fittings that are closed by end plates that connect to the cables and universal joints between the segments. The nose section transfers the load in the center cables to the tow line. An external bead/wear strip is added to the front segment for interfacing with the rigid nose portion. All segments have four enclosed foam strips mounted on the upper surface of the segments for initial buoyancy and to aid in controlling the attitude of the segments. Individual filling/discharging points are located on each segment for transferring chemicals or air. A relief valve controls the air pressure during the loading of chemicals into each of the inflated segments.

The drag skirt is fabricated separately and laced to the rear segment so its maximum height occurs at 80 percent of the segment's maximum diameter.

A modification to design Approach 3 was made to generate a container design concept that reduces the number of fill points and the number of container segments, Figure 28. The segments are filament wound and have longer cylindrical portions than the segments of the container concept presented in Figure 27. The filling hose is manifolded to hoses to each segment. The hoses are connected at each bulkhead, Figure 29. Each bulkhead is trapped between the end pieces wrapped in each segment. The end pieces are held together by a rim. The drag loads are carried by a group of longitudinal ropes attached internally between the end pieces.

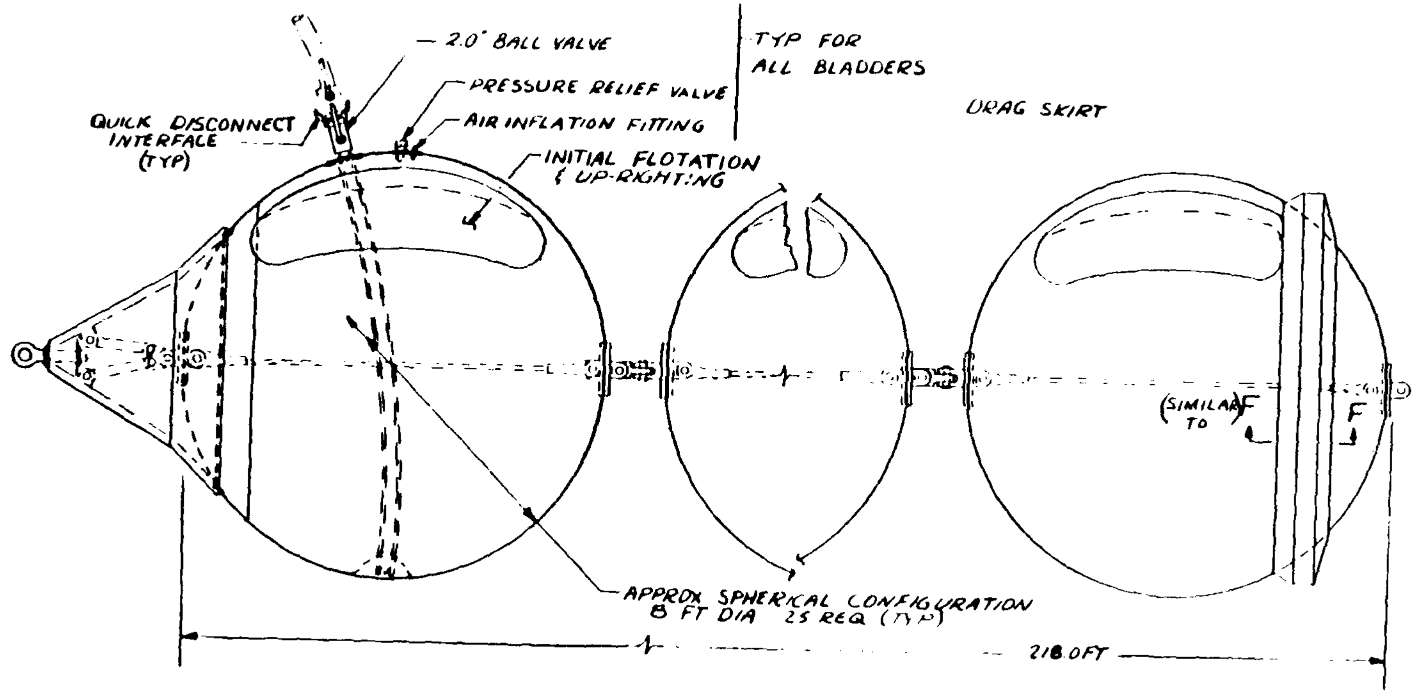


FIGURE 27--DESIGN APPROACH 3--CONTAINER CONCEPT WITH INTEGRAL AIR CHAMBERS IN MULTIPLE SEGMENTS--MULTIPLE POINTS FOR FILLING/DISCHARGING

AD-A114 141 GOODYEAR AEROSPACE CORP AKRON OH F/G 13/4
HAZARDOUS CHEMICAL CONTAINER FEASIBILITY/CONCEPT DESIGN STUDY.(U)
DEC 80 F BLOETSCHER, C A SUTER, J E HOUMARD DTCG39-80-C-80036
UNCLASSIFIED GAC-19-1480 CGR/DC-11/81 NL

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A114 141

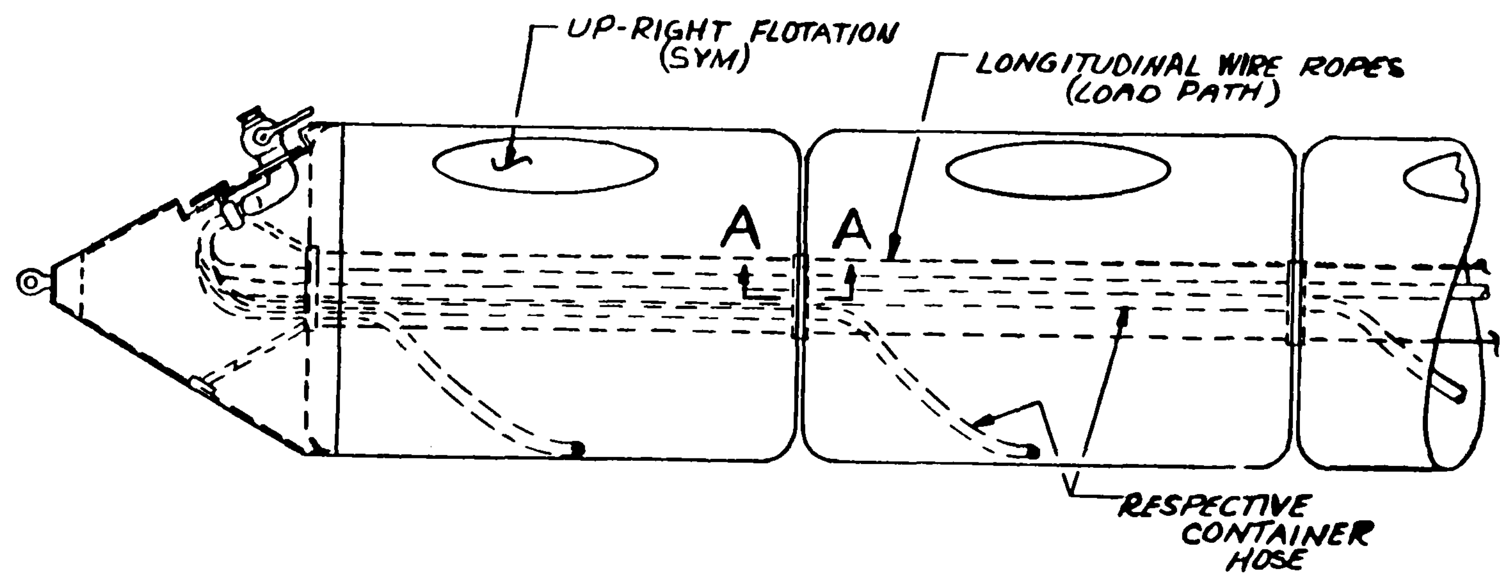


FIGURE 28--MODIFICATION TO DESIGN APPROACH 3--
MULTIPLE INTERNAL HOSES MANIFOLDED FROM PUMP TO SEGMENTS

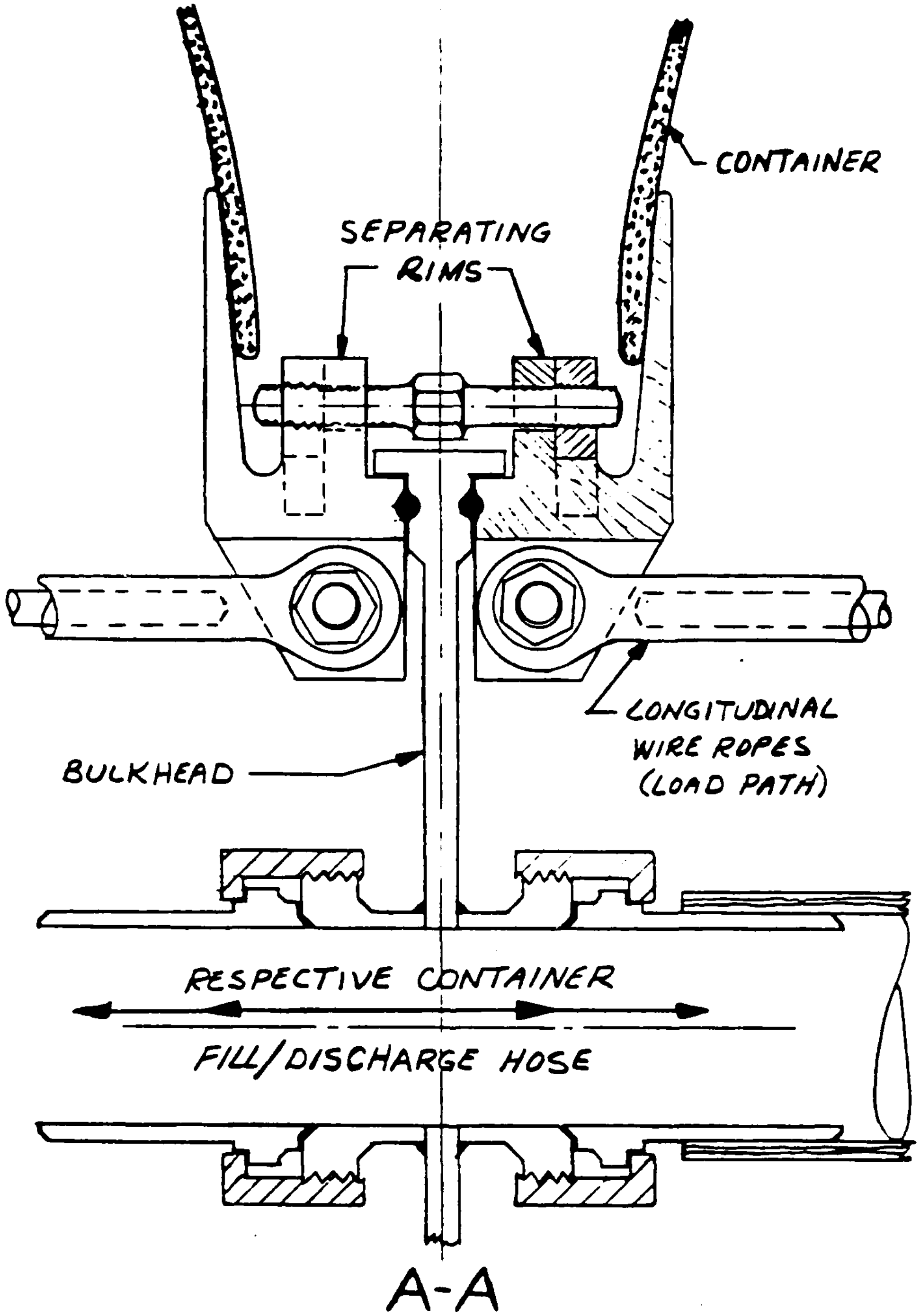


FIGURE 29--MODIFICATION TO DESIGN APPROACH 3--
DETAILS OF HOSE AND SEGMENT CONNECTIONS

c. Towing Drag

The towing drag of the configuration, a series of spheres, is based on the drag of a single sphere acting as the beginning and the end of the string and a factor times this coefficient for the other spheres located between them where the C_D for a sphere is 0.209 and the factor is 0.20, Reference 10. The total drag coefficient then becomes:

$$C_{D_{Total}} = 2(0.209) + 23(0.2)(0.209) = 1.38$$

$$\text{Total Drag} = C_{D_T}\ q\ S = 1.38 \times 284 \times \frac{\pi}{4}(8.5)^2 = 22{,}230 \text{ lbs.}$$

Because the system is only 79 percent submerged, the towing drag is 79 percent of 22,230 lbs. or 17,562 lbs.

d. Fabric Strength Requirements

The operating air pressure in the segments must be equal to or greater than the pressures due to the 12 feet wave height plus the air pressure required to maintain the segments' volume when the segments pitch. With 25 segments, the minimum required air pressure value for buoyancy is approximately 7 psi, Figure 20.

The approach used for determining the operating pressure on the fabric for the structural analysis is presented in Appendix C. The operating pressure consists of an air pressure of 8 psi plus an amplification factor of 2 times the pressure due to the height of heavy chemical when the segment is rotated 90°. The resulting operating pressure on the fabric is

$$8 + \frac{2 \times 1.9 \times 62.4 \times 4.25}{144} = 15 \text{ psi}$$

When this pressure is applied to the container fabric, the stresses presented in Appendix C are:

1) Each Helix Ply

Limit Stress = $\sigma p = \frac{15 \times 51}{3.7321} = 205$ lbs/inch

Ultimate Stress = $F_{tu} = 4 \times 205 = 820$ lbs/inch

2) Circumferential Wraps

Limit Stress = $\sigma_h = 0.9641 \times 15 \times 51 = 737.5$ lbs/inch

Ultimate Stress = $F_{tu} = 4 \times 737.5 = 2{,}950$ lbs/inch

3) End Reinforcement

Limit Stress = $\sigma_r = 0.8703 \times 15 \times 51 = 665.8$ lbs/inch

Ultimate Stress = $F_{tu} = 4 \times 665.8 = 2{,}663$ lbs/inch

e. Container Weights and Packed Volumes

The weights were calculated for the major components of the system, and the results are presented in Table 13. The unit weights of the fabric

TABLE 13--WEIGHTS AND VOLUMES OF DESIGN APPROACH 3

CONTAINER CONCEPTS FOR CHEMICALS WITH SPECIFIC GRAVITY = 1.9

Materials	Strength lb/inch	Filament Weight oz/sq yd	Elastomer Code-Thickness	Fabric Wt. oz/sq yd.	Fabric Area sq/ft	Weight, lbs	Volume, cu. ft.
A. 1. Fabric (Nitrile-Nylon) Container 60,139 Gallons	670 & 2420	13 & 24	M-906 25 mils	63	5,555	2,433	162
2. Domes-50 @ 13.3						665	30
3. Fittings 50 @ 4.54						227	3
4. Cables 25 @ 11.8						295	5
5. Hoses and Valves						350	20
6. Nose and Tail Fence						350	23
7. Total						4,320	243
B. 1. Fabric (Butyl-Polyester) Container 60,139 Gallons	670 & 2420	13 & 24	MA948 25 mils	57	5,555	2,200	162
2. Domes-50 @ 13.3						665	30
3. Fittings-50 @ 4.54						227	3
4. Cables-25 @ 11.8						295	5
5. Hoses and Valves						350	20
6. Nose and Tail Fence						350	23
7. Total						4,087	243
C. Fabric (Viton-Teflon) Container liner 60,139 Gallons				VT-0007 30	5,555	1,158	77
D. Fabric (Teflon-Glass) Container liner 60,139 Gallons				TG-4140 20	5,555	772	52
B + C Totals						5,245	320
B + D Totals						4,859	295

materials and their areas were used in calculating their weights. The weights of the domes, fittings, and cables are based on using stainless steel materials that can carry the loads with a design factor of 1.5. The weight of hoses and valves are based on similar catalog items. The weight of the nose is based on the metal parts. The weight of drag fence is based on fabric and foam weights.

The volumes of the fabric items are based on a packing density of 15 pounds per cu. ft. The packed volumes of the rigid items are based on their envelopes.

The weights and volumes of the containers are well within the transportation limits.

f. Deployment Sequence and Equipment

The major elements in the selected sequence for operating a container concept using design Approach 3 include:

1) Deploying the container from its pallet by faking into the water. Initial flotation and control of container attitude are provided by foam enclosed in strips on the surface of the segments.

2) Filling the segments of the container requires individual connections to the individual spheres. An initial volume of air is needed for floating the heavy chemicals, and the air is compressed as the chemicals are pumped in. Air pressure and free-board are monitored during the filling of each sphere.

3) Towing is then conducted.

4) Discharging the chemical can be by the action of the air pressure followed by suction pumping or by adding more air. The suction pump also can be used to collapse the segments for retrieval.

5) The container is then faked onto its pallet for refurbishment and/or reuse.

Deployment by faking the container segments from the pallet into the water is possible using a crane with a lifting capability of 1,000 pounds since many segments are involved in making the container, and their weights are considerably less than 1,000 pounds.

Initial buoyancy is provided by flexible foam packed in sealed strips along the upper surface of the spheres. External strips that flood can be located near lower portions of the spheres if more stability is required during filling and discharging.

Each segment of the chemical container is sized so it contains both the most dense chemical and the air required for buoyancy. The operating air pressure selected is based on the wave height of 12 feet pressures times a factor of 1.5 or 8 psi.

Without any losses, the work required to fill all of the integral buoyancy chambers is PV where: P is the added pressure, 8 x 144 or 1,152 PSF; and V is the total volume to be filled at that pressure. However, if the spheres are filled with air at small pressures initially, the addition of chemicals by a pump will compress the air to values greater than needed for maintaining the displacement. For example, the air pressure in the segments will rise from a minimal pressure differential when empty of chemical to 14.7 psi when one half full of chemical. Thus, air must be allowed to bleed off through the air-filled valve or the air relief valve when filling the segments with chemicals. Thus, the horsepower of the air compressor is based on volume requirements and the pressure losses through the inflation lines. If a 3 psi line loss is assumed, then $PV = 3 \times 144 \times \frac{60,139}{7.481} = 3,472,804$ lb-ft. If the work is accomplished in one hour, 1.75 horsepower will be developed.

g. <u>Material and Construction Evaluation</u>

Design Approach 3 led to container concepts that are filament wound. This approach leads to given segment shapes for given wrap angles. The shapes of the segments were selected to require end fittings as small as possible and still be able to wind a container segment on an inflatable building mandrel. The end fittings are located on the ends of the mandrel and become part of the container segment as it is wound. The total container segment is wound incorporating the fabric end reinforcements and fittings using a helix wrap. The cylindrical portions of the segments require additional hoop wraps to carry the additional loads per inch. The fabric segments of Approach 3A are lengthened versions of the segments of Approach 3. The length increase is accomplished by increasing the length of the cylindrical portion of the segment. The wound segment is wrapped in a vacuum blanket and then cured in an autoclave.

The use of reasonably sized mandrels and curing in available autoclaves are the result of the shorter lengths of the segments for Approaches 3 or 3A compared to the length of the single chemical container concepts resulting from design Approach 1, Table 14. The rating of 2 for the state-of-the-art of filament winding is associated with the materials. A process has been developed, but it is not associated with production items. The ratings in the table indicate similar shape and size segments which can be fabricated with woven fabric using sewing and bonding of the seams. The use of cord fabric and laying up shapes with small ends becomes unrealistic because of the directions and pileups of cord fabric strips approaching the end fittings.

The liner materials can be processed using a mandrel or in the same manner as presented for the liners of the Approach 1 concepts.

5. Summary of Feasibility of Developing a Container to 3.1 Requirements

The feasibility of developing a container to 3.1 Technical and Operational Requirements by individual requirements is presented in Table 15. The letter "X" is listed where the values for the requirements were used for design and/or the calculated values for the parameters were well within the values of the requirements. Comments are presented where the values approach their limits. Only two comments are listed. One is associated with Approach 1 concepts which require twin buoyancy cylinders to meet the draft limit while meeting all of the other requirements. The other is associated with Approach 2 concepts and the weights when rigid bulkheads are used to form the many compartments.

All containers were designed to have at least 25,000 gallons capacity of chemical with a specific gravity of 1.9. The materials and construction techniques were selected to attain the structural strengths required to meet the towing and survival conditions. The calculated results included container weights and packed volumes, provisions for initial flotation, and container draft. The ability to deploy the container using a crane with a 1,000 pound lift capability was judged based on the container's weight, length, flexibility, and possible methods of packing it on a pallet. The ability to be ready to receive the chemicals in less than four hours is based on judging the ability to deploy the container using the 1,000 pound lift capability

TABLE 14--DESIGN APPROACHES 3 AND 3A--
EVALUATION OF SELECTED MATERIALS AND CONSTRUCTION TECHNIQUES
FOR CONTAINER CONCEPTS FOR CHEMICALS WITH A SPECIFIC GRAVITY = 1.9

Filament Winding Construction

Selected Materials for Evaluation	Fabric Strength lb/in	Fabric Wt. oz/sq yd	Material Cost Ratio* Compared to Nitrile-Nylon 1450x1450 Fabrics	Fabrication State of Art**			Relative Equip. Req.***		
				Sewing & Bonding	Layup	Filament Winding	Sewing	Layup	Filament Winding
A. Container Structure 1. Nitrile-Nylon Chem. Sp. Grav. 1.9	670 & 2420	63	.60	1		2	1		2
2. Butyl-Polyester Chem. Sp. Grav. 1.9	670 & 2420	57	.55	1		2	1		2
B. Liner Fabric 1. Viton-Teflon	VT-0007	30	6.5	2			1		
2. Teflon-Glass	TG-4140	20	1.33	2, 4 Sealing seams			UKN Sealing seams		

TABLE 15--SUMMARY OF FEASIBILITY OF DEVELOPING A CONTAINER TO 3.1 TECHNICAL AND OPERATIONAL REQUIREMENTS USING APPROACHES 1, 2, AND 3

Technical and Operational Requirements	Approach 1	Approach 2	Approach 3
• Container has a capacity of at least 25,000 gallons for a chemical with a specific gravity = 1.9	X	X	X
• Container is towable fully loaded with wave heights of 5 ft. at speeds relative to water of 10 kts	X	X	X
• Container will survive, in any loaded condition, in seas with wave heights of 12 kts	X	X	X
• Container has a packed weight of less than 15,000 lbs.	X	Approaches weight limit	X
• Container can be packed in 1,250 cu. ft. (8 x 6 x 26)	X	X	X
• Container can be deployed from a ship using a 1,000 lb crane	X	X	X
• Container can be ready to receive chemical in less than 4 hours	X	X	X
• Container usable at water temperatures -2°C to 30°C	X	X	X
• Container floats when initially deployed	X	X	X
• Container has a draft of less than 10 ft. fully loaded	Requires multiple flotation chambers	X	X

crane plus the effort required to add buoyancy air to the container prior to adding the chemical. All concepts require air to be added before filling with heavy chemical. All of the Approach 1 concepts require the twin cylinder to be filled to the operating air pressure. The approach 2 concept requires the air pressure to seat the beads on the rigid bulkheads. The Approach 2A concept with flexible bulkheads and both of Approach 3 concepts can be filled with air at low pressure and then allow the air pressure to be built up by pumping in the chemicals. The air supply system for the air is more associated with volume than pressure when compared to normal air compressors. Pressures range from 3 to 8 psi and air volumes range initially from 26,000 to 60,000 gallons. Selecting a ten horsepower motor for driving a centrifugal blower system will accomplish their inflation in less than one hour.

Data was used to establish the suitability of the selected materials relative to the temperature requirements.

D. Feasibility of Developing a Container with Specific Changes

1. General

In addition to determining the feasibility of developing a container for use as indicated by the requirements of 3.1, GAC investigated the effect of specific changes in the values of the parameters on the feasibility of developing a container, other considerations, and described the advantages and disadvantages of the design concepts. The order of the investigation was:

a. Determine the feasibility of developing a container for use as indicated by the 3.1 requirements except that the maximum specific gravity carried is reduced from 1.9 to 1.4.

b. Consider a variety of buoyancy methods, placements, and attachment schemes and determine the required fabric and seam strength. Buoyancy methods include separate but attachable modules and buoyancy integral to the container. The use of air inflation, precured foam products, or foam-in-place methods to be used on site will be considered.

c. Determine the maximum feasible container size (volume) for transporting a liquid with a specific gravity of 1.9 within the technical and operational requirements of 3.1.

d. Determine the maximum specific gravity that can be carried in a 25,000 gallon (U.S.) container for the technical and operational requirements of 3.1.

e. Evaluate the concept's ability to operate in a partially full state within the technical and operational restrictions stated in 3.1.

f. Evaluate whether any given volume container, designed for a specific gravity of 1.9, can hold greater volumes of lighter materials (e.g., partial flotation or utilization of portions of flotation volume).

g. Evaluate possible deployment techniques.

h. Evaluate buoyancy placements effect on hydrodynamic stability.

i. Evaluate different types of coated fabrics and meshes, seaming methods, reinforcing, and construction techniques to determine their suitability for containing the chemicals for periods up to 200 hours.

If no single existing or state-of-the-art fabric is suitable for all the chemicals listed, identify a mix of existing or state-of-the-art container materials which will provide the maximum containment probability in the minimum number of containers.

Although the container is expected to be reusable, reuse after exposure to the most corrosive of the chemicals is not a rigid requirement.

j. Evaluate the container's ability to safely contain the liquids if placed and filled on the deck of a floating barge under the environmental conditions of 3.1.

2. Feasibility of Developing a Container for Chemicals with a Maximum Specific Gravity of 1.4 while Retaining the Values of the Other 3.1 Requirements

The feasibility of developing a chemical container to the 3.1 Technical and Operational Requirements for chemicals with a specific gravity of 1.4 instead of 1.9 was investigated next for all three approaches.

a. Investigation of Approach 1 Concepts

The size of the chemical container for carrying the chemical remains the same size for chemicals with a specific gravity of 1.4 as for 1.9. The size of the buoyancy cylinder decreases because of the decrease in buoyancy requirements for the less dense chemicals.

The major elements in the operating sequence remain the same as for the chemical container designed for chemicals with a specific gravity of 1.9. The container design concepts were investigated for Approaches 1, 2, and 3 to determine the effect on the container's characteristics of reducing the maximum specific gravity of the chemical carried from 1.9 to 1.4 while preserving the values of the other 3.1 requirements. The results are presented in the same format as used in the prior subsection of this report.

Reducing the chemical specific gravity from 1.9 to 1.4 reduces the size of the flotation cylinders and reduces the pressure loadings on the chemical container fabric due to the chemical height in waves 12 feet high and the associated dynamic amplification factor. The size of the chemical container portion remains the same.

A typical container design concept was presented in Figures 14 through 19 for the heaviest chemical. The change in the container's design for chemicals with a specific gravity of 1.4 instead of 1.9 is the change in the nominal diameter of the buoyancy cylinders, from four feet to three feet. The cross-sectional shapes and the drafts of the container design concepts for the two different specific gravities were presented in Figure 13.

The towing drag for the container with the smaller diameter buoyancy cylinders is based on the drag of the chemical container plus the drags of the two cylinders considering an interference factor with the drag coefficient of the cylinders. With the smaller cylinders, 3 feet nominal diameter instead of 4 feet, the cylinders are approximately 3 feet apart. The corresponding interference factor is one. Thus, total container system drag equals $(C_{D_{CC}} \times q \times S_{CC}) + (2 \times 1.0\ C_{D_{BC}} \times q \times S_{BC})$

or $\left[.765 \times 284 \times \frac{\pi}{4} (6^2)\right] + \left[2 \times .765 \times 284\ \frac{\pi}{4}\ (3^2)\right]$ or 9,214 pounds.

Where: $C_{D_{CC}}$ and $C_{D_{BC}}$ $= .765$ @ 10 kts for $l/d > 23$

$$q = 1/2\rho V^2 = 284 \text{ at 10 kts}$$

$$S_{CC} = \frac{\pi D^2}{4} \text{ where } D = 6 \text{ feet}$$

$$S_{BC} = \frac{\pi D^2}{4} \text{ where } D = 3 \text{ feet}$$

The fabric strength requirements were calculated using the same technique as for the Approach 1 container concepts with the heaviest chemical, see Appendix A. The values taken from Appendix A for the components of the container include:

The operating air pressure (p_o) is based on the wave pressure and the resulting depth of the cylinders in the water. This pressure under static conditions results in the greatest differential pressure (Δp) and from Figure 13 equals 16.48 x 64 = 1,055 PSF or 7.33 psi. The pressure value is similar to that of the air cylinders for the container designed for the heaviest chemical. With this smaller diameter the tension in the fabric (T) is:

$$T = 24.22 \times \frac{64}{12} = 129 \text{ lbs/inch}$$

and considering a dynamic amplification factor (α) of 2, the critical stress is:

$$\sigma = \alpha T = 2 \times 129 = 258 \text{ lbs/inch}$$

Using a design factor of 4.8 instead of 4 to account for the woven "Y" joint, the ultimate fabric stress (F_{tu}) is:

$$F_{tu} = 4.8 \times 258 = 1,240 \text{ lbs/inch}$$

The operating pressure in the chemical container under static conditions was selected for design as twice the water pressure on the top of the container. The static depth is 1.6 feet and $p_o = 2 \times 1.6 \times 64 = 205$ PSF. The pressure differential under static condition (Δp_s)is one half that value or 102 PSF. The pressure differential due to the chemical's dynamic actions (Δp_d) with waves 12 feet high is:

$$\alpha' \rho H = 2 \times 1.4 \times 62.4 \times 12 = 2{,}097 \text{ PSF}$$

The total pressure differential (Δp) acting on the fabric is:

$$\Delta p = \Delta p_s + \Delta p_d = 102 + 2{,}097 = 2{,}199 \text{ PSF}$$

The critical stress (σ) is:

$$\sigma = \Delta p R = 2{,}199 \times \frac{3}{12} = 549.7 \text{ lbs/inch}$$

The ultimate stress (F_{tu}) is:

$$F_{tu} = 4 \times 549.7 = 2{,}199 \text{ lbs/inch}$$

The weights and volumes of container concepts designed for chemicals with a specific gravity of 1.4 are presented in Table 16. The total weight is 75 percent of that for containers designed for the heaviest strength requirements for the fabrics and chemicals because of the reduced area of fabric for the flotation cylinders.

The selected sequence for operating these containers are the same as for the containers designed for the heaviest chemical. The containers for chemicals with a specific gravity = 1.4 weigh less and they can be handled, deployed, towed, and retrieved more easily than containers designed for the heaviest chemical.

The twin buoyancy cylinders contain approximately one half the volume of air at approximately the same pressure as do containers with the heaviest chemical. Thus, only one half the horsepower is required to fill the cylinder in the same time period or using the same air supply system they can be fill in one half the time.

TABLE 16--WEIGHTS AND VOLUMES OF DESIGN APPROACH 1
CONTAINER CONCEPTS FOR CHEMICALS WITH A SPECIFIC GRAVITY = 1.4

Materials	Strength lbs/in	Cloth Wt. oz/sq yd	Elastomer Code-Thickness	Fabric Wt. oz/sq yd.	Fabric Area sq/ft	Weight, lbs	Volume, cu. ft.
A. 1. Fabric (Nitrile-Nylon)							
Container 29,050 Gallons	1,800	36	M-906 25 mils	91	2,639	1,668	111
Twin Air Chambers 14,332 Gallons, each	915	18	M-906 15 mils	37	2,649	681	45
2. Hose (Nitrile-Nylon)						280	20
3. Nose and Tail Fence						350	23
4. Total						2,979	199
B. 1. Fabric (Butyl-Polyester)							
Container 29,050 Gallons	1,800	36		85	2,639	1,558	111
Twin Air Chamber 14,332 Gallons each	915	18		34	2,649	625	45
2. Hose (Butyl-Polyester)						280	20
3. Nose and Tail Fence						350	23
4. Total						2,813	199
C. Fabric (Viton-Teflon) Container liner 29,050 Gallons			VT-0007	30	2,639	550	37
D. Fabric (Teflon-Glass) Container liner, 29,050 Gallons			TG-4140	20	2,639	367	25
B + C Totals						3,363	236
B + D Totals						3,180	224

Woven fabrics with less strength and less unit weights were selected for the design. The fabrication techniques investigated and selected are the same as for the Approach 1 designs for chemicals with a specific gravity of 1.9. The results from the evaluation are presented in Table 17.

b. Investigation of Approach 2 Concepts

Typical container design concepts were presented in Figures 20 through 26 for the heaviest chemical. The change in the container's design for chemicals with a specific gravity of 1.4 instead of 1.9 is the change in diameter of the container since less displacement volume is required for buoyancy. The container's diameter changes from 8.17 feet to 7 feet for the same volume of chemical.

The towing drag at 10 knots for the container with its diameter of 7 feet and a l/d of greater than 23 is:

$$\text{Drag} = C_D q S = .765 \times 284 \times \frac{\pi}{4}(7^2) = 8{,}361 \text{ pounds}$$

Where: $C_D = .765$ @ 10 kts and $l/d > 23$

$q = 1/2 \rho V^2 = 284$ PSF

$S = \frac{\pi D^2}{4}$ where D = 7 feet.

The fabric strength requirements were calculated using the same techniques as for the Approach 2 container concepts with the heaviest chemical, see Appendix B. The values taken from Appendix B for the components of the container include:

The operating air pressure that is based on the wave pressure plus that needed for maintaining the container's displacement volume when the 116 inch long compartments tilt 90° or plus that required for seating the bead in each end of the fabric on the rim of the rigid bulkheads. The selected air pressure value is 1,152 PSF considering the wave pressure and an over pressure factor for seating the beads. The air pressure is the differential pressure for static conditions (Δp_s). The pressure of the chemical on the fabric due to the action of the waves was calculated using 4.71 feet as the height of the chemical. The resulting pressure differential (Δp_d) including a dynamic amplification factor of 2 is:

TABLE 17--DESIGN APPROACHES 1, 1A, and 1B--
EVALUATION OF SELECTED MATERIALS AND CONSTRUCTION TECHNIQUES
FOR CONTAINER CONCEPTS FOR CHEMICALS WITH A SPECIFIC GRAVITY = 1.4

Woven Fabric Construction									
Selected Materials for Evaluation	Fabric Strength lb/in	Fabric Wt. oz/sq yd	Material Cost Ratio* Compared to Nitrile-Nylon 1450x1450 Fabrics	Fabrication State of Art**			Relative Equip. Req.***		
				Sew & Bond	Layup	Filament Winding	Sewing	Layup	Filament Winding
A. Container Structure 1. Nitrile-Nylon Chem. Sp. Grav. 1.4	1880	91	1.2	1	1	2	1	3	3
2. Butyl-Polyester Chem. Sp. Grav. 1.4	1880	85	1.2	1	1	2	1	3	3
B. Liner Fabric 1. Viton-Teflon	VT-0007	30	6.5	2			1		
2. Teflon-Glass	16-4140	20	1.33	2, 4 Sealing seams			UNK Sealing seams		
C. Flotation Chambers 1. Nitrile-Nylon Chem. Sp. Grav. 1.4	915	37	.85	1	1	2	1	3	3
2. Butyl-Polyester Chem. Sp. Grav. 1.4	915	34	.85	1	1	2	1	3	3

Notes:

*Direct cost ratio to Nitrile-Nylon

**1. Production Method
2. Methods are Developed
3. Can be developed
4. Research Required

***1. Minor < $10K
2. Significant $10K--100K
3. Very Significant > $100K

$$\Delta p_d = 2 \times 1.4 \times 62.4 \times 4.71 = 822.6 \text{ PSF; and the total}$$

$$\Delta p = \Delta p_s + \Delta p_d = \frac{1,152 + 822.6}{144} = 13.7 \text{ psi}$$

The critical stress and required fabric strengths are:

$$\tau = 40.88 \times 13.7 = 560.6 \text{ lbs/inch}$$

$$F_{tu} = 4 \times 560.6 = 2,242 \text{ lbs/inch}$$

The weights of each bulkhead (142 pounds) and each rim assembly (151 pounds) are also calculated in Appendix B.

The weights and volumes of container concepts designed for chemicals with a specific gravity of 1.4 are presented in Table 18. The total weights of these containers are approximately 80 percent of those for containers designed for the heaviest chemical because of the reduced fabric strength requirements and the reduced fabric area for the same chemical capacity. The weights of the bulkheads and rim assemblies are reduced because of their smaller sizes and the reduced peak pressure loadings.

The selected sequence for operating these containers are the same as for the containers designed for the heaviest chemical. The containers weigh less, are smaller, and can be handled, deployed and retrieved more easily than the containers designed for the heaviest chemical.

Approximately one half the volume of air at the same pressure is required to fill the chambers. Thus, the air supply system requirements are reduced by one half.

Uncured cord fabric with less strength and less unit weight was selected for the design. The fabrication techniques investigated and selected are the same as for the Approach 2 designs for chemicals with a specific gravity of 1.9. The results from the evaluation are presented in Table 19.

c. Investigation of Approach 3 Concepts

Typical container design concepts were presented in Figures 27, 28, and 29 for the heaviest chemical. The change in the container's design for chemicals with a specific gravity of 1.4 instead of 1.9 is the change in diameter of the container since less displacement volume is required for buoyancy. The container's diameter changes from 8.5 feet to 7.5 feet for the same volume of chemical.

TABLE 18--WEIGHTS AND VOLUMES OF DESIGN APPROACH 2
CONTAINER CONCEPTS FOR CHEMICALS WITH A SPECIFIC GRAVITY = 1.4

Materials	Strength lbs/in	Cord Wt. oz/sq yd	Elastomer Code-Thickness	Fabric Wt. oz/sq yd	Fabric Area sq/ft	Weight, lbs	Volume, cu. ft.
A. 1. Fabric (Nitrile-Nylon) Container 43,885 Gallons	2 plies @ 1,890	2 @ 15 30	M-906 25 mils	88	3,659	2,236	150
2. Bulkheads, 16 @ 142						2,279	110
3. Clamp Rings 16 @ 151						2,420	20
4. Hose and Valves						350	20
5. Nose and Tail Fence						350	23
6. Total						7,635	323
B. 1. Fabric (Butyl-Polyester) Container 43,885 Gallons	2 plies @ 1,890	2 @ 15 30	MA948 25 mils	82	3,659	2,084	150
2. Bulkhead, 16 @ 142						2,279	110
3. Clamp Rings						2,420	20
4. Hose and Valves						350	20
5. Nose and Tail Fence						350	20
6. Total						7,483	323
C. Fabric (Viton-Teflon) Container liner 43,885 Gallons				VT-0007 30	3,659	762	51
D. Fabric (Telfon-Glass) Container liner, 43,885 Gallons				TG-4140 20	3,659	508	34
B + C Totals						8,245	374
B + D Totals						7,991	357

TABLE 19--DESIGN APPROACH 2 AND 2A--EVALUATION OF SELECTED MATERIALS AND CONSTRUCTION TECHNIQUES FOR CONTAINER CONCEPTS FOR CHEMICALS WITH A SPECIFIC GRAVITY = 1.4

Two-ply Cord Fabric Construction									
Selected Materials for Evaluation	Fabric Strength lb/in	Fabric Wt. oz/sq yd	Material Cost Ratio* Compared to Nitrile-Nylon 1450x1450 Fabrics	Fabrication State of Art**			Relative Equip Req.***		
				Sewing-Bonding	Layup	Filament Winding	Sewing	Layup	Filament Winding
A. Container Structure									
1. Nitrile-Nylon Chem. Sp. Grav. 1.4	2 @ 1890	88	.89	1	1	2	1	2	2
2. Butyl-Polyester Chem. Sp. Grav. 1.4	2 @ 1890	82	.83	1	1	2	1	2	2
B. Liner Fabric									
1. Viton-Teflon	VT-0007	30	6.5	2			1		
2. Teflon-Glass	TG-4140	20	1.33	2, 4 Sealing seams			UKN Sealing seams		

Notes:

*Direct Cost ratio to Nitrile-Nylon

**1. Production Method
2. Methods are Developed
3. Can be Developed
4. Research Required

*** 1. Minor < $10K
2. Significant $10K--$100K
3. Very Significant > $100K

The towing drag at 10 knots for the container with its diameter of 7.5 feet and a l/d of greater than 23 is:

$$C_{D_{Total}} = 2 \times 0.209 + 23 \times 0.2 \times 0.209 = 1.38$$

$$\text{Drag} = C_{D_{Total}} \times q \times A = 1.38 \times 284 \times \frac{\pi}{4} \times 7.5^2 = 17{,}314 \text{ pounds}$$

The fabric strength requirements were calculated using the same techniques as for the Approach 3 container concepts with the heaviest chemical, Appendix C. The values taken from Appendix C for the components of the container include:

The operating air pressure that is based on the wave pressure plus that needed for maintaining the container's displacement volume when the segments tilt 90°. The selected air pressure value is 1,152 PSF and it is the Δp under static conditions. The pressure on the fabric due to the chemical under the actions of waves 12 feet high including the dynamic amplification factor is:

$$\Delta p_d = 2 \times 1.4 \times 62.4 \times 3.75 = 655 \text{ PSF and}$$

$$\Delta p = \Delta p_s + \Delta p_d = 1{,}152 + 644 = 1{,}807 \text{ PSF or } 12.6 \text{ psi}$$

The required ultimate fabric strength with the design factor of 4 is:

For the filament wraps,

$$F_{tu} = 4 \times \frac{12.6 \times 3.75 \times 12}{3.7321} = 608 \text{ lbs/inch}$$

For the added reinforcement,

$$F_{tu} = 4 \times 0.8703 \times 12.6 \times 3.75 \times 12 = 1{,}974 \text{ lbs/inch}$$

For the hoop wraps on the cylindrical portion of the segments,

$$F_{tu} = 4 \times 12.6 \times 3.75 \times 12(1 - .5 \tan^2 15°) = 2{,}187 \text{ lbs/inch}$$

The weights and volumes of container concepts designed for chemicals with a specific gravity of 1.4 are presented in Table 20. The total weights are approximately 75 percent of those for containers designed for the heaviest chemical because of the reduced fabric weights and the reduced fabric area for the same chemical capacity.

The selected sequence for operating these containers are the same as for the containers designed for the heaviest chemical. The containers weigh less, are smaller, and can be handled, deployed, and retrieved more easily than the containers designed for the heaviest chemical.

Approximately one half the volume of air at the same pressure is required to fill the segments of these containers. Thus, the air supply system requirements are reduced by one half.

Filament winding was selected for fabricating the design. The results of the evaluation are presented in Table 21. Concept 3A uses 10 segments developed by increasing the length of the cylindrical sections of Concept 3 concepts.

d. Feasibility of Developing a Container for Chemicals with a Maximum Specific Gravity of 1.4 while retaining the Values of the Other 3.1 Requirements

Developing a container for the heaviest chemical, within the values of the other requirements, appears feasible. Reducing the density of the chemical used for design reduces the weight and draft of the system, thus improving feasibility.

3. Buoyancy Methods

a. Full Containers

A full container of heavy chemicals requires that large volumes of water be displaced for buoyancy. For the most dense chemical, the amount of water displaced approaches twice the volume of the chemical. Quantities of compressed air, flexible foam, and rigid foams approaching the 25,000 gallon volume of the chemicals were investigated for buoyancy.

TABLE 20--WEIGHTS AND VOLUMES OF DESIGN APPROACH 3
CONTAINER CONCEPTS FOR CHEMICALS WITH A SPECIFIC GRAVITY = 1.4

Materials	Strength lb/in	Filament Weight oz/sq yd	Elastomer Code-Thickness	Fabric Wt. oz/sq yd	Fabric Area sq /ft	Weight, lbs	Volume, cu. ft.
A. 1. Fabric (Nitrile-Nylon) Container 42,965 Gallons	510 & 1800	10 & 18	M-906 25 mils	41	4,498	1,281	85
2. Domes 52 @ 7.77						404	18
3. Fittings 52 @ 4.54						236	3
4. Cable Assys 26 @ 11.3						293	5
5. Hoses and Valves						350	20
6. Nose and Tail Fence						350	23
7. Total						2,914	154
B. 1. Fabric (Butyl-Polyester) Container 42,965 Gallons	510 & 1800	10 & 18	MA948 25 mils	40	4,498	1,250	85
2. Domes 52 @ 7.77						404	18
3. Fittings 52 @ 4.54						236	3
4. Cable Assys 26 @ 11.3						293	5
5. Hoses and Valves						350	20
6. Nose and Tail Fence						350	23
7. Total						2,883	154
C. Fabric (Viton-Teflon) Container liner 42,965 Gallons				VT-0007 30	4,498	937	63
D. Fabric (Teflon-Glass) Container liner 42,965 Gallons				TG-4140 20	4,498	625	42
B + C Totals						3,820	217
B + D Totals						3,508	196

TABLE 21--DESIGN APPROACHES 3 AND 3A--EVALUATION OF SELECTED MATERIALS AND CONSTRUCTION TECHNIQUES FOR CONTAINER CONCEPTS FOR CHEMICALS WITH A SPECIFIC GRAVITY = 1.9

Filament Winding Construction				Fabrication State of Art**			Relative Equip. Req.***		
Selected Materials for Evaluation	Fabric Strength lb/in	Fabric Wt. oz/sq yd	Material Cost Ratio* Compared to Nitrile-Nylon 1450x1450 Fabrics	Sewing & Bonding	Layup	Filament Winding	Sewing	Layup	Filament Winding
A. Container Structure									
1. Nitrile-Nylon Chem. Sp. Grav. 1.9	670 & 2420	63	.60	1		2	1		2
2. Butyl-Polyester Chem. Sp. Grav. 1.9	670 & 2420	57	.55	1		2	1		2
B. Liner Fabric									
1. Viton-Teflon	VT-0007	30	6.5	2			1		
2. Teflon-Glass	TG-4140	20	1.33	2, 4 Sealing seams			UKN Sealing seams		

To provide this displacement, the selected material must withstand the pressures associated with waves 12 feet high and any other pressures associated with the design. The pressures required for buoyancy with the different conceptual approaches range from 7 to 8 psi and determine the air pressure or the density of the foam material when expanded.

Selection of the buoyancy material must also consider weight, packed volume, technical risk, storage life, cost, reuse, and operational complexity.

Compressed air has advantages relative to weight, packed volume, storage life, cost, and container reuse. Technical risk is associated with leakage and can be reduced by using multiple compartments for redundancy. Operational complexity is associated with the equipment needed to inflate the container which is not normally carried aboard U.S. Coast Guard vessels.

Flexible foam with closed cells will alleviate any leakage problem; however, the packed volume will be excessive since it requires considerable pressure to compress closed cell foam. Open cell foam can be compressed more easily; however, multiple compartments are required for redundancy in case of leakage since water can flow through the foam. Open cell foam also tends to take a set when compressed and stored for a period of time. Thus, an auxiliary means for deploying and initially extending this foam from a compressed state is required.

Foam that is generated during container deployment to inflate the volumes required for buoyancy can alleviate many of the problems associated with manufactured flexible foams. However, the foamed-in-place foams are normally rigid for the operating pressures required and are difficult to remove for retrieving, repacking, and reusing the container. Operational complexity is also associated with the equipment needed to mix and inject the foam into the buoyancy chambers.

Since all foam materials must be protected from the chemicals, all of the foams must be enclosed by a fabric cover that can withstand the chemicals and the resulting operating pressures.

The characteristics of the different materials for the buoyancy chambers are defined and rated relative to their desirability for each of the listed parameters in Table 22. Based on the characteristics and the ratings listed in the table, air was selected as the material for providing buoyancy for a full container.

TABLE 22--CHARACTERISTICS AND RATINGS OF MATERIALS INVESTIGATED FOR

BUOYANCY OF FULL CONTAINERS

Material	Air		Closed Cell Foam		Open Cell Foam		Foam In Place Foam	
Chem. Sp. Gr.	1.9	1.4	1.9	1.4	1.9	1.4	1.9	1.4
Characteristics								
Volume req. cu. ft.	3,650	1,916	3,886	2,040	3,886	2,040	3,886	2,040
Density @ 8 psi, lbs/ cu. ft.	.12	.12	4	4	4	4	4	4
Weight, lbs.	438	230	15,544	8,160	15,554	8,160	15,544	8,160
Packed Vol., cu. ft.	0	0	2,000	1,000	1,000	500	0	0
Ratings								
Technical risk	2	2	1	1	3	3	2	2
Storage Life	1	1	2	2	3	3	2	2
Cost	1	1	2	2	2	2	3	3
Container Reuse	1	1	1	1	1	1	3	3
Operational Complexity	2	2	1	1	1	1	2	2

Ratings: 1. Desirable; 2. Acceptable; 3. Not Desirable

b. Initial Buoyancy

Because of the large weights and volumes of manufactured foams required for floating full containers, its use was considered only for initial flotation and control of the container's attitude. Initial buoyancy requirements and the corresponding quantities of the foam required are presented in Table 22. The nose sections are neutrally buoyant for all design concepts.

Approach 1 designs without liners for chemicals with a specific gravity of 1.9 require 8 to 10 cubic feet of foam for initially floating the empty containers and the empty air cylinders. For systems with containers having liners 14 to 15 cubic ft. of foam are required. Approach 1 designs without and with liners for chemicals with a specific gravity of 1.4 have smaller air cylinders and require 6 to 8 or 11 to 12 cubic feet of foam, respectively.

Approach 2 designs for chemicals with a specific gravity of 1.4 or 1.9 have three inch thick bulkheads that provide more than adequate initial buoyancy.

Approach 3 designs have a considerable amount of dense hardware. Designs without and with liners for chemicals with a specific gravity of 1.9 require 26 to 27 or 34 to 36 cubic feet of foam, respectively. System designs without and with liners for chemicals with a specific gravity of 1.4 are smaller and the foam requirements are 20 to 21 or 27 to 28 cubic feet, respectively.

The locations of the foam for initial buoyancy and control of the container's attitude are presented in Figures 14, 21, and 27. The closed cell foam for Approach 1 is located in the apex of the buoyancy cylinders. The amount of foam required for neutral buoyancy with the heaviest container in the water is 11-12 cubic feet. Selecting a buoyancy factor of two, a total of 22-24 cubic feet is required. With two cylinders, each 130 feet long, the average cross-sectional area of the foam is $\frac{24}{2 \times 130}$ or .1 square feet. This amount of foam will have little effect on the ability to pack this container.

The closed cell foam for Approach 2 is associated with attitude control since the rigid bulkheads displace more water than needed for initial buoyancy. Enclosed foam pads are located on the outside of the upper portions of each segment to control roll attitude, Figure 20. Also shown are open cell foam pads that are flooded by being vented to the sea water. They are located on the outside of the lower portions of each segment to control attitude when it is partially filled. The combination of the upper and lower pads reduces and damps rolling motion.

TABLE 23--QUANTITIES OF FOAM REQUIRED TO PROVIDE

INITIAL BUOYANCY FOR EMPTY CONTAINERS

Container Approach	1				2				3			
Chem. Sp. Gr. for Design	1.9		1.4		1.9		1.4		1.9		1.4	
A. Container Structural Matl	N-N	B-P	N-N	B-P	N-N	B-P	N-N	B-P	N-N	B-P	N-N	B-P
Structural Matl Wt. lbs.	4,046	3,829	2,979	2,813	3,010	2,810	2,586	2,434	2,783	2,550	1,631	1,600
Sp. Gr. of Structural Matl	1.17	1.22	1.17	1.22	1.17	1.22	1.17	1.22	1.17	1.22	1.17	1.22
Wt. of Structural matl in Sea Water, lbs.	501	610	368	448	371	448	319	388	343	406	201	255
Vol. of foam @ 4 lb/cu. ft. req. cu. ft.	7.8	10.2	6.1	7.5	6.2	7.5	5.3	6.5	5.7	6.8	3.5	4.3
Wt. of foam req., lbs.	31.2	40.8	24.4	30	24.8	30	21.2	26	22.8	27.2	14	17.2
B. Container Hardware, Wt. lbs.	Nose and Tail				7,220		5,049		1,537		1,283	
Wt. in Sea Water, lbs.	Hardware are Self-Buoyant				-3,927		-3,608		1,209		90	
Vol. of foam @ 4 lbs/cu. ft. req. cu. ft.	-0-				Bulkheads Provide				20.2		16.5	
Wt. of foam req. lbs					Excess Buoyancy				80.6		66	
C. Liner Matl	V-T	T-G	V-T	T-G	V-T	T-G	V-T	T-G	V-T	T-G	V-T	T-G
Liner Matl wt., lbs	550	376	550	376	767	511	762	508	1,158	772	937	625
Liner Matl Sp. Gr.	1.9	2.26	1.9	2.26	1.9	2.26	1.9	2.26	1.9	2.26	1.9	2.26
Liner Wt. in Sea Water, lbs.	253	205	253	205	353	279	351	277	533	422	431	342
Vol. of foam @ 4 lb/cu. ft. req. cu. ft.	4.2	3.4	4.2	3.4	5.9	4.7	5.9	4.6	8.9	7.0	7.2	5.7
Wt. of foam req., cu. ft.	16.8	13.6	16.8	13.6	23.6	18.8	23.6	18.4	35.6	28	28.8	22.8
D. Totals N-N and Hardware Foam Vol. Req. cu. ft.	7.8		6.1		-0-		-0-		25.9		20	
E. Totals B-P, Hardware and VT liner Foam Vol. Req., cu. ft.	14.4		11.7		-0-		-0-		35.9		28	
F. Totals B-P, Hardware and TG liner Foam Vol. Req., cu. ft.	13.6		10.9		-0-		-0-		34		26.5	

The closed cell foam pads illustrated in Figure 27 are located on the outsides of the upper portion of the spherical segments for initial flotation and control of attitude. Enclosed open cell foam pads that are flooded by being vented to the sea water can be located on the outside of the lower portions of the spherical segments to provide additional stability when the segments are inflated and only partly filled. The displacement volume of the foam in the upper buoyancy pads for neutral buoyancy of the 25 segments is 34 to 36 cubic feet. Selecting a buoyancy factor of two, the displacement required per segment is $\frac{2 \times 36}{25} = \frac{72}{25} = 2.88$ cubic feet. The length of each pad on a segment is approximately four feet. Thus, the cross-sectional area is $\frac{2.88}{4 \times 4} = .18$ sq. feet.

4. Maximum Container Size for Carrying Chemicals with a Specific Gravity of 1.9 within the Technical and Operational Requirements of 3.1

a. Investigation of Approach 1

Several constraints limit the container size. Considering the weight limit first, the weights of the system were calculated versus chemical volumes for container concepts using design Approach 1, Figure 30. The calculated results indicate that a system weighing 15,000 pounds, including a provision for a 25 percent weight growth, can be designed to carry approximately 70,000 gallons of chemical with a specific gravity of 1.9. The second limitation investigated was the draft of the system versus container volume. The results indicate that the draft limit of 10 feet is reached for this design when chemical volume is approximately 36,000 gallons. The draft of the design at the weight limit is 13.7 feet. The volume limit based on 15-20 pounds per cubic feet is less demanding than the limits on weight or draft for this design.

The operational requirements of handling the 15,000 pound container system with a crane with a 1,000 pound lifting capacity appears possible since this container is approximately 190 feet long and can be folded on a pallet so the folds can be faked into the water within the crane's capacity.

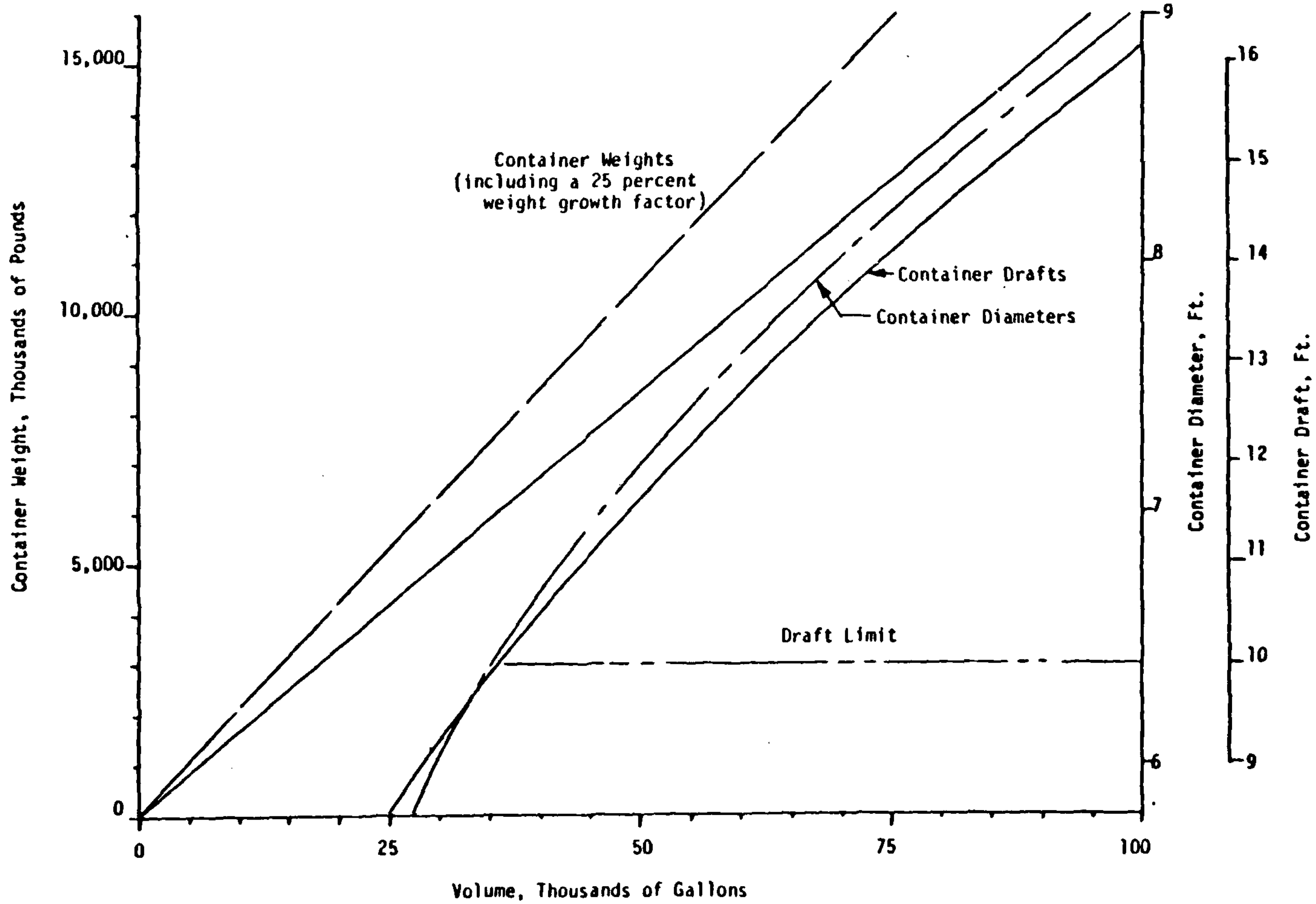


FIGURE 30--DESIGN APPROACH 1--CALCULATED CONTAINER WEIGHTS AND DRAFTS VERSUS CHEMICAL VOLUMES FOR CHEMICALS WITH A SPECIFIC GRAVITY = 1.9

b. Investigation of Approach 2

Design Approach 2 with rigid bulkheads is presently near the weight limit and wasn't investigated for larger capacity.

c. Investigation of Approach 3A

Design Approach 3 concepts have weights similar to Approach 1 concepts for the 25,000 gallon size. Approach 3 was investigated as modified to 3A, ie, a series of wound cylinders attached together in the same manner as the original wound spheres. This approach was chosen over making larger spheres or adding more spheres. Larger spheres result in a blunt, large drag system. Using more spheres of the original size results in weights that increase at a rate faster than the volume increases because of the increased drag and corresponding loads and weights of the cables and assembly hardware in the forward spheres. The weight constraint for the modified configuration was investigated by calculating container weights versus volume for chemicals with a specific gravity of 1.9. The calculated results are presented in Figure 31. The calcualted results indicate that a system weighing 15,000 pounds, including the 25 percent weight growth provisions, can carry approximately 110,000 gallons of chemical with a specific gravity of 1.9.

The second limitation investigated was the draft of the system versus chemical volume. The draft limit of 10 feet is reached when the chemical volume is 55,000 gallons. The draft corresponding to the weight limit is 12 feet. The other operational limits can be met with this design.

5. Maximum Specific Gravity that can be Carried in a Chemical Container Designed for 25,000 Gallons Within 3.1 Requirements

All three design approaches result in container concepts that can carry 25,000 gallons of chemical with a specific gravity of 1.9. If denser chemicals are to be carried, then the volumes of the chemical has to be reduced.

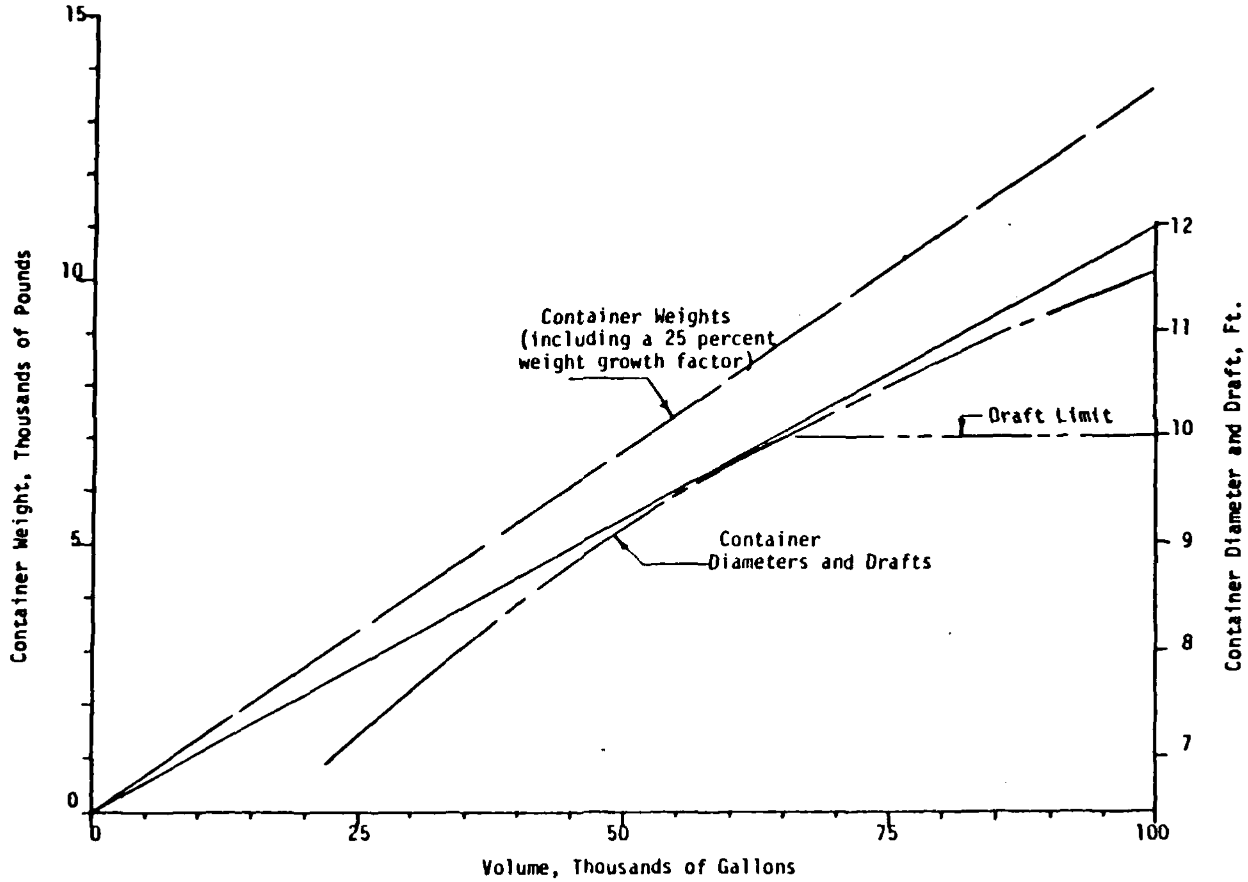


FIGURE 31--DESIGN APPROACH 3A--CALCULATED CONTAINER WEIGHTS AND DRAFTS VERSUS CHEMICAL VOLUMES FOR CHEMICALS WITH A SPECIFIC GRAVITY = 1.9

a. Investigation of Approach 1

For Approach 1 the buoyancy consists of the weight of water displaced by the chemical, the air cylinders, and the container material; and it is equal to the weight of the chemical, the air, and the container material or:

$$64\left(\frac{\text{Gallons of Chem.}}{7.481}\right) + 64\left(\frac{\text{Vol. of the Air Cyl., Gals.}}{7.481}\right) + 64\left(\frac{\text{Wt. of the Container}}{\text{Density of Material}}\right)$$

$$= 62.4 \times \text{Sp. Gr. of Chem}\left(\frac{\text{Gallons of Chem.}}{7.481}\right) + .12\ (\text{Vol. of the Air Cyl.}) + \text{Wt. of}$$

$$\text{Container, or Gals of Chem}\left(1 - \frac{62.4}{64}\gamma\right) = \text{Gals of Air}\left(\frac{.12}{64} - 1\right) + 7.481\ \text{Container}$$

$$\text{Wt}\left(\frac{1}{64} - \frac{1}{62.4\rho}\right) \quad ; V_c\ (1 - .975\gamma) = V_{air}\ (-.998125) + 60,\ \text{gals.}$$

Where: γ = Chem. Sp. Gr.

ρ = Container Material Density

Vol. of chem $\leq$ 25,000 gallons

Vol. of air = 21,294 gallons

Using no excess of air for buoyancy, the chemical volume that can be carried was calculated for a system sized for 25,000 gallons. No more than 25,000 gallons can be carried because of the size of the chemical compartment. The calculated results are presented in Figure 32. The amount of chemical that can be carried decreases from 25,000 gallons of chemical with a specific gravity of 1.9 to 11,000 gallons with a specific gravity of 3.0. The decrease is at a rapid rate since the chemical portion of the container contracts, thus displacing less water with the denser chemicals.

b. Investigation of Approaches 2 and 3

Approaches 2 and 3 use pressurized air within the chemical compartment for buoyancy. Thus the volumes of air and chemical can be traded off from a buoyancy standpoint within the total container volume (air + chemical); that is, 25,000 gallons of chemicals with specific gravity of 1.9 is 25,000 + 21,294 or 46,295 gallons total.

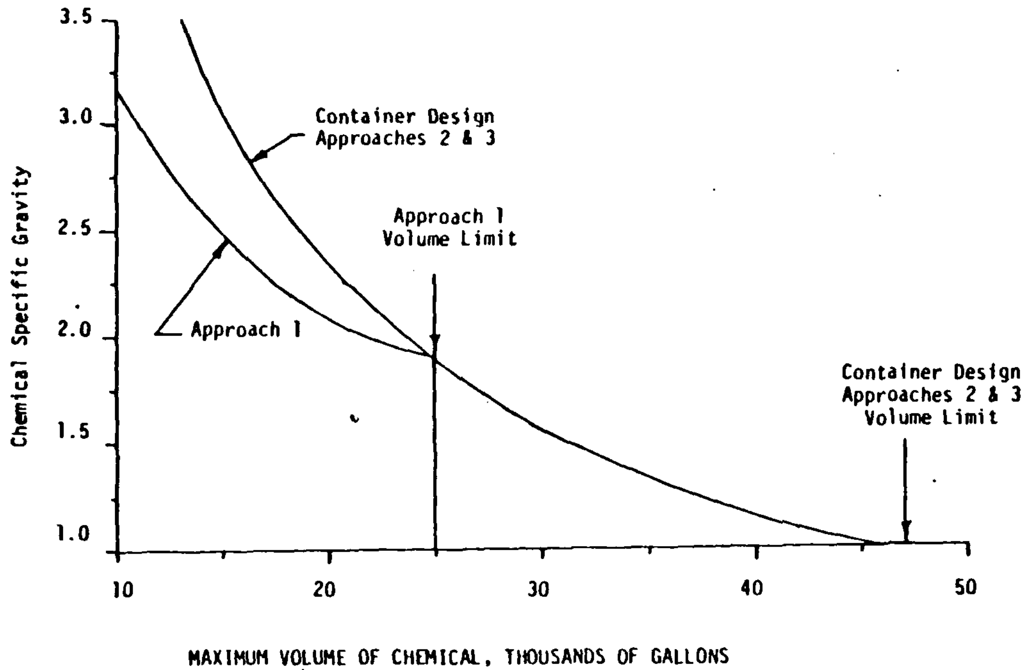


FIGURE 32--DESIGN APPROACHES 1, 2, AND 3--
MAXIMUM VOLUMES OF CHEMICALS VERSUS CHEMICAL SPECIFIC GRAVITY FOR CONTAINERS DESIGNED FOR 25,000 GALLONS OF CHEMICALS WITH A SPECIFIC GRAVITY = 1.9

The calculated number of gallons of chemicals versus chemical specific gravities for design Approaches 2 and 3 container concepts are presented in Figure 32. Approximately 46,000 gallons of chemical with a specific gravity of one can be carried in the container designed for chemicals with a specific gravity of 1.9. Approximately 16,000 gallons of a chemical with a specific gravity of 2.9 can be carried by the same containers.

6. Operation While Partially Filled

The results presented up to this point are for operation of the containers while full. The effect of operating these same designs when partially full is discussed in this subsection.

a. Investigation of Approach 1

This configuration has been presented as a single chemical compartment, is filled by one hose, and a pair of air cylinders are inflated individually using one or two air lines. This simple form requires that the twin air cylinders be completely inflated and pressurized before partly filling the container with heavy chemicals because the heavy chemicals will flow to the lowest portion of the container. The chemical will continue to flow to the lowest portion of the container until that portion is filled. The twin flotation cylinders at the design operating pressures will prevent any full region from sinking to a depth where the pressure is greater than the pressure within the buoyancy cylinders.

The twin buoyancy cylinders during tow will be full and semi-rigid at the design operating pressures. The partially full system will tow with a shape that is curved, ie, the nose will be near design depth since the nose has its own flotation; the forward empty portion of the container will ride at less than design depth because of the excess buoyancy of the air cylinder; and the rear portion of the container will operate at design depth since that portion of the container will be full. There will be some reduction in drag. However, the amount is difficult to estimate and will have to be determined empirically.

b. Investigation of Approaches 2 and 3

These approaches have integral chemical/air chambers. As was discussed in Subsection C-3 for full containers, the chambers require increasing air pressures over the design value as the number of compartments are decreased, Figure 20. The same trend applies to the partially filled container. With one compartment,the heavy chemical can flow to one end, thus sinking that end and the air above the chemical to a depth that will compress the air and reduce the buoyancy for the container. A family of curves presenting the pressures required versus the number of compartments can be calculated based on the ratio of the chemical volume at partial fill to rated volume of the container for this chemical. The calculated results assuming all compartments are equally filled with chemicals having a specific gravity of 1.9, are presented in Figure 33.

Partially filled containers of design Approach 2 and 3 are pressurized to maintain the shape of the compartments or segments under the actions of waves 12 feet high and the chemicals flowing to one end of a segment. If the chemicals are loaded equally into each segment, the container segments will operate at less than design depth. The nose with its flotation will operate nearer design depth. The drag of the containers will be associated with the container have its shape but operating at less than design depth. The ratio of the drag of the partially filled to the maximum filled container can also be approximated by calculating the ratio of their cross-sectional areas in the water.

7. Maximum Volume of Lighter Chemicals that can be Carried in a Container Designed for 25,000 Gallons of Chemicals with a Sp. Gr. of 1.9

The maximum volumes of lighter chemicals that can be carried in container concepts following Design Approaches 1, 2, and 3 are also presented in Figure 32. Approach 1 design concepts are limited by the size of the chemical container, ie, 25,000 gallons. Thus, no increase in chemical volume is available for the lighter chemicals. Concepts using Approches 2 and 3 have integral chemical/air flotation, thus greater volumes of the lighter chemicals and lesser volumes of air can be carried. The maximum volume, however, is limited to approximately 46,000 gallons by the container's maximum dimensions. The chemical specific gravity corresponding to this volume is a little less than one.

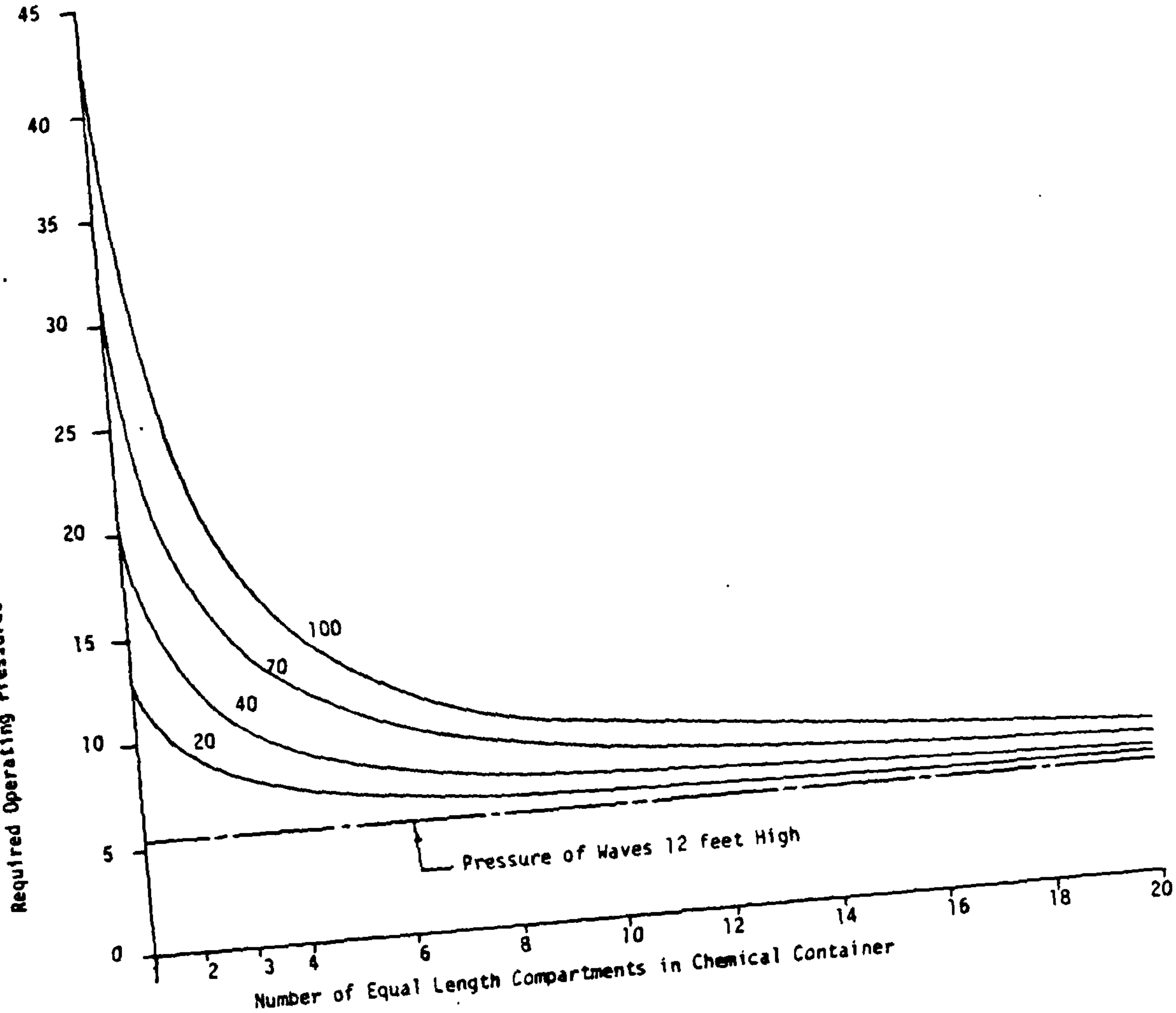


FIGURE 33--DESIGN APPROACHES 2 AND 3 WITH INTEGRAL AIR FLOTATION OPERATING PRESSURES REQUIRED VERSUS NUMBER OF EQUAL LENGTH COMPARTMENTS OR SEGMENTS PARTIALLY FILLED OF CHEMICAL WITH A SPECIFIC GRAVITY = 1.9

8. Evaluation of Possible Deployment Techniques

The length of the containers, their flexibility, the size of the package for transporting the container, and the limited capacity of the crane led to the concept of accordion folding the container such that the folds can be flaked into the water by lifting only some portions of the many folds at one time. This approach also lends itself to deploying the containers by pulling and extending them a fold at a time, using the force of a separate craft or drag devices trailing the craft carrying the packed containers.

Once the containers are extended, air is added so they take their shapes. The twin buoyancy cylinders of design Approach 1 concepts will orient and control the overall length of the container. At operating pressure the cylinders will be semi-rigid so the system will be stretched out and hanging between them. The container will fill out as the chemical is added. The container will remain horizontal under static conditions because the cylinders have sufficient buoyancy for a full container.

Container concepts of design Approaches 2 and 3 take their final shapes as they are filled with air. Air is compressed and bled-off as the chemical is added. They reach their capacity when they are approximately one half filled with chemicals with a specific gravity of 1.9.

9. Evaluation of Buoyancy Placements on Hydrodynamic Stability

The distribution of buoyancy along the length of the container is essentially uniform for controlling the shape and the pitch attitude of the container. The buoyancy cylinders of Approach 1 concepts attempt to keep the chemical container straight and horizontal. The air pressure in the multiple compartments of Approach 2 concepts also attempt to keep the container straight and horizontal. The air pressure in the segments of Approach 3 concepts will tend to keep the segments on the surface; however, the container is free to bend at the joints of each segment.

The distribution of buoyancy along the length of the container controlling roll is the placement of the flotation strips for initial buoyancy, outboard of the container centerliner, and near the water's surface. The twin air cylinders of Approach 1 concepts greatly increase its roll stability. Inflation of Approach 2 and 3 concepts doesn't add to their roll stability. Flooded strips are illustrated low in the water for Approach 2 designs to help control the amount of roll, Figure 21.

The shape of the nose, its buoyancy, and the tow point are chosen to limit diving actions during tow.

The shape of the tail with its drag fence is to limit snaking actions during tow.

10. Evaluation of Different Types of Coated Fabrics and Construction Techniques for Fabricating Containers Suitable for Up to 200 Hours Exposure to the U.S. Coast Guard Listed Chemicals

The evaluation and selection of coated fabric suitable for fabricating a minimum of chemical containers using state-of-the-art techniques are presented in Subsection II-B.

Background on construction techniques is presented in Subsection II-A.

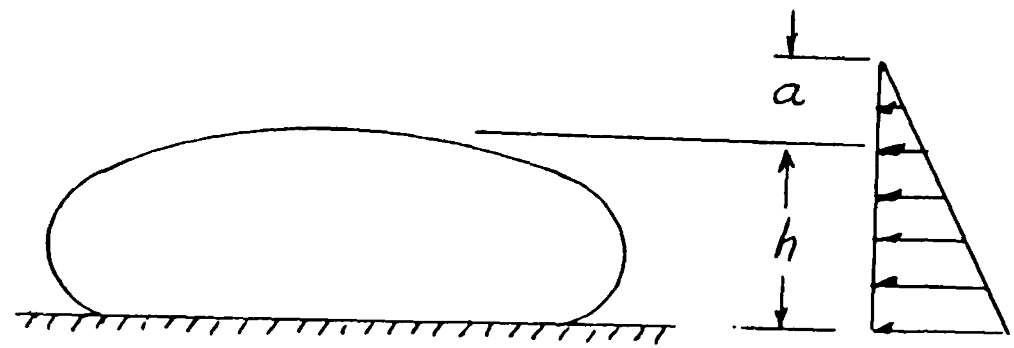
11. Evaluation of Container's Ability to Safely Contain Liquids if Placed and Filled on the Deck of a Floating Barge under the Environmental Conditions of 3.1 Requirements

The ability of safely using containers on a barge that is designed for use in the water with 25,000 gallons of chemicals with a specific gravity of 1.9 was investigated for container concepts of design Approaches 1, 2, and 3. The barge was assumed to reach an angle of tilt so the difference in heights of the two ends equaled the wave height. The length of barge equaled 150 feet. The method of analysis for determining the static tensions in the fabric of a container in a barge is presented in Reference 3 and are related to size and percent of fill, Figures 34 and 35.

The sum of the static stress and the stress due to dynamics was set equal to the fabric stress used for the design of each of the three containers. The dynamic stresses are less for Approaches 2 and 3 then for Approach 1 because the lengths are less; that is, the same tilt angle of the barge results in smaller differences in chemical heights within the shorter segments or compartments and thus less dynamic stresses. The fill percentage based on the allowable static stresses were calculated, and the results are presented in Figure 36.

12. Summary of the Feasibility of Developing a Container with Changes to the Values of the 3.1 Requirements and Other Considerations

The results of the efforts presented in this subsystem are summarized in Table 24. Approach 1 results in container concepts that meet the requirements



- PERIMETER = πD
- PERCENT FILLING = $100 \dfrac{(a+h)^2(F-2E)+a^2F}{\frac{\pi D^2}{4}}$

WHERE F, E = COMPLETE ELLIPTIC INTEGRALS OF THE FIRST AND SECOND KIND

FIGURE 34--PARAMETERS FOR FLEXIBLE CONTAINERS ON A FLEXIBLE BARGE

- $D = 1$ FT.
- S. G. $= 0.8$
- STRESS

$$\sigma = \frac{\rho D^2}{4}\frac{h}{D}\left(1 + \frac{h}{a+h}\right)$$

WHERE:

$$\frac{h}{D}\left(1 + \frac{h}{a+h}\right) = f_{\text{(PERCENT FILLING)}}$$

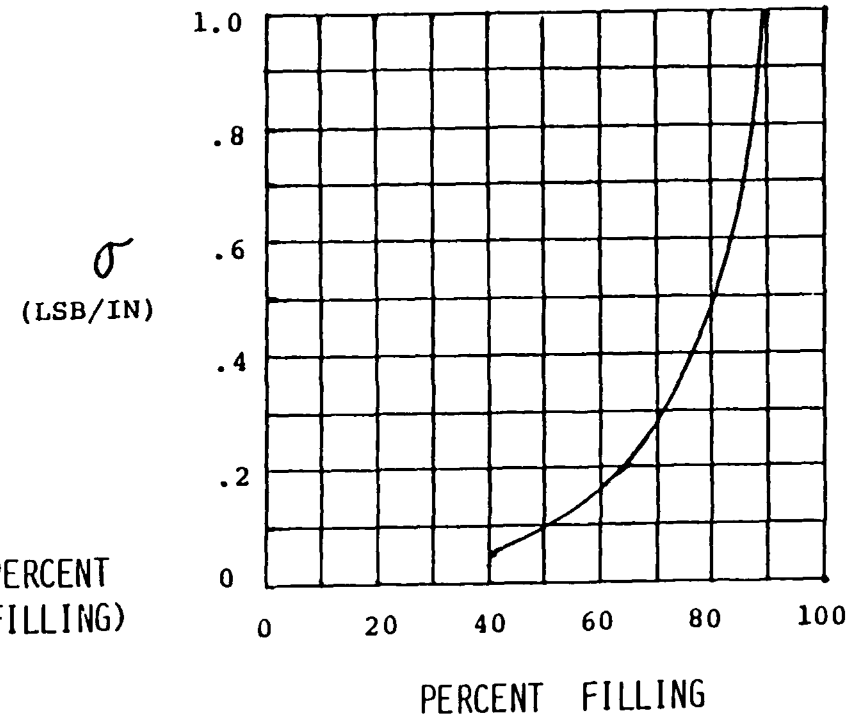


FIGURE 35--FABRIC STATIC LIMIT STRESSES VERSUS PERCENT FILL

- USE THE BARGE BASED STRESS CURVE (FIG. 35)

- CURVE STRESS = $\left(\frac{0.8}{\gamma D^2}\right)$ x STATIC LIMIT STRESS (FLOATING ANALYSIS)

CONFIG.	D FT.	γ = RATIO S. G.	PRESSURE, PSF STATIC	PRESSURE, PSF STATIC + DYNAMIC	LIMIT STRESS, LBS/IN STATIC + DYNAMIC	LIMIT STRESS, LBS/IN STATIC	(FIG. 35) CURVE STRESS LBS/IN	PERCENT FILLING
1	6	1.9	208	3053	763	52	0.67	84
		1.4	102	2199	550	26	0.41	78
2	8.2	1.9	1152	2338	664	327	2.06	100
	7	1.4	1152	1975	561	327	3.8	100
3	8.5	1.9	1152	2160	738	394	2.3	100
	7.5	1.4	1152	1807	547	349	3.6	100

FIGURE 36--ALLOWABLE PERCENT FILL BASED ON CONTAINER FABRIC STRENGTHS

TABLE 24--FEASIBILITY OF DEVELOPING A CONTAINER WITH CHANGES TO THE VALUES OF THE 3.1 REQUIREMENTS AND OTHER CONSIDERATIONS

Requirements and Other Considerations	Approach 1	Approach 2	Approach 3
• Container has a capacity of at least 25,000 gallons for chemical with a Sp. Gr. = 1.4 within the 3.1 Requirements	Yes	Yes	Yes
• Acceptable Buoyancy Methods	Yes	Yes	Yes
• Container Sizes Greater than 25,000 gallons of Sp. Gr. = 1.9 Chemical are possible	Yes	Yes Limited Increase with Rigid Bulkheads	Yes
• Specific Gravities greater than 1.9 can be carried in Design for 1.9	Yes Reduced Volume	Yes Reduced Volume	Yes Reduced Volume
• Operation Possible at Partial Fill	Yes Reduced Speeds	Yes	Yes
• Design for 1.9 can carry greater volumes of lighter materials	No	Yes	Yes
• Deployment is possible with 1,000 lb. crane	Yes	Yes	Yes
• Hydrodynamic stability can be acceptable by proper placement of buoyancy	Yes	Yes	Yes
• Coated Fabrics can be fabricated into containers that are compatible with the U.S. Coast Guard List of Hazardous Chemicals	Proper selection of two unlined containers can probably carry 29 of the 35 chemicals. Proper selection of two containers, one unlined and one lined, can probably carry all 35 chemicals		
• Container can be filled and safely contain liquids if placed on deck of a barge	Yes, 80 percent of Rated Capacity	Yes, 100 percent of Rated Capacity	Yes, 100 percent of Rated Capacity

with some limitations. Some of the limitations apply to the specific designs, ie, (1) reduced volumes of chemicals with specific gravities greater than 1.9 can be carried in containers designed for chemicals with a specific gravity of 1.9; or (2) no greater volumes of lighter chemicals can be carried because of the volume limit of the specific container design. Towing speed at partial fill may be limited because of the amount of loose fabric. The operation of the system on a barge is possible at some reduced capacity.

The limitations of Approach 2 are associated with weight, if rigid bulkheads are used and which carry a lesser volume of chemicals with specific gravities greater than 1.9.

The limitation of Approach 3 is associated with carrying a lesser volume of chemicals with specific gravities greater than 1.9.

E. Effect of Variations in the Values of 3.1 Requirements on the Feasibility of Developing a Container

GAC investigated the effect of varying the values of 3.1 Requirements to determine which requirement values have the greatest impact on concept feasibility. The values of the following parameters were evaluated for concept sensitivity by:

1. Variations in towing speed and/or wave height guidelines.
2. Increasing the packageable weight and/or size limitations.
3. Variations in survivability condition.
4. Advances in the state-of-the-art fabric and/or seam strength.
5. Variations in set-up time.
6. Availability of a ship with 20,000-pound lifting capability for deployment (Buoy Tender).
7. Increasing limiting draft.
8. Variations in the 200-hour containment goal.

One parametic value that significantly affects the values of the other parameters is that for the specific gravity of the chemical selected for designing a 25,000 gallon container. The effects of the selected value on material strength requirements, container weights and packed volumes, towing force, draft, and the possible container volume capabilities for chemicals with other specific gravities are presented in Figure 37, 38, and 39 for design Approaches 1, 2, and 3, respectively. The same scales are used in all three figures for the same parameters. Thus the relative heights of the curves and their slopes indicate the significance of each parameter and its sensitivity to changes in the value of the specific gravity used for design.

The drag at 10 knots increases with increasing specific gravity of the chemical used for designing a 25,000 gallon container because more water must be displaced to support the same volume of the denser chemical. Thus the containers become larger, displace more water, and have more drag. The drag is made up of a shape-drag coefficient, the cross-sectional area of the container, the density of the fluid that the container is towed through, and its relative velocity squared.

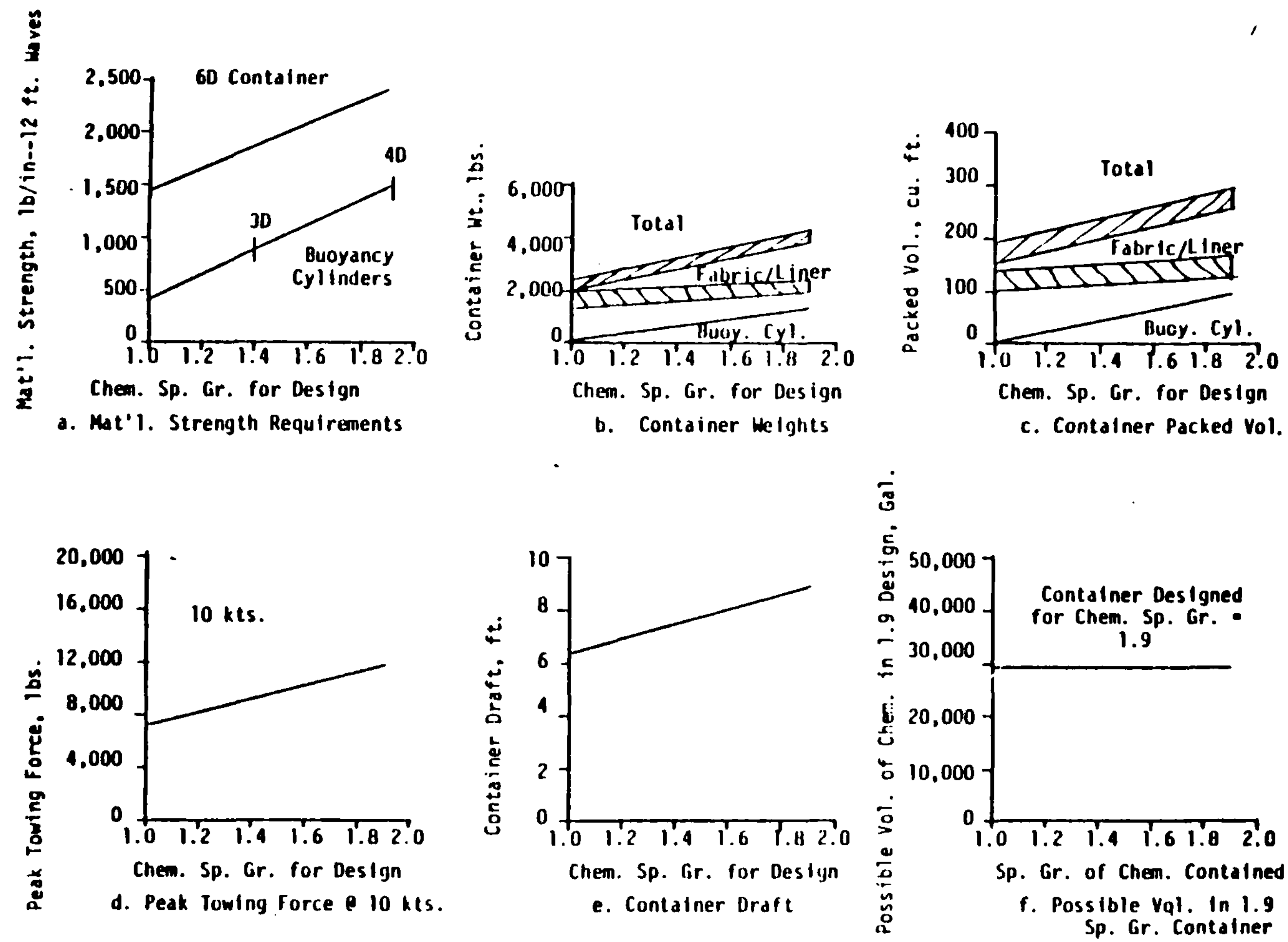


FIGURE 37--DESIGN APPROACH 1--EFFECT OF CHEMICAL SPECIFIC GRAVITY SELECTED FOR DESIGN ON OTHER DESIGN VALUES

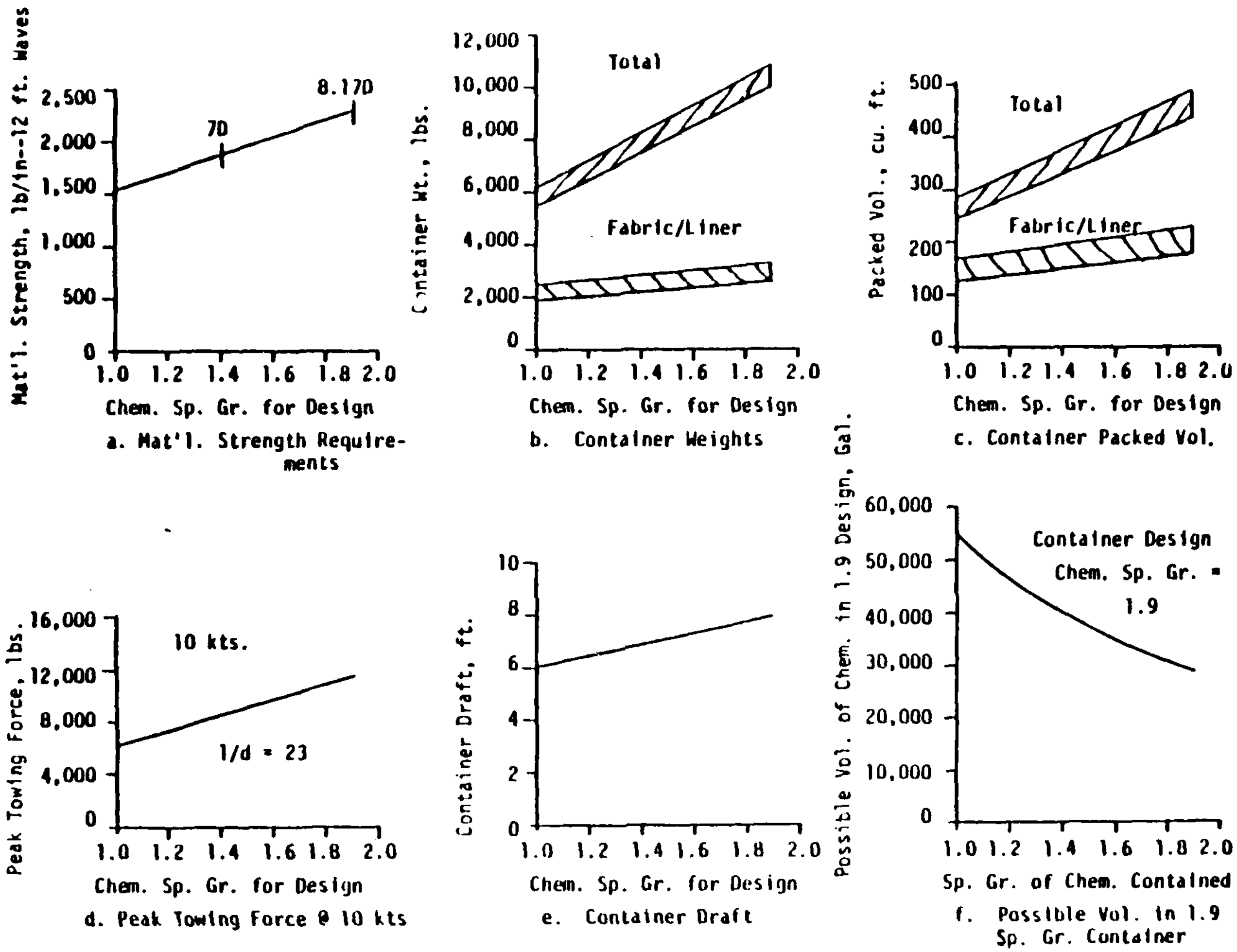


FIGURE 38--DESIGN APPROACH 2--EFFECT OF CHEMICAL SPECIFIC GRAVITY SELECTED FOR DESIGN ON OTHER DESIGN VALUES

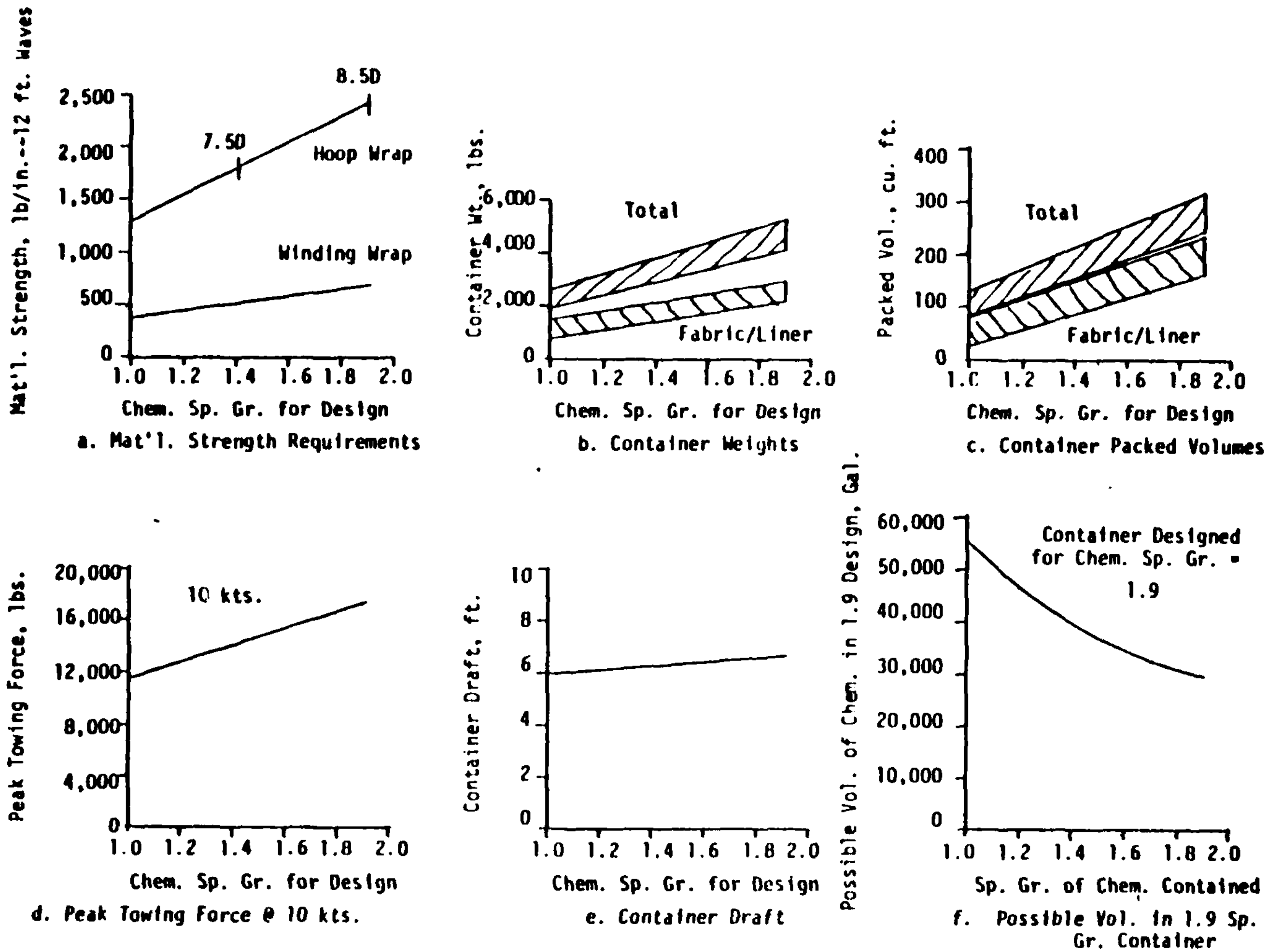


FIGURE 39--DESIGN APPRAOCH 3--EFFECT OF CHEMICAL SPECIFIC GRAVITY SELECTED FOR DESIGN ON OTHER DESIGN VALUES

For a given velocity, drag is associated with the shape factors and the cross-sections of the containers associated with the designs for different specific gravities. The drag of the Approach 3 concept is the greatest because of large C_D for its shape factor and its large cross-sectional area.

The effect of wave height is reflected in the required strengths of the fabric materials. The dynamic portion of the design pressure differential as a function of the amplification factor, the specific gravity of the chemical and the wave height, ie, $\Delta p_d = \propto(S.G.)62.4 \times H$, PSF. Thus for containers with small static operating pressures, Approach 1 containers, the container's fabric weight is nearly directly proportional to wave height or chemical specific gravity. For containers with larger static operating pressures, Approaches 2 and 3 containers, the container's fabric weight is less than directly proportional to wave height or chemical specific gravity.

Advances in the state-of-the-art of structural materials for design Approaches 1, 2, and container concepts are not required. Some engineering is required to develop efficient lap seams with design Approach 1 container concepts.

The state-of-the-art of materials for containing all of the listed chemicals for 200 hours has not been completely demonstrated. An approach using two containers of different materials and providing a liner in one for the strong acids is the combination nearest to the state-of-the-art for containing the chemicals based on available knowledge.

The weights and volumes of the containers indicate that they can be made within the limits of transportation weights and volumes. The only container concept approaching the weight limit is design Approach 2 with rigid bulkheads. Thus no increase in the weight or volume limit appears necessary.

The survivability condition is associated with wave heights which affects the dynamic portion of the design pressure differential discussed earlier. The container concepts were designed to survive the actions of waves 12 feet and, thus changes to this condition are not necessary.

Changing the time period for setting up the container is associated with the deployment time and the inflation time to provide buoyancy and stability before the chemical is loaded. Deployment times are associated with how the system is packed for deployment and how many separate events must be handled by the crew. With reasonable effort, a technique to deploy the system can be developed that limits the handling by the crew members. For instance, large parachute systems are deployed by the single action of a separate drag device.

The second portion of the set-up time is associated with inflating the buoyancy systems. Calculations indicate that a 10 horsepower system can accomplish this within one hour. The diameters and lengths of the inflation hose will affect the inflation times.

The availability of a crane with 20,000 pound lift capability would allow placing the total package overboard and deploying the container by pulling it, a fold at a time, off its pallet.

Increasing the draft limit allows the use of a single buoyancy cylinder with design Approach 1 concepts. The drafts of these concepts with single and twin cylinders are presented in Figures 12 and 13. Thus increasing the draft limit isn't a priority item.

The effect of changing the 200 hour containment goal is difficult to determine at this time because the compatibility data are not necessarily presented versus time. Gross changes in containment times are necessary before the ratings listed in Subsection II-B can be changed.

The results in this subsection are summarized in Table 25.

TABLE 25--EFFECTS OF VARIATIONS IN THE VALUES OF 3.1 REQUIREMENTS ON THE FEASIBILITY OF DEVELOPING A CONTAINER

• Towing Speed	--Drag is a function of velocity squared, a container shape factor, and the container cross-sectional area.
• Wave Height	--Pressures due to dynamic actions--fabric stress and fabric weight are related to wave height.
• Increasing Packageable Weight and/or Size Limitations	--Not required considering other 3.1 requirements.
• Survivability Condition	--Associated with acceptable wave height, 12 feet, used for design.
• Advances in State-of-Art	--Fabric structures of the required strengths can be made using state-of-art methods. Seams are only associated with Approach 1. Sewing requires some development to obtain seams with good efficiencies.
• Variations in Set-up Time	--Changing the four-hour time limit affects the deployment technique and the diameter of the inflation hoses.
• Availability of 20,000 lb. Lift Capability	--Not required. However, total pallet can be lifted.
• Increasing Draft Limit	--Associated only with Approach 1. Design with a single buoyancy cylinder becomes possible.
• 200-hour Containment Goal	--Data limited to gross time changes of exposure.

F. Description of the Advantages and Disadvantages of the Different Candidate Concepts

Items selected for describing the advantages and disadvantages of the container concepts designed using the three different approaches are presented in Table 26. The values presented are based on judgments. Operational and state-of-the-art factors are presented. The ratings for the operational factors are based on judgments of how much more difficult it is to operate these different container concepts than it is to operate a system designed for chemicals with a specific gravity of one. Ratings are from 1 to 5 and ratings of 1 = the same difficulty; 3 = several times the difficulty; and 5 = an order of magnitude increase in difficulty. The operational factors include: transportability, training, deploying (including special equipment), towing, discharging, retrieval, and refurbishing (including repacking and operating while partially filled).

Transportability is based on the packed weight and the packed volume of the container. Container weights range from two to five times the weights of a container designed for chemicals with a specific gravity of one. The packed volumes are also related to the weights. Thus the ratings are associated with the relative weights of the containers.

More difficulty in training is associated with teaching the added operations associated with providing buoyancy, controlling air pressures, filling/discharging, and refurbishing the containers. All designs require the crew to operate an air system and some containers require multiple connections. Training effort is judged to be two to three times that required for container designed for chemicals with a specific gravity of one.

The difficulty of deploying the container is associated with placing it into the water, extending it, and adding all of the air for flotation prior to loading the chemical. The difficulty of placing it into the water is associated with the container's weight, its flexibility, and the technique used to pack the container. Weight was used as the basic criterion. Extending the container to its length should be of the same order of effort for all containers. Adding air to the containers is associated with number and location of fill points.

TABLE 26--ADVANTAGES AND DISADVANTAGES OF CONCEPTUAL DESIGN APPROACHES 1, 2, and 3 FOR CONTAINING CHEMICALS WITH A SPECIFIC GRAVITY OF 1.9--CONSIDERING OPERATIONAL AND STATE-OF-THE-ART FACTORS

Factors	Approach 1 Single Chemical Containers With One Compartment and Twin Air Cylinders			Approach 2 Container has Multiple Bulkheads and Integral Buoyancy		Approach 3 Container has Multiple Segments and Integral Buoyancy	
	1	1A	1B	2	2A	3	3A
Operational--Relative to a Single Container Designed for Sp. Gr. = 1.0							
--Transportability	2	2	2	4	2	2	2
--Training	2	2	2	3	2.5	3	2.5
--Deploying	2	2	2	3	2.5	4	2.5
Filling--Function	1	1	1	2	2	3	2
--Personnel Exposure	1	1	1	3	1.5	3	1.5
Towing--Stability	2	2	2	1.5	1.5	1.5	1.5
--Operating Partially Filled	2	2	2	1.5	1.5	1.5	1.5
Discharging--Function	1	1	1	2	2	3	2
--Personnel Exposure	1	1	1	3	1.5	3	1.5
Retrieving	2	2	2	3	2.5	3	2.5
Refurbishing	2	2	2	3	3	3	3
Fabrication State-of-the-Art							
--Construction with Selected Materials	1	1	1	1	1	3	3
--Obtaining Seam Strengths	2	1	2	1	1	1	1
--Retaining Seam Strengths	1	3	1	1	1	1	1

The difficulty of filling the container with chemicals is associated with the number of fill points and any other operations necessary to accomplish filling. The basic Approach 2 design has a single point for filling but requires a specific filling sequence. Approach 3 has many filling points. Approaches 2A and 3A have single fill point manifolds to the compartments or segments.

The difficulty of limiting the exposure of personnel to the chemicals is associated with the number of hose connections to be made and whether the men might be exposed to spilled chemicals in the water. Containers with single fill points for the air and for the chemical were judged to have exposure potentials equal to the present systems. Concepts with multiple fill points or complex filling systems were judged to increase the exposure potential.

Towing difficulty is associated with container stability during tow when it is filled to capacity and when it is partially filled. Approach 1 container design configurations have not been tested. Tests will be required to develop the nose and bridle shapes for successful towing.

The discharging function is similar to the filling function and the same ratings are repeated.

The relative difficulty of retrieving the containers is associated with their weight and the amounts of rigid items that must be stacked onto a deck with a crane. The ratings are similar to those for deployment.

The relative difficulty for refurbishing the containers is related to cleaning, checking out, repairing, and repacking them considering any special equipment. The difficulty of cleaning the containers may be similar for those with one large or many smaller compartments. Checking out the container will require an air supply system not normally available. Factory air supplies are low volume, high pressure systems and will require long time periods and excessive horsepower to accomplish the check-out task. Repairing the containers with single compartments will be more difficult than repairing containers with the smaller compartments or segments. In fact, a badly damaged compartment or segment can be removed from the container for operation at a reduced capacity. Difficulty of repacking the containers is associated with weight and the amount of rigid items.

Fabrication state-of-the-art ratings consider the state-of-the-art for constructing containers of these high strength materials, the state-of-the-art of seam strengths, and the state-of-the-art for retaining seam strength after immersion in the different chemicals. Approach 1 concepts are made from woven cloth and require seams. The basic fabrication process is state-of-the-art with the selected materials or rating of 1. Developing good efficiency seams with the greater strength fabrics will take engineering efforts, 1.5 rating. Sewn seams are expected to retain an acceptable portion of their initial load capability after chemical exposure, 1.0 rating. The ability of two-ply fabric construction with its very large, unsewn lap seams to withstand the chemical action is unknown, and it is given a 3 rating for this factor.

Approach 2 concepts are layed-up using cord fabric and the process is state-of-the-art for these strong materials. No seams are involved, thus 1 ratings are indicated.

Approach 3 concepts are filament wound, and the process needs more engineering development with the materials chosen and a 3 rating is indicated. No seams are involved, thus the corresponding ratings are 1.

The values in Table 26 have not been totaled because the relative importance of each of the factors listed has not been established. In general, the container concepts resulting from design Approach 1, 1A, 1B, 2A, and 3A appear to be the most desirable.

Physical factors can also be used to rate the different container concepts. This was done and the results are presented in Table 27. The values presented are based on the values of ratios calculated using the value for that factor for a container concept designed for chemicals with a specific gravity of 1.9 and the corresponding value for a container designed for chemicals with a specific gravity of one. The ratios were set up for each factor so that values greater than one indicate it is less desirable, and values less than one indicate it is more desirable than a container designed for chemicals with a specific gravity of unity.

The ratings for draft were calculated from the draft of the concepts for chemicals with a specific gravity of 1.9 divided by the draft of a concept for chemicals with a specific gravity of 1, or 6 feet.

FIGURE 27--ADVANTAGES AND DISADVANTAGES OF CONCEPTUAL DESIGN APPROACHES 1, 2, AND 3 FOR CONTAINING CHEMICALS WITH A SPECIFIC GRAVITY OF 1.9--CONSIDERING PHYSICAL FACTORS

Physical Factors Relative to a Con-Container Designed for Sp. Gr. = 1.0	Approach 1 Single Chemical Containers With One Compartment and Twin Air Cylinders			Approach 2 Container has Multiple Bulkheads and Integral Buoyancy		Approach 3 Container has Multiple Segments and Integral Buoyancy	
	1	1A	1B	2	2A	3	3A
Draft of S. G. = 1.9/SG = 1.0	1.4	1.4	1.4	1.2	1.2	1.2	1.2
Chem. Capability at SG = 1.0/SG = 1.9	1	1	1	.54	.54	.54	.54
Required Fabric Strength at SG = 1.9/SG = 1.0	1.7	1.7	1.7	1.6	1.6	1.7	1.7
Available Fabric Tear Strength at SG = 1.9/SG = 1.0	.3	.3	.3	.3	.3	.3	.3
Weight of Container of SG = 1.9/SG = 1.0	2.9	2.9	2.9	7	4	3	3.3
Packed Volume of Container at SG = 1.9/SG = 1.0	2.9	2.9	2.9	4.6	4	2.5	2.8
Towing Force for SG = 1.9/SG = 1.0	1.9	1.9	1.9	2.2	2.2	2.5	2.5

The ratings for the volume capabilities of containers for chemicals with specific gravities of unity was calculated based on the volume of the containers designed for chemicals with a specific gravity = 1.0 divided by the volume capability for chemicals with a specific gravity of 1.9 or 25,000 gallons.

The ratings for the required tensile strengths of the seams is the value of the ratio of the required fabric strengths for containers designed for chemicals with a specific gravity of 1.9 to the required fabric strength of a container designed for chemicals with a specific gravity of unity or 1,400 pounds/inch.

The ratings for available tear strength of the fabric are less than one and are based on the values for the ratio of the tear strengths of the material for containers designed for chemicals with a specific gravity of 1.9 to that for material for a container designed for chemicals with a specific gravity of unity.

The ratings for the packed weight and packed volumes of the container are more than one and are based on the values for the ratios of weight and packed volumes of containers designed for chemicals with a specific gravity of 1.9 to those for a container designed for chemicals with a specific gravity of unity.

Towing force ratings are more than one and are based on the value of the ratio of the towing drag of containers designed for chemicals with a specific gravity of 1.9 to the drag of a container designed for a chemical specific gravity of unity.

The ratings in Table 27 have not been totaled because the relative importance of each of the factors listed has not been established. In general, the container concepts from design Approaches 1, 1A, and 1B appear to be the most desirable, unless the greater capability of Approaches 2 and 3 for the lighter chemicals is a very significant factor.

G. Concept Evaluation

1. General

The selected construction for the three design Approaches reflects the materials and fabrication techniques that are most state-of-the-art for their unique designs. Materials in different states of processing are included for constructing some of the designs to determine their effect on risk or cost. The material and construction matrix for the different container design Approaches include:

a. Single Container, Single-Point Filling, Separate Buoyancy Chambers

Approach No. 1--Uncured Woven Fabric, Sewed-Lap Seams, and Autoclave Cure.

Approach No. 1A--Uncured Woven Fabric, Two-Ply Construction, Lap Seams 1/2 Fabric Width, and Autoclave Cure.

Approach No. 1B--Cured Woven Fabric, Sewed-Lap Seams (Dracone Construction), and Press or Autoclave Cure the Seams.

b. Compartmented Container, Single-Point Filling, Air Filled to Ensure Buoyancy

Approach No. 2--Uncured Cord Fabric, Unidirectional, Two-Ply Layup, Autoclave Cure, Rigid Bulkhead Separators, Internal Hose.

Approach No. 2A--Uncured Cord Fabric, Unidirectional, Two-Ply Layup, Flexible Bulkheads, and Manifold with External Hoses.

c. Segmented Container, Partially Filled to Ensure Buoyancy

Approach No. 3--Filament Wound Spherical Segments, Autoclave Cure, and Segments are Individually Filled.

Approach No. 3A--Filament Wound Cylindrical Segments, Autoclave Cure, Small Rigid Bulkheads, and Internal Hoses for Single-Point Filling.

Several liner materials and construction were included to determine their effect on risk and cost. The material and construction matrix for liners suitable for all three design Approaches include:

a. Teflon on Glass Fabric Liner

--State-of-Art Material for Rigid Seams.

--Development and Fabrication Costs for Flexible Seams Received from Vendor.

b. Viton on Teflon Fabric Liner

--State-of-Art for Flexible Seams.

--Cemented Lap Seams that are Autoclave Cured.

c. Brush Coating of Viton on Butyl-Polyester Fabric

--State-of-Art for Selected Chemical Resistant Viton is Unknown

--Requested Information from Vendor

d. Attachment of Liner to Container Structure

--Mechanical using Tab/Patch Connections

2. Technical and Development Risk for Design Approach 1 Container Concepts

These container design concepts are presented in Figures 14 through 17. Three techniques for fabricating this container concept of woven cloth fabric were investigated as Approaches 1, 1A, and 1B.

Uncured woven fabric was chosen for fabricating Approach 1 container concepts to limit the efforts required for removing the coating before seaming and sewing the lap joints. After assembly of the panels, the assembly is rolled on a drum and cured in an autoclave.

The fabrication technique for Approach 1 container concepts includes:

a. Fabric Components

--Single container and two air cylinders.

--Fabricated in these basic fabric parts (nose, center, tail).

--Center part sewn and seamed to nose and tail parts.

--Fabric lapped over bead at nose and tail for joining to rigid parts.

--Chemical container and buoyancy chambers connected permanently by flexible Y tapes.

b. Basic Material

--Uncured coated woven fabric.

--Container 48 oz/yd^2 cloth, 110 oz/yd^2 coated fabric, 25 mil gum each side.

--Buoyancy Chambers, 22 oz/yd^2 cloth, 57 oz/yd^2 coated fabric, 15 mil gum each side.

c. Seams

--Eight to 12 rows of stitching per lap seam.

--Cloth exposed at seams before sewing.

--Seams covered with gum on both sides after sewing for curing.

d. Attachments

--Woven "Y" Tapes used for sewed attachments between container and buoyancy cylinders.

e. System Cure

--Total system cured by rolling it on a drum and curing it in an autoclave.

f. Foam Drag Skirt

--Formed separately, laced to tail section and fastened to rear bead clamp.

g. Rigid Nose

--Contains Buoyancy, tow connection, fill/drain point and interfaces with fabric.

h. Single Point Filling at Nose

The fabrication technique for Approach 1A container concepts uses two plies of uncured woven fabric with large laps, approximately one half the width of the material. With these large laps, sewing of the laps between panels is minimal or eliminated. The fabrication technique for Approach 1A container concepts includes:

a. Fabric Components

--Single container and two air cylinders.

--Fabricated in three basic fabric parts (nose, center, tail).

--Center part sewn and seamed to nose and tail parts.

--Fabric lapped over bead at nose and tail for joining to rigid parts.

--Chemical container and buoyancy chambers connected permanently by flexible Y tapes.

b. Basic Material

--Uncured coated woven fabric.

--Contains two plies of 24 oz/yd^2 cloth, 60 oz/yd^2 coated fabric, and 15 mil gum on each side.

--Buoyancy chambers, two plies of 11 oz/yd^2 cloth, 30 oz/yd^2 coated fabric, 15 mil gum on each side.

c. Seams

--Eight to 12 rows of stitching per seam for joining nose part to the center part and the tail part to the center part.

--Cloth exposed at seams before sewing.

--Seams covered with gum on both sides.

d. Attachments

--Woven "Y" Tapes used for sewed attachments between container and buoyancy cylinders.

e. System Cure

--Total system cured by rolling it on a drum and curing it in an autoclave.

f. Foam Drag Skirt

--Formed separately, laced to tail section and fastened to rear bead clamp.

g. Rigid Nose

--Contains buoyancy, tow connection, fill/drain point and interfaces with fabric.

h. Single Point Filling at Nose

i. Typical Layup Approaches

The fabrication technique for Approach 1B container concepts uses cured fabric and the coating is layed back in the lap region for seaming and sewing the cloth. The coating is then repositioned and covered with gum and tapes for a press or an autoclave cure of the seams. The fabrication technique for Approach 1B container concepts includes:

a. Fabric Components

--Single container and two air cylinders.

--Fabricated in one basic fabric part.

--Fabric lapped over bead at nose and tail for joining to rigid parts.

--Chemical container and buoyancy chambers connected permanently by flexible Y tapes.

b. Basic Material

--Cured coated woven fabric.

--Coating is lifted locally for seaming and sewing.

--Container 48 oz/yd^2 cloth, 110 oz/yd^2 coated fabric, 25 mil gum each side.

--Buoyancy Chambers, 22 oz/yd^2 cloth, 57 oz/yd^2 coated fabric, 15 mil gum each side.

c. Seams

--Eight to 12 rows of stitching per seam.

--Cloth exposed at seams before sewing.

--Seams covered with gum on both sides after sewing for curing.

d. Attachments

--Woven "Y" Tapes used for sewed attachments between container and buoyancy cylinders.

e. System Cure

--Seams are cured using a press or by rolling system on a drum and curing the seams in an autoclave.

f. Foam Drag Skirt

--Formed separately, laced to tail section and fastened to rear bead clamp.

g. Rigid Nose

--Contains buoyancy, tow connection, fill/drain point and interfaces with fabric.

h. Single Point Filling at Nose

An evaluation of the state-of-the-art of fabrication techniques using woven cloth for constructing the containers was made based on judgments relative to the ability of creating the fabric, attaining the desired seam strengths, and retaining these strengths after immersion of the fabric in the chemicals. Fabric materials are readily available using present equipment. The required seam strengths are beyond those presently demonstrated for fabrics. High-strength sewn lap seams have been demonstrated using cloth or webbings without coatings. Approaches 1 and 1B lay back the coating on the cloth in the seam area prior to seaming and sewing for obtaining high-strength joints. Approach 1A uses two plies so that the bonded lap joints are several feet wide and require minimal or no sewing for strength. The ability of the seam to retain its strength after immersion in chemicals is based on the compatibility of the coatings with the chemicals. Sewing does prevent possible peeling and can act as a backup load path if the bond fails locally, so it is a desirable feature.

Approaches 1 and 1B require development to establish that high-strength sewn and bonded seam can be attained. Approach 1A requires development to determine how much, if any, sewing is required to prevent delamination of the wide bonded seams after immersion in the chemicals considering flexing actions.

Design Approach	1	1A	1B
Fabricating Desired Matl.	Materials and Tech. Available	Materials and Tech. Available	Materials and Tech. Available
Obtaining High-Strength Seams with Selected Matl.	Requires Dev. Testing	Limited Testing	Requires Dev. Testing
Retaining High-Strength Seams in Selected Chem.	Requires Limited Testing	Requires Dev. Testing	Requires Limited Testing

One basic reason for choosing woven fabric for Approach 1 container concepts is related to the size of the tooling and equipment required for making this large container by other fabrication techniques; such as, the layup process or the filament winding process where the container components are made and cured on full-size molds. The expense for large molds, building equipment, and curing facility prohibits the selection of other fabrication techniques for the quantities anticipated for this unique container.

3. Technical and Development Risks for Design Approach 2 Container Concepts

Two container design concepts are presented in Figures 21 through 26. The basic fabric part is layed up on a male mold using the same techniques for both container concepts. The basic difference between the two container design concepts is related to the construction of the bulkheads that divide the container into separate compartments. Approach 2 container concepts have rigid bulkheads and Approach 2A container concepts have hemispherical fabric bulkheads. The fabrication technique for Approach 2 container design concepts includes:

a. Fabric Components

--Nose, 14 identical compartments and tail

--Two-ply layup construction of unidirectional uncured tire cord material.

--Fabric lapped over beads at ends for joining to bulkheads.

--Beads hold fabric compartments rigid to bulkhead rims; ie, similar to the "tubeless tire/rim mechanism."

b. Basic Material

--Two-plies of uncured cord fabric.

--18 oz/yd^2 of cloth each ply; 104 oz/yd^2 total for two plies of coated fabric, 25 mil gum each side.

c. Seams

--No seams with two-ply layup on a form.

--Cured in an autoclave. The fabric portion of each compartment is on a form and enclosed within a vacuum blanket.

d. Cure

e. Rigid bulkheads

--Contain valves and hose connections.

f. Foam Drag Skirt

--Formed separately and laced to tail section.

g. Rigid Nose

--Contains buoyancy, tow connection, fill/drain point, and interfaces with fabric.

h. Single Point Filling at Nose

The fabrication technique for Approach 2A container design concepts that have flexible bulkheads includes:

a. Fabric Components

--Nose, 14 identical compartments and tail.

--Two-ply layup construction of unidirectional uncured cord material.

--Fabric lapped over beads at nose and tail for joining to rigid parts.

--Flexible hemispherical bulkheads and compartments fastened together with woven "Y" tapes.

b. Basic Material

--Two plies of uncured cord fabric.

--18 oz/yd^2 of cloth each ply; 104 oz/yd^2 total for two plies of coated fabric, 25 mil gum each side.

c. Seams

--No seams with two-ply layup on a form.

d. Cure

--Cured in an autoclave. The fabric portion of each compartment is on a form and enclosed within a vacuum blanket.

e. Flexible Bulkheads

--Hemispherical ends fastened permanently to each end of the compartment using woven "Y" tapes; inspection/clean-out port installed in hemispherical ends.

f. Foam Drag Skirt

--Formed separately and laced to tail section.

g. Rigid Nose

--Contains buoyancy, tow connection, fill/drain, and interfaces with fabric.

h. Single Point Filling at Nose

--Hose manifold in nose. Sixteen hoses of different length are harnessed to outer surface of container.

An evaluation of the state-of-the-art of the fabrication techniques using plies of uncured cord fabric to construct high-strength fabric for the container compartments is based on experience. Attaining the required fabric strengths with the selected materials is well within the state-of-the-art for this fabrication technique. Since seams are not present for design Approach 2 concepts, the same comment applies. Seams are present for design Approach 2A concepts relative to connecting the woven "Y" tapes to the container walls and the hemispherical fabric bulkheads. The hemispherical bulkheads are also made of woven cloth seamed and sewn together.

The lack of seams results in being able to use the data for the basic fabric of design Approach 2 concepts for strength after immersion in chemicals.

A summary of the state-of-the-art is as follows:

Design Approach	2	2A
Fabricating Desired Matl	Demonstrated	Demonstrated
Obtaining High Seam or Fabric Strengths with Selected Matl.	No Seams with This Technique	Seams Associated with Fab. Bulkheads
Retaining High Seam or Fabric Strengths in Selected Chem.	Part of Basic Matl. Testing	Part of Basic Matl and Seam Testing

4. Technical and Development Risks for Design Approach 3 Container Concepts

Two container design concepts are presented in Figures 27 through 29. The basic fabric part consists of continuous filaments wound on a male mold. The metal parts for attaching the segments together are incorporated in the fabric during the winding process. The drag loads are carried by central cables. The basic differences between the two container design concepts are the number of segments and the number of filling/discharging points. Approach 3 container design concepts have 25 nearly spherical segments that have individual fill/discharge points. Approach 3A container design concepts have 14 cylindrical segments and a manifold system with the hoses passing through the center of the rings attaching the segments together, Figure 29.

The fabrication technique for Approach 3 container design concepts includes:

a. Fabric Components

--Nose, 25 identical spherical chambers, and tail.

--Filament wound spheres of 8 feet diameter.

b. Basic Material

--Filaments wound over gum on male form.

--Two plies of filaments wrapped at angles over total surface.

--Five additional hoop plies over the short cylindrical portion.

c. Seams

--No seams with continuous filaments.

d. End Fittings

--Incorporated during winding process.

--Facilitate mandrel removal after construction.

--Facilitate part inspection, cleaning and repair.

e. Cure

--Cured in an autoclave. The fabric portion of each segment is on a form and enclosed within a vacuum blanket.

f. Foam Drag Skirt

--Formed separately and laced to tail section.

g. Rigid Nose

--Contains buoyancy, tow connection and interfaces with fabric.

h. Individual Filling and Draining Provisions for each Segment.

The fabrication technique for Approach 3A container design concepts includes:

a. Fabric Components

--Nose, 14 identical cylindrical segments, and tail.

--Filament wound cylinders of 8 feet diameter and 12 feet length.

b. Basic Material

--Filaments wound over gum on male form.

--Four plies of filaments wrapped at angles over total surface.

--Additional hoop plies and gum added to the cylindrical portion.

c. Seams

--No seams with continuous filaments.

d. End Fittings

--Incorporated during winding process.

--Facilitate mandrel removal after construction.

--Facilitate part inspection, cleaning and repair.

e. Cure

--Cured in autoclave. The fabric portion of each segment is on a form and enclosed in a vacuum blanket.

f. Foam Drag Skirt

--Formed separately and laced to tail section.

g. Rigid Nose

--Contains buoyancy, tow connection, manifold assembly and interfaces with fabric.

h. Single Point Filling at Nose

--Individual hoses go from manifold, through rigid rings connecting the segments and into the individual segments.

An evaluation of the state-of-the-art of the fabrication technique using plies of wound filaments constructing high-strength segments is based on judgments using the selected materials. The technique has been established for high-strength components using liquid elastomers. Only limited experience is associated with the use of elastomers in gum form. Thus, the technique has to be demonstrated with the chosen materials to further establish the state-of-the-art.

The lack of seams allows the use of data for the basic fabric for both Approach 3 and Approach 3A design concepts for initial seam strength and after immersion in chemicals strength values for the container.

A summary of the state-of-the-art is as follows:

Des.gn Approach	3	3A
Fabricating Desired Matl.	Technique Requires Dev. for Selected Matl.	Technique Requires Dev. for Selected Matl.
Obtaining High Fabric Strengths with Selected Matl.	Demonstrated with Other Elastomers	Demonstrated with Other Elastomers
Retaining High Fabric Strengths in Selected Chem.	Part of Basic Matl. Testing	Part of Basic Matl. Testing

5. Summary of Technical and Development Risks for Flexible Container Design Approaches

The major factors related to the technical and development risks for constructing the containers are listed in Table 28. The factors with numerical values reflect simple ratios between the values for containers designed for chemicals with a specific gravity of 1.9 and the values for containers designed for a specific gravity of one. The values illustrate the changes required to carry the heavy chemicals. Required fabric and seams strengths are 1.6 to 1.7 times those for chemicals with a specific gravity of one. Weights and packed volumes increase even more because of the added material for the buoyancy provisions.

Construction state-of-the-art listings consider the selected materials and the selected fabrication techniques. The listings are based on experience and judgments. The materials for design Approaches 1 and 2 can be made using state-of-the-art methods. The material and fabrication technique for Approach 3 needs to be developed. The technique has been demonstrated using other elastomers.

Development is also associated with obtaining high-strength seams in Approaches 1 and 1B designs where lap joints are used to assemble the woven fabric panels. Limited testing is associated with demonstrating the fabrication technique for Approach 1A designs. No seams are associated with Approach 2 and 3 design concepts. A typical selection for constructing high-strength pressurized structures, such as tires, is using gum and plies of cord fabric. Filament winding is also a typical selection for high-pressure system, such as, rocket cases and pressure bottles. However, the elastomer is normally in liquid form instead of gum form.

Retaining the high seam strengths in the selected chemicals is listed as requiring limited testing for Approaches 1 and 1B since the basic materials will have been tested for chemical compatibility. The only seam requiring development testing in the chemicals is associated with Approach 1A where large lap seams have limited or no sewing. This development is associated with assuring that the seams do not peel after chemical exposure and flexing.

TABLE 28--SUMMARY OF TECHNICAL AND DEVELOPMENT RISKS FOR FLEXIBLE CONTAINER DESIGN APPROACHES

Factors	Design Approach 1			Design Approach 2		Design Approach 3	
	Single Container with Twin Buoyancy Cylinders			Multiple Compartment w/Integral Buoyancy		Mutliple Segments with Integral Buoyancy	
	Constructed of Woven Fabric			Constructed of Cord Fabric Plies		Constructed by Filament Winding Layers	
	1	1A	1B	2	2A	3	3A
Required Fabric/Seam Strengths, Ratio of Ult. for SG = 1.9/Ult. for SG = 1.0	1.7	1.7	1.7	1.6	1.6	1.7	1.7
Weight of Container, Ratio of Wt. for SG = 1.9/Wt. for SG = 1.0	2.9	2.9	2.9	7	4	3	3.3
Pack Volume of Container Ratio of Vol. for SG = 1.9/Vol for SG = 1.0	2.9	2.9	2.9	4.6	4	2.5	2.8
State-of-the-Art Fabricating Desired Matl.	Matl & Tech. Avail.	Matl & Tech. Avail.	Matl & Tech. Avail.	Demonstrated	Demonstrated	Tech. Req. Developed	Tech. Req. Developed
Obtaining High Seam or Fabric Strengths with Selected Materials	Seams Req. Dev.	Seams Req. Limited Testing	Seams Req. Dev.	No Seams with this technique	Seams Associated with Fabric Bulkheads	No Seams with this Technique	No Seams with this Technique
Retaining High Seam or Fabric Strengths in Selected Chemicals	Seams Req. Limited Testing	Seams Req. Dev.	Seams Req. Limited Testing	Part of Basic Matl. Testing	Part of Basic Material and Seam Testing	Part of Basic Matl. Testing	Part of Basic Matl. Testing

6. Technical and Development Risks for Liner Concepts

The liners are associated with the Butyl-Polyester cloth fabric tanks, and they upgrade the tanks so they are compatible with all of the chemicals not compatible with the Nitrile (High-Vinyl)-Nylon cloth fabric tanks.

Three materials and the associated techniques for constructing the liners were selected for further investigation.

a. Teflon-Glass cloth fabric liner--This material is available in rolls as a finished fabric. The fabric must be seamed and sealed to prevent leaks. The strength requirements are based on handling, and relative motions between the liner and the structural fabric liner is large enough so that it bears against the container structure and the container structure carries the large pressure loads instead of the liner. Thus, liner material strength and seam strength requirements are very nominal.

To attain a seal with these chemicals, it is required that the Teflon surfaces be fused together at 700°F and still remain flexible. Fabricating flexible liquid tight seams needs to be demonstrated. Only one company is distributing the fabric, and they have quoted to GAC for fabricating flexible liners of this material for design Approach 1.

b. Viton - Teflon cloth fabric liner--This material is available in rolls as a finished fabric. The strength requirements for handling and relative motion can also be met with this fabric using state-of-the-art seaming techniques. Several companies can construct flexible liners from these materials. The seams are flexible and considered to be state-of-the-art.

c. Adding a 25 mil Viton coating directly onto the Butyl coating--This approach requires investigation to determine whether the desired Viton coating will bond to the selected Butyl coating.

Attachments are required to position either of the first two fabric liners relative to the structural fabric. The use of mechanical tension ties between patches on the structure and on the liner is one approach. Some development will be required because of the differences between the elongation characteristics of the liner and of the structure under the different loadings and with the frictional forces between the surfaces.

7. Total System Development Costs

Contractor total system development costs include contractor-supplied efforts and materials through the Prototype Test and Operational Evaluation Phase IV of Figure 40. The costs were estimated for all of the container design concepts presented. The factors used for generating the costs include:

a. Containers are designed to carry 25,000 gallons of chemical with a specific gravity of 1.9.

b. The selection of either Nitrile-Nylon or Butyl-Polyester fabric has little significance on total system development costs.

c. The chemical containers have 25 mils of coating on the inner and outer surfaces for protection against the chemicals and for wear.

d. Assembly and final check out before shipment.

e. A common time period for all labor rates and material purchases.

f. The costs for fabrication aids related to the container concept.

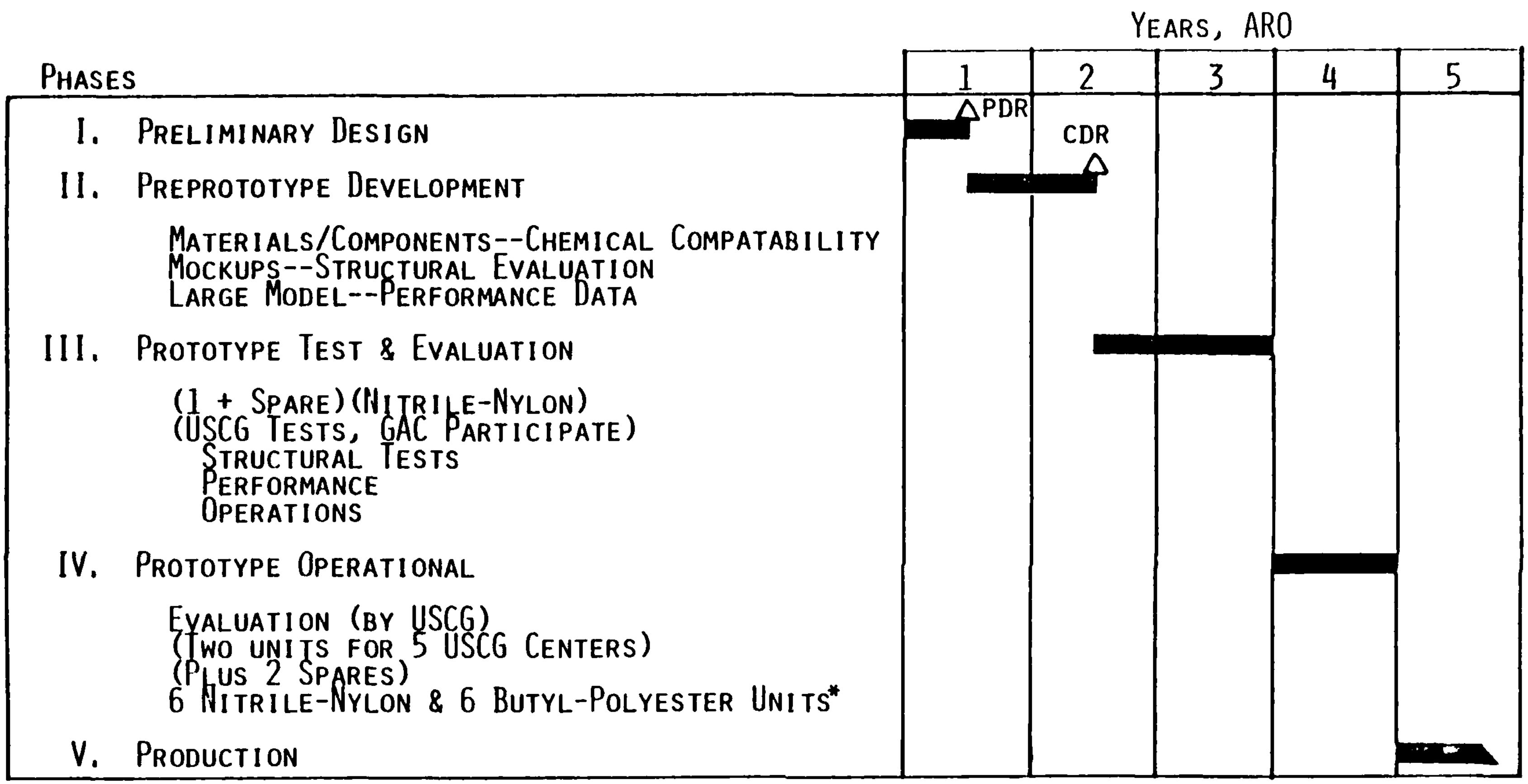
g. The costs for 14 containers in the total program. Only six of the containers have liners in the program for containers with liners.

h. Towing tests of full-scale containers by the U.S. Coast Guard with GAC support.

The contractor system development costs for all concepts were then divided by the cost of the system that is the least to obtain the relative cost ratios listed in Table 29.

The systems resulting from design Approaches 2 and 2A with the demonstrated construction methods to obtain the required container strengths are the most costly. These costs are associated with the costs of fabricating the containers. Approach 2 designs have many expensive stainless steel bulkheads and valves. Replacing the stainless steel bulkheads with fabric bulkheads in design Approach 2A doubles the number of bulkheads and requires considerable sewing to attach the "Y" tapes to the bulkheads, to the compartments, and to beads for connecting the compartments together.

The systems resulting from design Approaches 1, 1A, and 1B with requirements to develop high-strength seams are less costly than systems using design Approach 2 concepts. The lesser costs reflect the reduced costs for constructing containers. The least costly of these containers results from design Approach 1A where sewing is minimized by use of the 2-ply construction with the very wide vulcanized seams.



* WITH AND WITHOUT LINERS.

FIGURE 40--DEVELOPMENT PROGRAM SCHEDULE

TABLE 29--CONTRACTOR TOTAL SYSTEM DEVELOPMENT COST RATIOS

Concept	W/O Liner	With Liner
1	1.6	1.8
1A	1.1	1.3
1B	1.6	1.8
2	2.5	2.8
2A	2.5	3.0
3	1.7	2.2
3A	1.0*	1.5

*For Phases I through III, a value of 1 equals approximately 1 million 1980 dollars
For Phases I through IV, a value of 1 equals approximately 3 million 1980 dollars.

The least costly program results from design Approach 3A that requires development of the construction technique using the selected elastomer in uncured gum form as compared to other elastomers in liquid form. The greater cost of the program for containers resulting from design Approach 3 reflects the greater container costs due to the many valves.

The relative costs of programs with the same container systems that include liners in 6 of the 12 containers are listed in the last column of Table 29. GAC costs for constructing Viton-Teflon cloth fabric liners and vendor costs for constructing Teflon-Glass cloth fabric liners were similar for design Approach 1 containers, and GAC costs were used for the liners for the containers resulting from the other design Approaches.

8. Operational Hardware Production Costs

The hardware production costs are based on building 10 units and includes amortizing the costs of fabrication aids over these units. A common rate period was used for the effort, and the costs for these units was divided by the cost of the units that is the least to obtain the relative cost ratios listed in Table 30.

The relative costs of systems with liners includes liners in one half of the systems and are presented in the last column of Table 30. The matrix presented in the Table also lists the items considered in making up the relative production costs. Nonrecurring fabrication aid costs were similar for the different container design concepts and fabrication approaches and had little affect on overall production costs.

TABLE 30--MATRIX OF PRODUCTION HARDWARE COST RATIOS

	Recurring Fabrication Costs				Nonrecurring Equipment Costs			Fabrication Cost Ratio*	
Candidate Concepts	Sewing-Lap Seams-Bonding	Two-Ply Lap Seam	Layup	Filament Winding	Sewing Equip.	Fabrication Aids	Filament Winding Equip. Mod.	All Without Liner	One Half With Liner**
1	X				X	X		1.9	2.3
1A		X			X	X		1.1	1.5
1B	X				X	X		1.8	2.2
2			X			X		3.3	3.8
2A			X			X		3.2	4.1
3				X		X	X	2.1	2.9
3A				X		X	X	1.0***	1.7

*1980 cost rates used, nonrecurring costs amortized over 10 units.

Fabrication aids include templates, layup molds, curing molds, assembly fixtures.

**Liner materials are Teflon-Glass and Teflon-Viton.

***A value of 1 equals a unit cost of approximately 150 thousand 1980 dollars.

H. Detailed Development Approach, Schedules, and Costs

1. General

The proposed program schedule was presented in Figure 40. The first four phases include all efforts prior to supplying operational hardware in Phase V.

2. Preliminary Design--Phase I

The schedule for the preliminary design efforts is presented in more detail in Figure 41 and consists of two parts. The first part establishes the filament winding technique for constructing chemical container concepts for design Approach 3A. This construction technique has a technical advantage in that it is seamless and its strength is not restricted by the state-of-the-art for seam strengths as are the construction techniques for design Approaches 1, 1A, and 1B. The filament winding construction technique also can lead to the least costly system because it uses machinery compared to the extensive hand labor associated with design Approaches 1 and 2.

The efforts for part one include:

a. Design of a model for establishing the filament winding technique for constructing chemical containers made from Nitrile/Nylon and Butyl/Polyester materials and prearing for their fabrication.

b. Eight models, five of Butyl/Polyester materials and three of Nitrile/Nylon, will be made to establish the processes.

c. Testing of the models to determine the ultimate load capability of the fabric and testing samples of the fabric for quality; ie, peel, adhesion, and porosity.

The efforts for part two are typical preliminary design efforts and include:

a. Updating the container requirements based on results from this study and other U.S. Coast Guard studies.

b. Establishing a baseline container concept for preliminary design analysis.

c. Conducting a structural analysis to refine the loads and weights.

d. Reviewing operations to refine requirements for packing, deploying, inflating, filling with chemical, towing, discharging, retrieving, refurbishing, repacking the system, and for any special equipment.

e. Preparing and testing samples of the selected container and liner materials in the listed chemicals. Specifically, in the chemicals that the materials are rated as being a probable yes (PY) for compatibility.

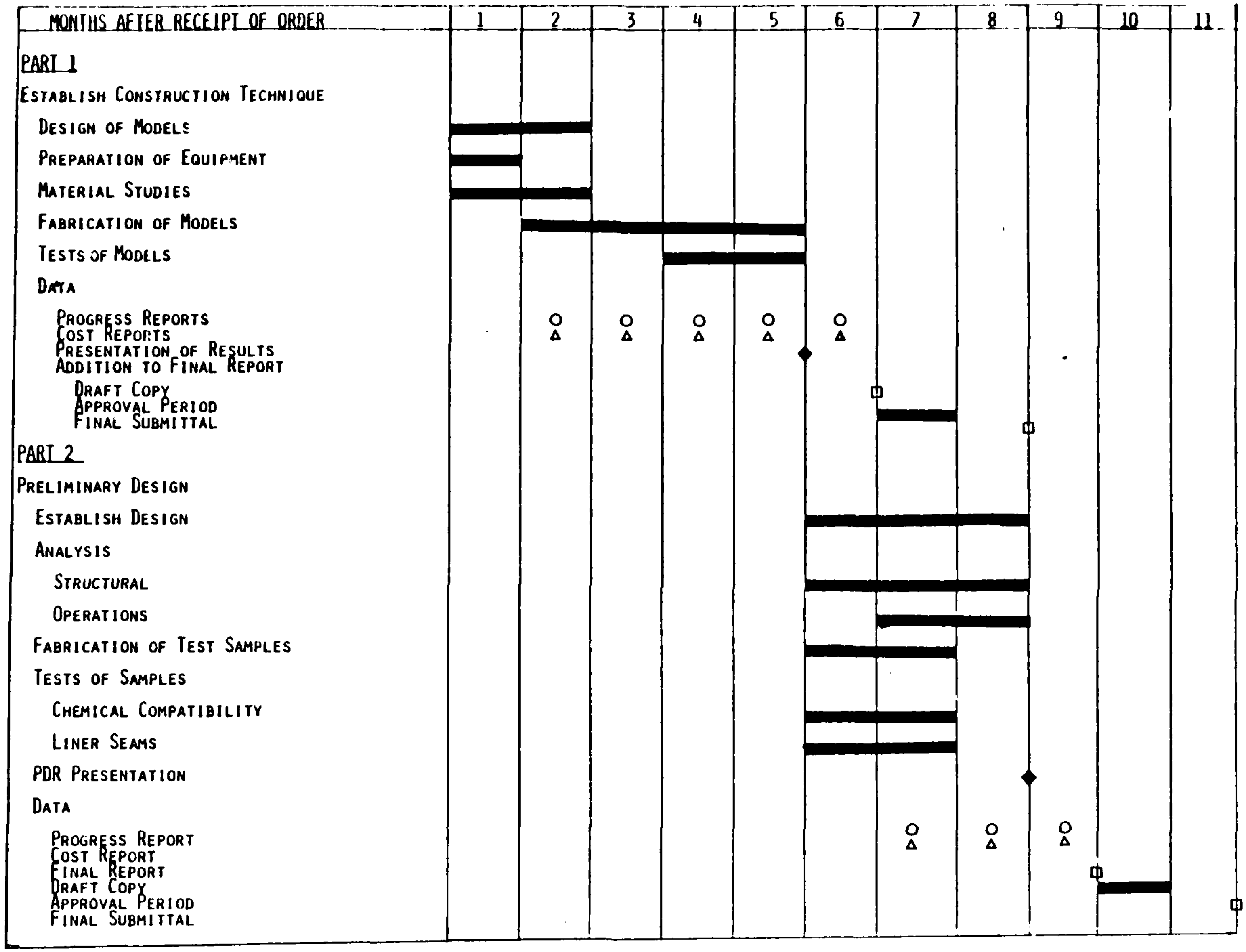


FIGURE 41--PRELIMINARY DESIGN SCHEDULE--PHASE I

The purpose of the total Preliminary Design efforts is to define and document the design in sufficient detail for a formal Preliminary Design Review (PDR) that can result in an approval.to start the Detailed Design Phase (II).

Documentation covering the design effort includes test reports, analysis reports, and preliminary design drawings presented as separate items and as part of the PDR information. Progress reports, cost reports, and a final report completes the proposed program documentation.

A program of approximately nine months duration is proposed for both parts. Additional one-month periods are indicated for U.S. Coast Guard review of the draft and for resubmittal of the Final Report.

3. Detail Design--Phase II

This phase, Figure 42, generates the detail design drawings and specifications and supporting data and analysis required for a Critical Design Review (CDR) that can result in an approval to fabricate the pre-prototype units for testing and evaluation in Phase III.

The detail design is supported by the results from testing that includes:

a. Tests of samples of the materials and seams for the container structure and liner;

b. Tests of full-scale components of the container and liner;

c. Towing tests by USCG and GAC personnel of an approximately one-half scale container system for establishing a stable towing configuration; and

d. Packing and deployment tests using the large model.

The analysis will include:

a. Stress analysis of the system, components, and parts.

b. Weight, balance, and buoyancy analysis;

c. Towing drag and towing stability analysis;

d. Operations;

e. Defining special equipment; and

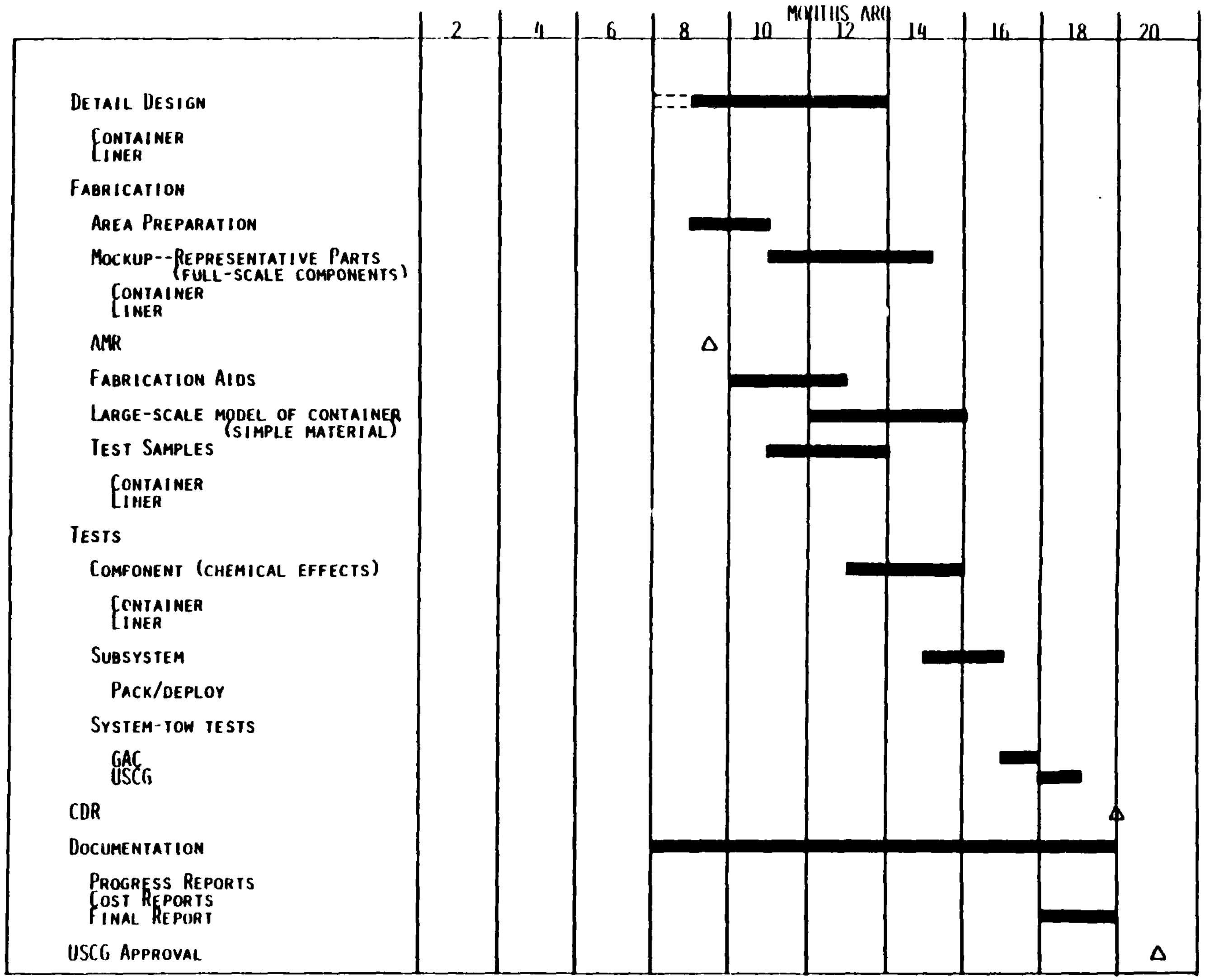


FIGURE 42--DETAIL DESIGN SCHEDULE--PHASE II

f. Refining and detailing performance, delivery and costs on selected materials and components.

Fabrication efforts will include:

a. Constructing material samples of the container and liner fabrics;

b. Constructing full-scale container components;

c. Building a one-half scale container system;

d. Defining area and equipment requirements for building the large model;

e. Defining fabrication aids required for building the large model; and

f. Defining and preparing Advanced Material Releases (AMR) for long lead items needed to construct the large model.

Documentation includes test reports, analysis reports, and the detailed design drawings as separate items and as part of the CDR package. Progress reports, cost reports, and the final report document the program efforts. An 11-month program is proposed with an additional month for U.S. Coast Guard review and approval of the Final Report.

4. <u>Preprototype Test and Evaluation--Phase III</u>

This phase, Figure 43, builds two preprototypes to the detail design drawings and specifications, tests the prototypes, and evalutes the design relative to the technical and operational requirements.

Two full-scale container systems are constructed for U.S. Coast Guard testing with GAC supplying test support personnel. The tests include those associated with operation of the system and the performance of the container when carrying liquids of different densities.

A preliminary operations manual will be generated prior to the tests, and it will be refined and updated where needed during the test period. The final manual will be submitted as part of the program documentation that includes the final specifications and the final detail design drawings.

Other program reports include the progress reports, cost reports, and the Final Report. A 18-month program is proposed with an additional month for U.S. Coast Guard review and approval of the Final Report.

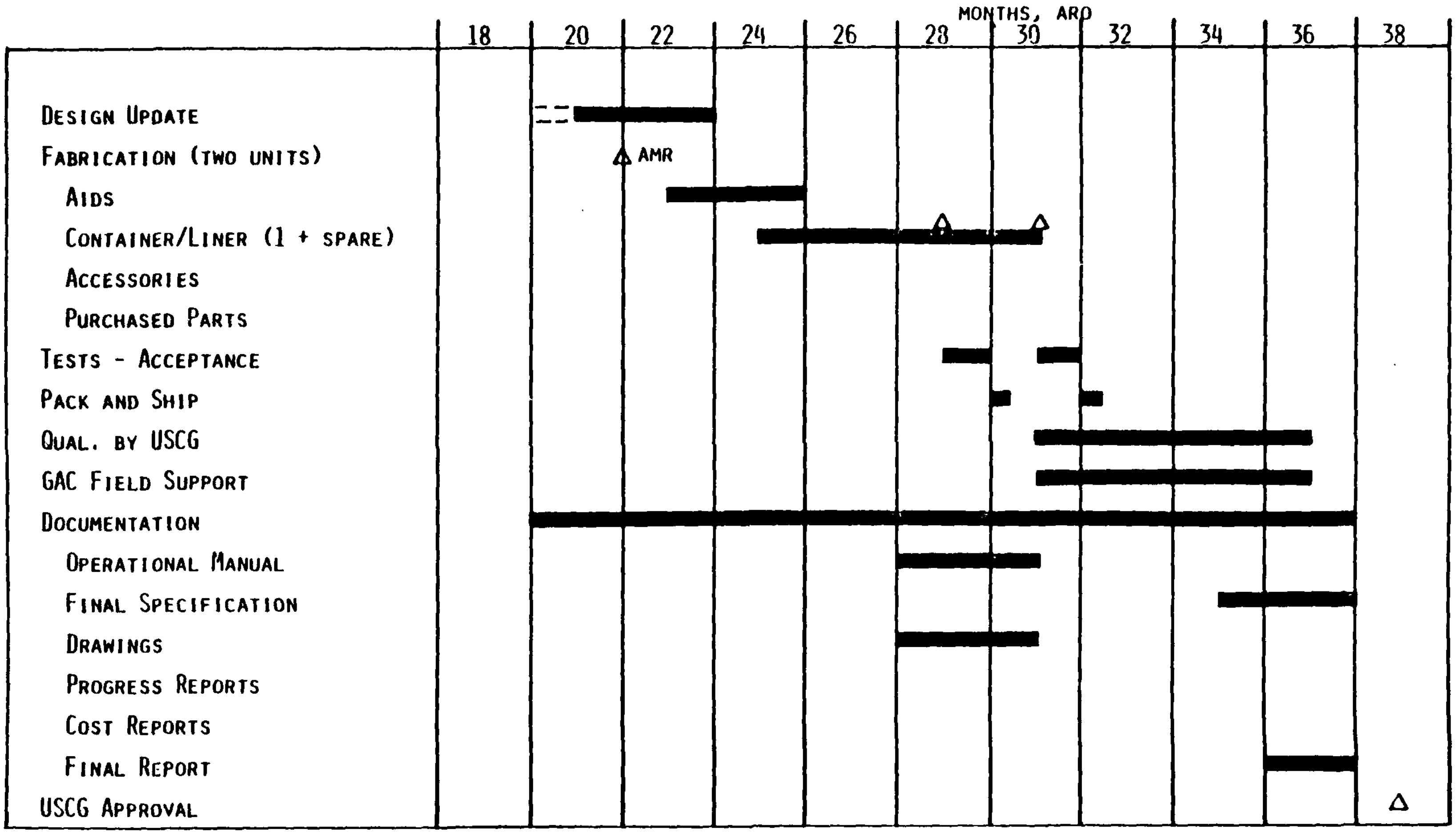


FIGURE 43--PREPROTOTYPE TEST AND EVALUATION SCHEDULE--PHASE III

5. Prototype Operational Evaluation--Phase IV

This phase, Figure 44, constructs 12 container systems for evaluation by different U.S. Coast Guard Centers with GAC supplying test support during the first six months of testing. Six of the 12 container systems have liners.

This phase runs for approximately one year and is based on a U.S. Coast Guard testing period beginning 6 months after the start of this phase. Documentation consists of progress cost reports and updates of the drawings, specifications, and operations manual.

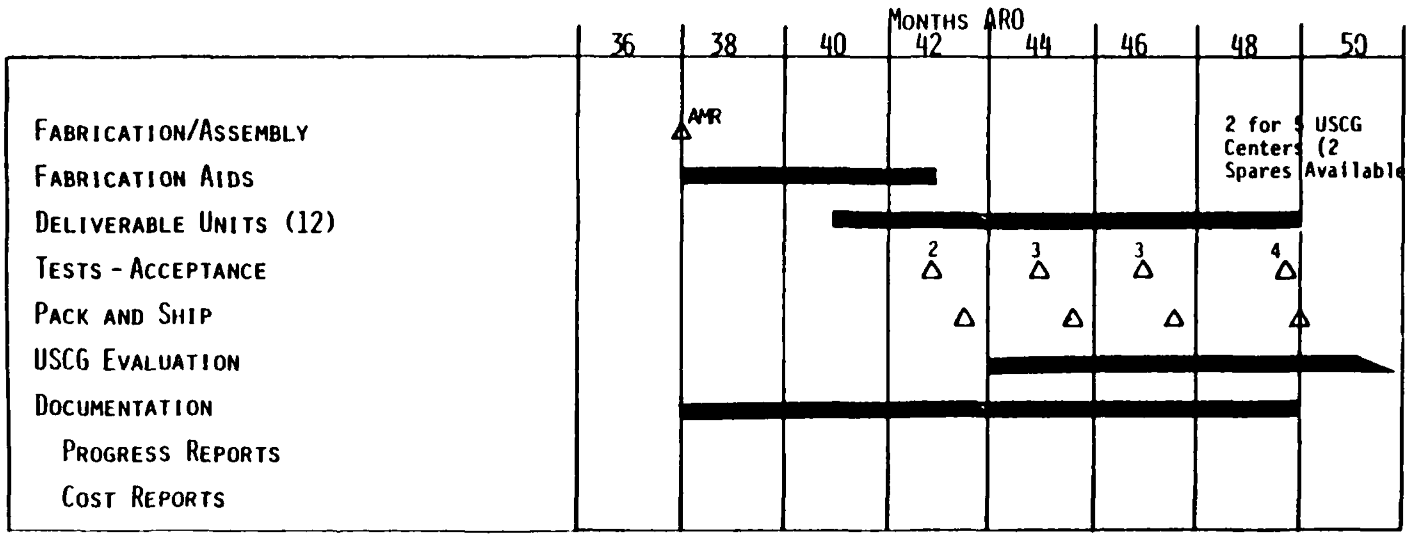


FIGURE 44--PROTOTYPE OPERATIONAL TEST AND EVALUATION SCHEDULE--PHASE IV

I. Study of Other Container Concepts

1. Other Container Concepts Considered

Three basic container concepts other than all flexible were considered relative to the 3.1 Technical and Operational Requirements and included rigid containers, expandable containers, and modifications to present all-flexible containers to carry chemicals with specific gravities greater than one that can be contained by their fabrics. Typical design concepts were generated for each container type to describe each design, its physical characteristics, and to determine its attractiveness relative to the rest of the container design concepts.

2. Rigid Chemical Containers

a. General

Rigid container concepts were designed for maximum capacity consistent with the transportation envelope limitations. With this approach the rigid container capacity is only a fraction of the desired 25,000 gallons.

b. Candidate Materials

The rigid container structure can be made of many candidate materials. If stainless steel is selected, the structure itself can contain the chemicals. If less expensive structural materials are selected; such as, carbon steel or fiber-glass, then a liner must be included to contain all of the chemicals. Bonded on glass or Teflon are candidate materials for rigid container liners.

The materials for auxiliary buoyancy are the same type of fabric materials as selected for the twin buoyancy cylinders of design Approach 1 container concepts. Because of the larger diameters of these buoyancy cylinders, the strength of the fabric for the buoyancy cylinders approaches that for the chemical container itself for the concepts resulting from design Approach 1.

c. Typical Design Concepts

A typical design concept for a rigid container with auxiliary flotation and a typical design concept for a rigid container with integral flotation are presented in Figures 45 and 46, respectively.

A stainless steel container with auxiliary buoyancy cylinders and a capacity for 8,117 gallons of chemical that has a specific gravity of 1.9 can fit within an 8 x 8 x 26 envelope. The draft of the system is 11 feet.

The container concepts with integral buoyancy can be only partially filled with 3,615 gallons of chemicals with a specific gravity of 1.9. This container will take a spar buoy attitude since the fluid flow is not restricted by the volume of air. Approaches; such as, using internal foam cylinders or internal air cylinders to distribute the chemical and eliminate the tendency of the container to take a vertical attitude have to be protected from the chemicals and would be more useful as exterior flotation devices. Another approach would be to add a bulkhead and fill one compartment completely. A second fill valve could be added for filling both compartments with less dense chemicals. A torus is indicated around one end of the container to orient it for filling and discharging chemicals. This container system concept is towed in a vertical position. Towing it at one end with a partially filled tank can lead to violent pitching about a horizontal attitude.

The pallets are an integral part of the container design concept for transmitting handling and towing loads. The pallet also acts as a flow separation fence when the container is towed in a vertical attitude. The draft of the system with a maximum capacity of a chemical with a specific gravity of 1.9 is approximately 25 feet.

d. Towing Drag

The towing drag of a rigid container with auxiliary flotation cylinders is based on the drag of the container plus the drags of the twin flotation cylinders, including an interference factor. The interference factor applies when the twin cylinders are less than one diameter apart, Reference 11.

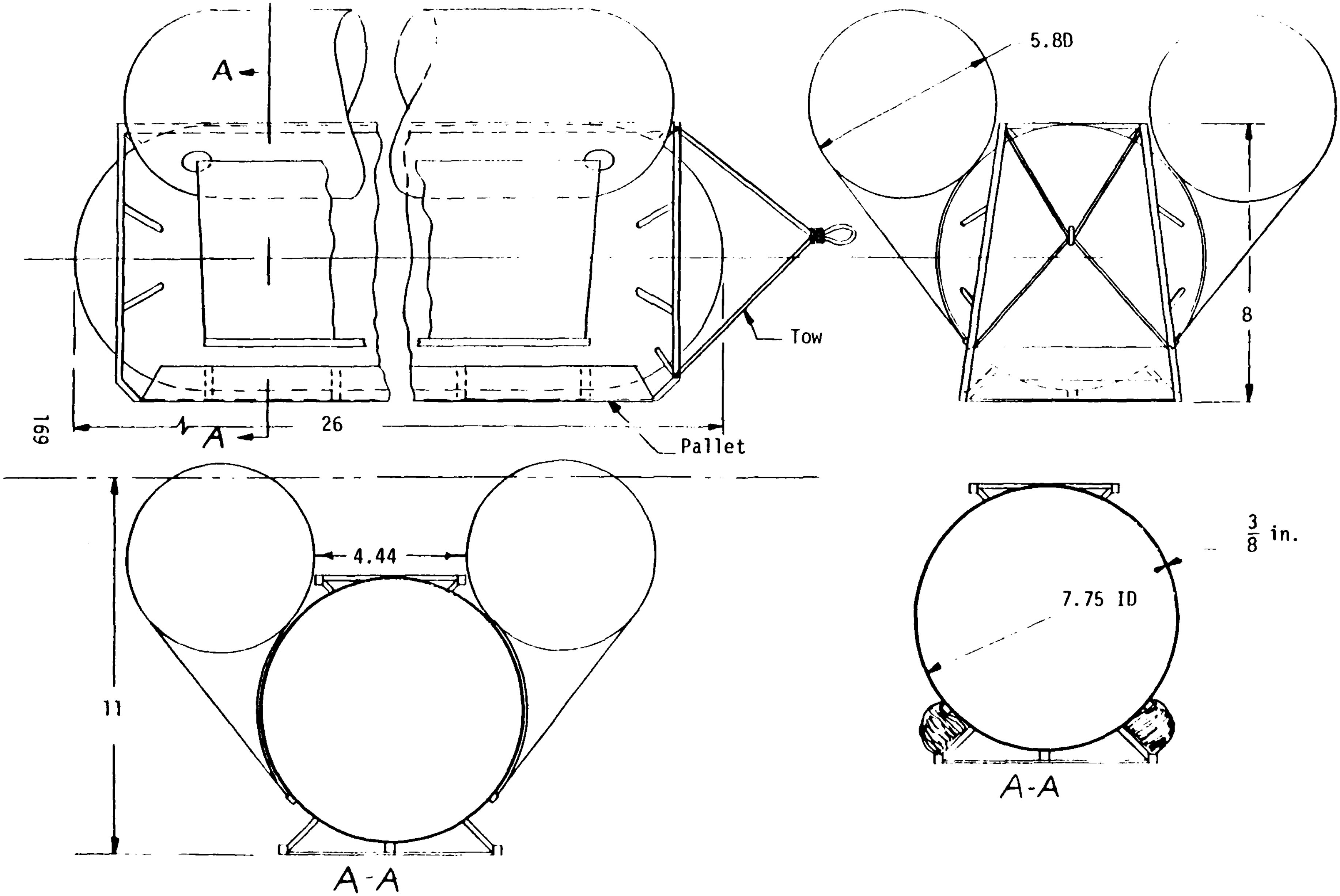


FIGURE 45--RIGID CONTAINER WITH TWIN AUXILIARY FLOTATION CYLINDERS

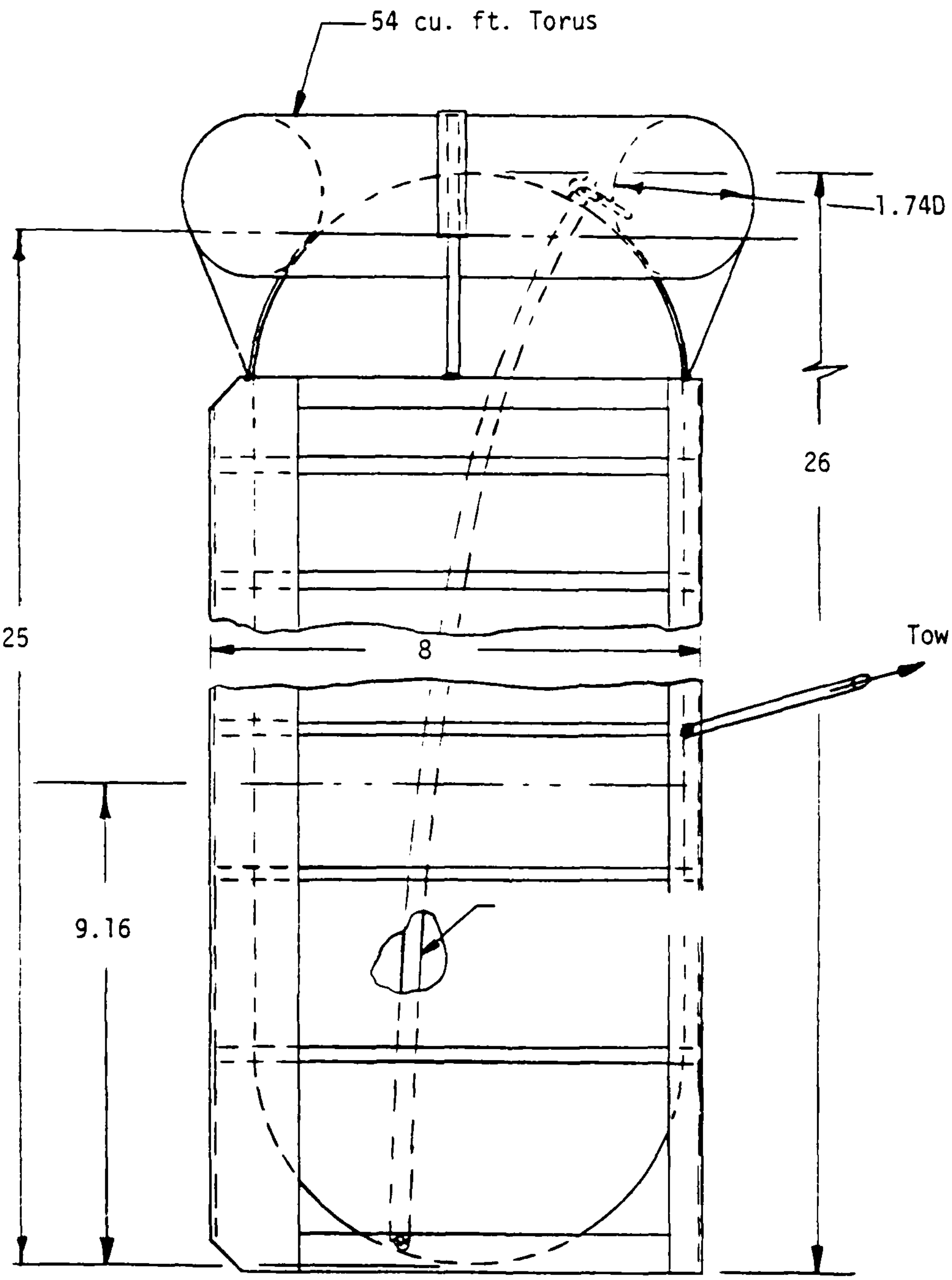


FIGURE 46--RIGID CONTAINER WITH INTEGRAL FLOTATION

The total drag of this design concept is:

$$D_{Total} = \left[C_{D_{cc}} \times S_{cc} + XC_{D_{BC}} S_{BC}\right] q$$

$$D_{Total} = [(.8 \times 47.2) + (1.2 \times .8 \times 26.4)]\ 284 = 17{,}922 \text{ lbs/ @ 10 kts.}$$

Where :

$C_{D_{cc}} = .8$; $X = 1.2$; $C_{D_{BC}} = .8$

$S_{cc} = 47.2$ sq. ft.; $S_{BC} = 26.4$ sq. ft.

$q = 1/2 \rho V^2 = 284$ PSF @ 10 kts.

The total drag of a rigid container with integral flotation and towed while it is in a vertical attitude is:

$$D_{Total} = C_D\ S\ q = .75 \times 208 \times 284 = 44{,}300 \text{ lbs @ 10 kts}$$

Where :

$C_D = .75$

$S = 8 \times 26 = 208$ sq. ft.

$q = 284$ PSF @ 10 kts.

e. Typical Strength Requirements

1) Container with Auxiliary Twin Buoyancy Cylinders

The rigid tank, being large and subjected to handling loads, was estimated to need a wall thickness of 3/8 inches. The tank was then investigated relative to pressure stresses due to a full load of chemicals with a specific gravity of 1.9.

$$\text{Pressure Stress} = \sigma = \Delta p \frac{R}{t} = 2{,}845\ \frac{7.75}{2 \times 3/8}\ \frac{1}{12} = 2{,}450 \text{ psi}$$

Where : $\Delta p = \alpha \rho H$, α = dynamic factor = 2

ρ = density of chemical = 1.9×62.4, PCF.

H = wave height = 12 feet

R = container radius = 7.75/2, ft.

t = container thickness = 3/8, inches

This stress compares with a yield strength value of 30,000 psi for steel. Thus, a D.F. of $\frac{30,000}{2,450}$ or approximately 12 is available.

The pallet frame is estimated to weigh 1,500 pounds for supporting the tank.

The twin buoyancy cylinders were positioned to minimize the footprint or force against the container while minimizng draft requirement. They were sized to provide 6 percent excess buoyancy when the container is filled with chemicals with a specific gravity of 1.9.

Buoyancy system requirements is the total weight of the system minus the weight of water displaced by the container or:

$$F_{Buoyancy} = 1.06\left[(1.9 \times 62.4 \times 1,085) - (64 \times 1,085) + 11,225\right]$$

Where : Volume disp. by container = 1,085 cu. ft.
Wt. of system in air = 11,225 lbs., and

$$F_{Buoyancy} = 75,000 \text{ lbs. total}$$

$$\text{Displacement Required} = \frac{75,000}{2 \times 64} = 586 \text{ cu. ft. each}$$

Thus, the cylinders need to be 5.81 feet in diameter. The operating pressure to maintain displacement with waves 12 feet high is 16.7 feet of water.

$$\text{Static stress } \sigma_s = pR = 16.7 \times 64\left(\frac{5.81}{2}\right)\frac{1}{12} = 259 \text{ lbs/inch}$$

$$\text{Dynamic stress} = 2\sigma_s = 2 \times 259 = 518 \text{ lbs/inch}$$

Ultimate stress= DF $(2\sigma_s)$ = 4.8 x 518 = 2,484 lbs/in., which is very similar to the material requirements for the containers for design Approach 1 components.

2) Container with Integral Flotation

The rigid tank design is based on the handling loads. The pressure loads are less because the tank is only partially filled.

The pallet frame is estimated to weigh 2,000 pounds because of the greater towing loads and stability provisions.

The attitude control torus is positioned on one hemispherical end so it remains in place after inflation. It is sized to displace 5 percent as much water as the basic container.

Thus, displacement = .05 x 1,085 = 54.25 cu. ft.

Where : Vol. of container = 1,085 cu. ft.

The size of the torus meeting the positioning and displacement requirements has an inner diameter of less than 7.74 feet and a maximum diameter of 9.5 feet. The diameter of the torus section = 1.74 feet. The operating pressure is 16.7 feet of water for water 12 feet high.

$$\text{The static stress, } \sigma_s = \frac{pr}{2}\left[1 + \frac{(R+r)\cos\theta}{(R+r)\cos\theta - r}\right] = \frac{pr}{2}\,(2.315)$$

$$\sigma_s = 16.7 \times 64 \times \frac{.87}{2} \times \frac{2.315}{12} = 89.7 \text{ lbs/inch}$$

$$\text{Dynamic stress} = 2\sigma_s = 179.4 \text{ lbs/inch}$$

$$\text{Ultimate stress} = DF \times 2\sigma = 4.8 \times 179.4 = 861 \text{ lbs/inch}$$

Thus, constructing the torus of woven materials is well within the state-of-the-art.

f. <u>Weights and Packed Volumes</u>

The estimated weights and packed volumes for the two rigid container design concepts are presented in Table 31 for several candidate materials. The rigid container comprises the greatest weight and packed volume of the system. The cylindrical container is sized to occupy the allowable transportation envelope with the auxiliary portions of the system packed in the lower quadrants of the envelope; ie, between the cylinder and the pallet. The weights and volumes of the twin buoyancy cylinders correspond to the sizes required to support the container when filled with a chemical having a specific gravity of 1.9. The total weight is within the 15,000-pound limits of the 3.1 Requirements.

g. <u>Deployment Sequence and Equipment</u>

The major elements in the selected sequence for operating the rigid container concept with twin buoyancy cylinders include:

1) Either deploying the container attached to its pallet frame using a crane or sliding the total system into the water. The required lifting capability greatly exceeds the 1,000-pound limit of the 3.1 Requirement. To easily slide the total system into the water requires an interface structure between the pallet frame and the craft.

TABLE 31--RIGID CONTAINER WEIGHTS AND PACKED VOLUMES

Components	Stainless Steel		Carbon Steel/Liner		Fiber Glass/Liner	
	Weights LBS	Packed Vol CU. FT.	Weights LBS	Packed Vol CU. FT.	Weights LBS	Packed Vol CU. FT.
A. Container with Aux. Flotation						
--Container Cylinder	9,725	7.75D x 26	9,725	7.75D x 26	4,860	7.75D x 26
--Pallet/Frame	1,500	6 x 8 x 26	1,500	6 x 8 x 26	1,500	6 x 8 x 26
--Container Liner	-0-	-0-	90	In Container	90	In Container
--Flotation Subsystem	750	50	750	50	750	50
--Hoses and Fittings	180	10	180	10	180	10
Totals	12,155	8 x 8 x 26 1,664	12,245	8 x 8 x 26 1,664	7,380	8 x 8 x 26 1,664
B. Container with Integral Flot.						
--Container Cylinder	9,725	7.75D x 26	9,725	7.75D x 26	4,860	7.75D x 26
--Pallet/Frame	2,000	6 x 8 x 26	2,000	6 x 8 x 26	2,000	6 x 8 x 26
--Container Liner	-0-	-0-	90	In Container	90	In Container
--Attitude Contr Subsystem	50	4	50	4	50	4
--Hoses and Fittings	180	10	180	10	180	10
Totals	11,955	8 x 8 x 26 1,664	12,045	8 x 8 x 26 1,664	7,180	8 x 8 x 26 1,664

2) The rigid container provides its own initial buoyancy.

3) Air is added to the twin buoyancy cylinders until they are full and pressurized using an auxiliary air supply.

4) Chemical is pumped into the container until it is full. A pressure relief valve allows the air to exit.

5) Towing is conducted.

6) The chemical is pumped out. A negative pressure valve allows air to enter the container.

7) The air cylinders are deflated.

8) The container on its pallet is lifted aboard for refurbishment, repacking the flotation system, and reuse.

The twin buoyancy cylinders are pressurized to maintain their volumes under wave heights of 12 feet. The volume corresponds to floating the system when filled with a chemical having a specific gravity of 1.9. The operating pressure is 1,069 PSF. The displacement volume is 587 cu. ft. for each cylinder. The work associated with filling the cylinders is PV = 1,069 x 2 x 587 lbs. ft. If the work is accomplished in one hour, the horsepower developed is:

$$\text{Horsepower} = \frac{PV}{33{,}000 \times 60} = \frac{1{,}255{,}006}{1{,}980{,}000} = .6$$

The selected air source will require a larger rating to overcome line losses and to reflect the efficiency of the system.

The major elements in the selected sequence for operating the rigid container concept with integral buoyancy and an attitude control torus include:

1) Either deploying the container on its pallet using a crane or sliding the container on its pallet into the water.

2) The rigid container provides its own buoyancy.

3) Air is added to the attitude control torus using an auxiliary air supply.

4) Chemical is pumped into the container until it reaches its operating draft limit. A pressure relief valve allows air to exit.

5) Towing is conducted with the container in a vertical position. The pallet acts as a flow separator for towing stability.

6) The chemical is pumped out. A negative pressure valve allows air to enter the container.

7) The torus is deflated.

8) The container on its pallet is lifted aboard for refurbishment, repacking the torus, and reuse.

The torus is pressurized to maintian its volume under a wave height of 12 feet. The volume of the torus corresponds to displacing five percent of the volume of the rigid container. The operating pressure is 1,069 PSF, and the displacement volume is 54 cu. ft. The work associated with filling the torus is PV = 57,726 lbs/ft. If the work is accomplished in one hour, the horsepower developed is:

$$\text{Horsepower} = \frac{PV}{33{,}000 \times 60} = .03$$

The PV of this unit is small enough that a bottle system may be desirable. The volume of a 2,000 psi system can be estimated as follows:

$$(PV)_{Bottle} = (PV)_{Torus}$$

$$(2{,}000 + 14.7)144\ V_{Bottle} = (1{,}069 + 2{,}116)54$$

$$V_{Bottle} = .6 \text{ cu. ft. or } 1{,}024 \text{ cu. in.}$$

h. Summary of the Physical Characteristics of Rigid Container Concepts for Chemicals with a Specific Gravtiy = 1.9

The major physical characteristics of the two rigid container concepts are listed in Table 32. The rigid container capacities for chemicals with a specific gravity of 1.9 are 8,117 gallons with auxiliary flotation and 3,615 gallons with integral flotation. These capacities are considerably less than the 25,000 gallons listed in the 3.1 Requirements. The towing drags exceed the values for

TABLE 32--PHYSICAL CHARACTERISTICS OF TYPICAL RIGID CONTAINER CONCEPTS--

CHEMICAL SPECIFIC GRAVITY = 1.9

Factors	Container With Auxiliary Flotation	Container With Integral Flotation
Capacity, Gallons	8,117	3,615
Towing Drag, lbs. (10 kts in 5 ft. waves)	17,920	44,300
Handling Requirements, Survivability--12 ft. waves	3/8 inch Steel or Equiv. < 3/8 inch Steel or Equiv.	3/8 inch Steel or Equiv. < 3/8 inch Steel or Equiv.
Packed Weight, lbs.	7,380 to 12,245	7,180 to 12,045
Packed Volume Dimensions, ft.	8 x 8 x 26	8 x 8 x 26
Crane Lifting Requirements, lbs.	7,380 to 12,245	7,180 to 12,045
Time to Receive Chemicals, hrs.	Less than 4 hours	Less than 4 hours
Useful Water Temp. Range, °C	Greater than -2 to +30	Greater than -2 to +30
Initial Flotation Approach	Container Displacement	Container Displacement
Draft, ft.	11	25

the 25,000 gallon all flexible container concepts. The rigid material thickness is based on handling considerations and survivability requirements. The weights and packed volumes are within the limits of the 3.1 Requirements; however, they are considerably greater than the values for the 25,000 gallon all flexible container concepts.

The rigid containers require a crane with a lifting capacity equal to their total weights; ie, 7,200 to 12,250 pounds.

The requirements relative to receiving chemicals, useful operating temperature range and providng initial flotation can be met with the design concepts.

The draft of the system concept with twin buoyancy cylinders is 11 feet, and it slightly exceeds the draft limit of 10 feet while the draft of the design concept with integral buoyancy exceeds 25 feet.

3. Expandable Chemical Containers

a. General

Expandable container concepts were designed using aircraft pallet and "Pillow Tank" technologies. The system consists of components similar to those in production. Multiple units can be transported within the transportation envelope of 8 x 6 x 26 feet.

b. Candidate Materials

A typical pallet structure is made of aluminum extrusions that are only exposed to spills of the chemical. The "Pillow Tank" structure is Nitrile (high Vinyl)/Nylon cloth fabric or Butyl/Polyester cloth fabric. A liner of either Viton/Teflon cloth fabric or Teflon/Glass cloth fabric is used to upgrade the capability of the Butyl/Polyester cloth fabric container. The auxiliary flotation cylinders are made of the same fabrics as used for the flotation cylinders of design Approach 1 container concepts.

c. Typical Design Concept

A typical design concept for an expandable container with auxiliary flotation for carrying 5,000 gallons of chemical with a specific gravity of 1.9 is

AD-A114 141 GOODYEAR AEROSPACE CORP AKRON OH F/G 13/4

HAZARDOUS CHEMICAL CONTAINER FEASIBILITY/CONCEPT DESIGN STUDY.(U)

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presented in Figure 47. The pallet acts as a "spreader bar" between the twin flotation cylinders supporting the container. The sealed "Pillow Tank" is attached to the pallet using a series of clamps around a bead strip attached to the "Pillow Tank." The packed thickness of the system is approximately one foot, and multiple systems can be stacked within the transportation envelope and weight limits.

The twin buoyancy chambers are sized to float the system when the "Pillow Tank" is filled to its capacity with chemicals having a specific gravity of 1.9.

One possible multiple segment container approach is to connect pallets together to form a train of individual containers. A single fill/discharge point is possible by adding longitudinal hoses and "Tees" for connecting all of the hoses together.

The draft of the system with a maximum capacity of a chemical with a specific gravity of 1.9 is 9.7 feet.

d. Towing Drag

The towing drag of an expandable container with auxiliary flotation cylinders is based on the drags of the "Pillow Tank," the pallet, and the twin flotation cylinders including any interference factor. The factor only applies when the twin cylinders are less than one diameter apart. For this configuration the cylinders are 1.25 diameters apart, thus $X = 1$. The total drag of the concept is:

$$D_{Total} = \text{Drag of Pillow Tank} + \text{Drag of Pallet} + \text{Drag of Flotation Cylinders}$$

$$= \left[\left(C_{D_{PT}} \times S_{PT}\right) + \left(C_{D_P} \times S_P\right) + \left(XC_{D_{BC}} \times S_{BC}\right)\right]q$$

$$= \left[(.6 \times 30.5) + (1.0 \times 1.6) + (1 \times .8 \times 25.1)\right] 284$$

$$= 11{,}350 \text{ pounds}$$

Where :

$C_{D_{PT}} = .6;\ C_{D_P} = 1.0;\ C_{D_{BC}} = .8;\ X = 1.0$

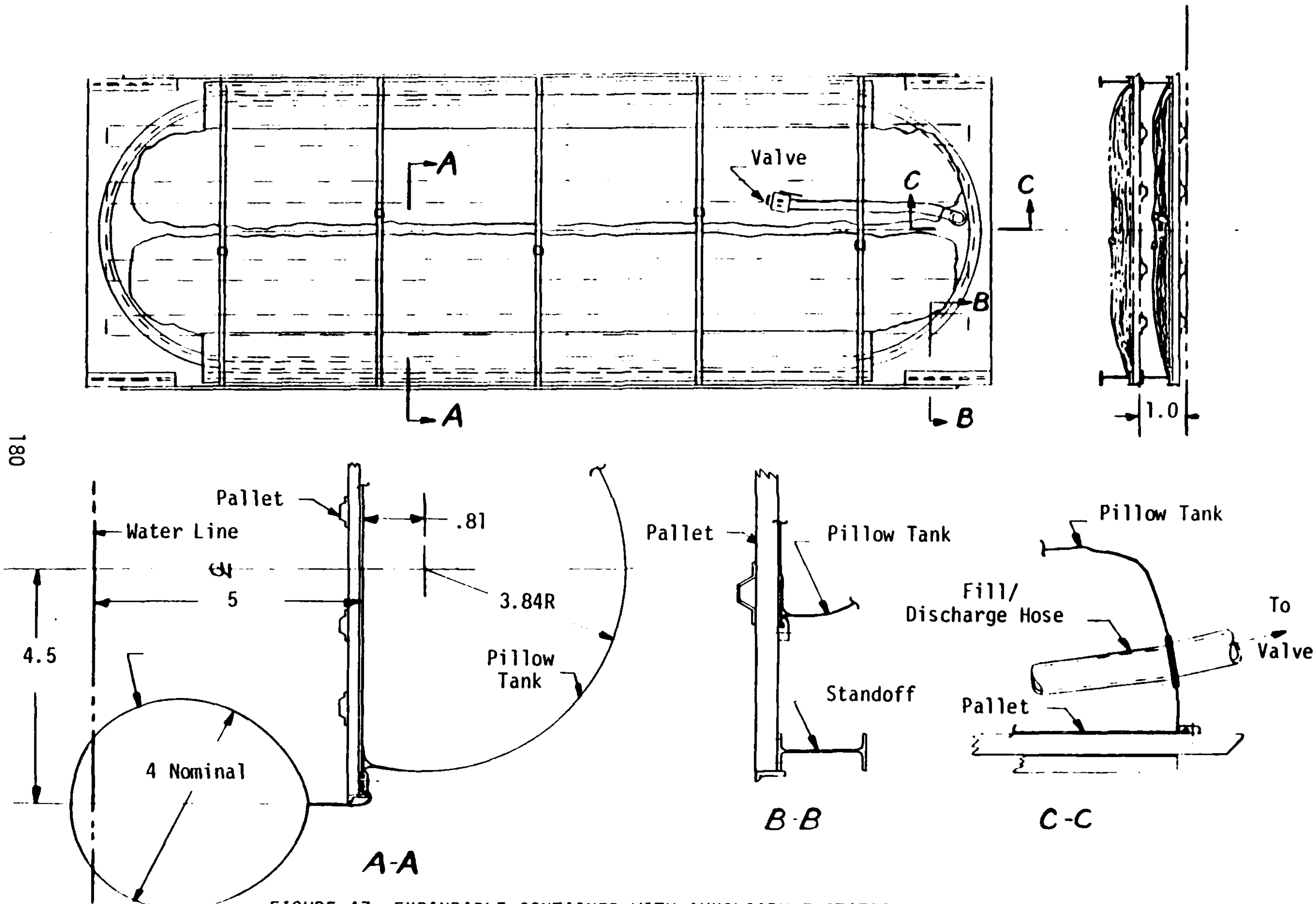


FIGURE 47--EXPANDABLE CONTAINER WITH AUXILIARY FLOTATION CYLINDERS

$S_{PT} = 30.5$ sq. ft.; $S_P = .2 \times 8 = 1.6$ sq. ft.; $S_{BC} = \frac{\pi 4^2}{4} \times 2 = 25.1$ sq. ft.
$q = 284$ PSF at 10 kts.

The total drag of many units hinged closely together consists of the drag of one individual unit representing the front half of the first unit and the rear half of the last unit plus a portion of that value for individual units in between to represent the shielded units.

$$\text{Drag}_{n\text{ units}} = \text{Drag of one Unit} + K(n-1)\text{ Drag of one Unit}$$
$$= 11{,}350 + 2{,}270\,(n-1),\ \text{lbs.}$$

Where : $K = 0.2$ and n = number of units

e. Typical Strength Requirements

1) Pallet

The pallet chosen is made of extruded aluminum and is used with U.S. Air Force air supply systems. Provisions are incorporated for locking the pallet to the aircraft system. The pallets are strong enough for air carriage and handling of the packed container systems. The pallets will also carry the loads associated with towing individual filled containers. The use of pallets in a train requires connections that allow freedom in pitch and roll between pallets or the pallet structure will have to be reinforced. The weights of the pallet materials with clamping provisions for the Pillow Tank include:

Basic pallet extrusion panels	1,477 lbs.
Edge members	62 lbs.
Skids	291 lbs.
Clamp bands	158 lbs.
Total for Materials	1,988 lbs.

Adding 20 percent for fasteners and towing provisions, the weight of the pallet is:

$$\text{Total Weight} = 1.2 \times 1{,}988 = 2{,}385\ \text{lbs.}$$

2) Pillow Tank

The pillow is designed to have a static differential pressure equal to 5 feet of water when filled in still water, thus $p_s = 320$ PSF. The pressure differential due to the action of the waves 12 feet high considers a dynamic factor of 2 and the ratio of the container length to the 1/2 wave length times the height of the waves. The pressure differential due to dynamics is:

$$\Delta p_d = 2(1.9)(62.4)(26/130)12 = 569 \text{ PSF.}$$

The limit load per inch in the fabric considering the shape of the membrane with a flotation cylinder that has a lifting force (T) of 133.3 lbs per inch is:

$$\sigma_{limit} = \frac{\Delta p_s + \Delta p_d}{\Delta p_s} \times T = \frac{889}{320} 133.3 = 370 \text{ lbs/inch}$$

The ultimate fabric strength requirement is 4.8 x 370 = 1,778 lbs/inch. A design factor of 4.8 was chosen in place of 4.0 because of the lower efficiencies associated with the clamp attachment.

3) Flotation Cylinders

The flotation cylinders are large enough so that the container follows the slope of the waves under all fill conditions. The selected operating pressures considers the initial position of the cylinders in the water plus the action of waves 12 feet high. Operating pressure is (4.7 + 12)64 = 1,069 PSF. The cylinders that provide 5 percent excess buoyancy have the same cross-sections as the flotation cylinders for the design Approach 1 containers and have the same stress levels (see Appendix A).

$$\text{Tension} = 33.46 \frac{64}{12} = 178.5 \text{ lbs/inch}$$

$$\text{Limit Load} = \sigma \times 178.5 = 2 \times 178.5 = 357 \text{ lbs/inch}$$

Applying a design factor of 4.8 for the reduced efficiency of the "Y" tapes, the ultimate fabric stress (F_{tu}) is:

$$F_{tu} = 4.8 \times 357 = 1{,}714 \text{ lbs/inch}$$

f. Weights and Packed Volumes

The estimated weights and packed volumes for an individual expandable container are presented in Table 33. The rigid pallet comprises the greatest weight of the system. The pallet is sized to occupy the 8 x 26 feet portion of the transportation envelope. The height includes the volume for packing the fabric portions and being able to stack individual containers as packed--on top of each other. The pillow tank size is based on a capacity of 5,000

TABLE 33--WEIGHTS AND PACKED VOLUMES OF A TYPICAL EXPANDABLE CONTAINER CONCEPT FOR CARRYING CHEMICALS WITH A SPECIFIC GRAVITY = 1.9

FACTORS	ONE UNIT	THREE UNITS	FOUR UNITS
CAPACITY, GALLONS	5,000	15,000	20,000
TOWING DRAG, LBS. (10 KTS IN 5 FT. WAVES)	11,350	SEPARATE 3 x 11,350 SERIES 1.4 x 11,350	SEPARATE 4 x 11,350 SERIES 1.6 x 11,350
SURVIVABLE REQUIREMENTS (12 FT. WAVES)			
PILLOW TANK STRENGTH, LB/IN	1,778	1,778	1,778
FLOTATION CYLINDERS, LB/IN	1,714	1,714	1,714
PACKED WEIGHT, LB.	3,349	10,047	13,396
PACKED VOLUME, CU. FT.	8 x 26 x 1	8 x 26 x 3	8 x 26 x 4
CRANE REQUIREMENTS, LBS.	3,349	3,349	3,349
TIME TO RECEIVE CHEMICAL	LESS THAN 4 HOURS	MORE THAN 4 HOURS	MORE THAN 4 HOURS
USEFUL WATER TEMP. RANGE, °C	GREATER THAN -2 TO +30	GREATER THAN -2 TO +30	GREATER THAN -2 TO +30
INITIAL FLOTATION	40 CU FT OF ENCLOSED FOAM	40 CU. FT. OF FOAM EACH	40 CU FT OF FOAM EACH
DRAFT, FT.	9.7	9.7	9.7

gallons. Its surface area is 530 sq. ft. The twin buoyancy cylinders' weights and volumes correspond to the sizes and strengths required to support the system when the container is filled with a chemical having a specifiv gravity of 1.9. The buoyancy cylinders have a nominal diameter of four feet. The fabric area is 312 sq. ft. each.

The total weight and volume of an individual system are such that more than one system can be carried within the transportation limitations. Based on a volume envelope limit of 8 x 26 x 6 ft, six containers can be carried. Based on a weight limit of 15,000 pounds, only four can be carried. The total capacity of the four containers is 20,000 gallons of chemical with a specific gravity of 1.9.

g. Deployment Sequence and Equipment

The major elements in the selected sequence for operating the expandable container include:

1) Either deploying the system using a crane or sliding the system into the water. Lifting requires a crane with a capability of 3,349 pounds.

2) The twin buoyancy cylinders contain foam strips to provide initial buoyancy.

3) Air is added to the twin buoyancy cylinders until they are filled and pressurized to the design operating pressure using an auxiliary air supply.

4) Chemical is pumped into the tank, expanding the tank.

5) Towing is conducted.

6) The chemical is pumped out, collapsing the tank.

7) The air cylinders are deflated.

8) The container is lifted aboard for refurbishment, repacking of the Pillow Tank and the air cylinders, and for reuse.

The twin buoyancy cylinders are pressurized to maintain their volumes under wave heights of 12 feet. The total volume corresponds to floating the system when filled with a chemical having a specific gravity of 1.9. The operating oressure is 1,069 PSF, and the total volume is 637 cu. ft.

The work associated with filling the cylinders is PV = 680,953 lbs.ft. If the work is accomplished in one hour, the horsepower developed is:

$$\text{Horsepower} = \frac{PV}{33{,}000 \times 60} = .34$$

Thus, the horsepower required for the air supply system is fairly small.

h. Summary of the Physical Characteristics of an Expandable Container Concept for Chemicals with a Specific Gravity = 1.9

The major physical characteristics of an expandable container concept are listed in Table 34. The capacity of an individual container is 5,000 gallons of chemical. That maximum number of containers, based on transportation limitations, is four;and their capacity is 20,000 gallons of chemicals. The towing drag of an individual container and of more than one container in a series are listed. The drag value for one container is similar to the value for a 25,000 gallon all flexible container. The strengths of the fabric materials are based on surviving the actions of waves 12 feet high. The materials used in available aircraft pallets are based on handling and aircraft safety requirements.

The weights and volumes are within the transportation limitations; however, the weight of one unit approaches the values for the 25,000 gallon all flexible container concepts.

The expandable containers require a crane with a lifting capacity equal to the weight of an individual unit; ie, approximately 3,349 pounds.

The expandable container design concept can meet the requirements relative to the deployment time to receive chemicals, operating temperature range, and providing initial flotation.

The draft of the system concept, 9.7 feet, approaches the limit of 10 feet.

TABLE 34--PHYSICAL CHARACTERISTICS OF TYPICAL EXPANDABLE CONTAINER CONCEPTS FOR CARRYING CHEMICALS WITH A SPECIFIC GRAVITY = 1.9

Components	Weights, lbs.	Packed Vol., Cu. Ft. or Envelope Dimensions, Ft.
Pallet and Clamp, Aluminum	2,385	8 x 26 x 1 max. dimensions
Pillow Tank, Fabric	277	18 cu. ft.
Liner, Fabric	74	5 cu. ft.
Flotation Cylinders, Fabric	303	20 cu. ft.
Initial Flotation (Using 40 cu. ft. of foam)	160	40 cu. ft.
Stabilization Device, Hoses, and Fittings	150	15 cu. ft.
Totals	3,349	8 x 26 x 1 includes 98 cu. ft. of fabric

4. Typical Concepts for Modifying Present All-Flexible Containers

a. General

Concepts to modify present all-flexible containers were based on only increasing the buoyancy capability of these units. Two present containers were investigated; ie, the Dracone model D and model F. The chemical specific gravity selected for design was based on the most dense chemical that the fabric materials of these units can contain. Design material strength of 1,000 lb/inch and 1,400 lb/inch, respectively, were then used to determine the limiting wave height for survivability with the most dense chemical that the fabric material can contain for 200 hours. The strength, weight, and volume of the auxiliary flotation cylinders were calculated for the same design condition limits that were calculated for the basic container. The weights and volumes for the flotation cylinders were added to the published values for the Dracone units.

b. Investigation of Design Materials for Chemical Compatibility and Determining Chemical Specific Gravity for Design

The results of the chemical compatibility efforts are listed in Table 35. Eleven of the chemicals can be contained by the fabric material, and three of the eleven chemicals have specific gravities greater than one. Two of the heavy chemicals, caustic soda and copper fluoroborate, have specific gravities of 1.5 and 1.54, respectively. Thus, a chemical specific gravity of 1.54 was selected for design of the flotation cylinders and determining the performance limits of the modified containers.

c. Typical Design Concepts

Typical design concepts for modifying two of the present all-flexible containers so they can carry chemicals with a specific gravity of 1.54 are presented in Figures 48 and 49. The containers are modified by attaching twin flotation cylinders. The cylinders must support the container when it is full and when it is partially filled and limp. The cylinders are continuously attached along the central chemical container to transmit the drag and flotation forces under all conditions. The drafts of the two systems are 6.3 feet and 12 feet, respectively, when filled with a chemical having a specific gravity of 1.54.

TABLE 35--MATERIAL COMPATIBILITIES WITH CHEMICALS, CHEMICAL SPECIFIC GRAVITIES, AND REQUIREMENTS FOR AUXILIARY FLOTATION

U.S. Coast Guard Hazardous Chemical List	Material Compatibility Nitrile (Med) Nylon Yes or No, 200 hrs.	Chemical Specific Gravity @ 20°C	Auxiliary Flotation Required for Compatible Chemicals Yes or No
Acetic Acid	N	1.051	N
Acetic Anhydride	N	1.08	N
Acetone	N	0.791	N
Acrylonitrile	N_3	0.8075	N
Ammonia (28% aq)	N_3	0.899	N
Benzene	N	0.879	N
Caustic Soda (Solution)	Y	1.5	Y
Copper Fluoroborate	Y	1.54	Y
Copper Naphthenate	Y	0.93-1.05	Y
Cresols	N	1.03-1.07	N
Cyclohexane	Y	0.779	N
Ethyl Acetate	N	0.902	N
Ethyl Acrylate	N	0.923	N
Ethyl Alcohol	Y	0.79	N
Ethylene Dichloride	N	1.253	N
Hexane	Y	.659	N
Hydrochloric Acid	N	1.19	N
Isopropyl Alcohol	Y	0.785	N
Methyl Acrylate	PN	0.956	N
Methyl Alcohol	Y	0.792	N
Methyl Ethyl Ketone	N	0.806	N
Nitric Acid (Conc.)	N	1.49	N
Oleum	N	1.91-1.97	N
Phenol	N_3	1.058	N
Phosphoric Acid	N	1.892	N
Styrene	N_3	0.906	N
Sulfuric Acid (Dilute)	N	1.84 (98%)	N
Toluene	N	0.867	N
Turpentine	Y	0.86	N
Vinyl Acetate	N	0.934	N
Xylene m,p,o	N	0.864,0.861,0.880	N
Xylenol	N_7	1.01	N
Hydrocarbon Fuels	Y	<1.0	N
Fresh and Sea Water	Y	1.0-1.026	N
Chem. with Y Ratings	11		

Notes: See Table 2

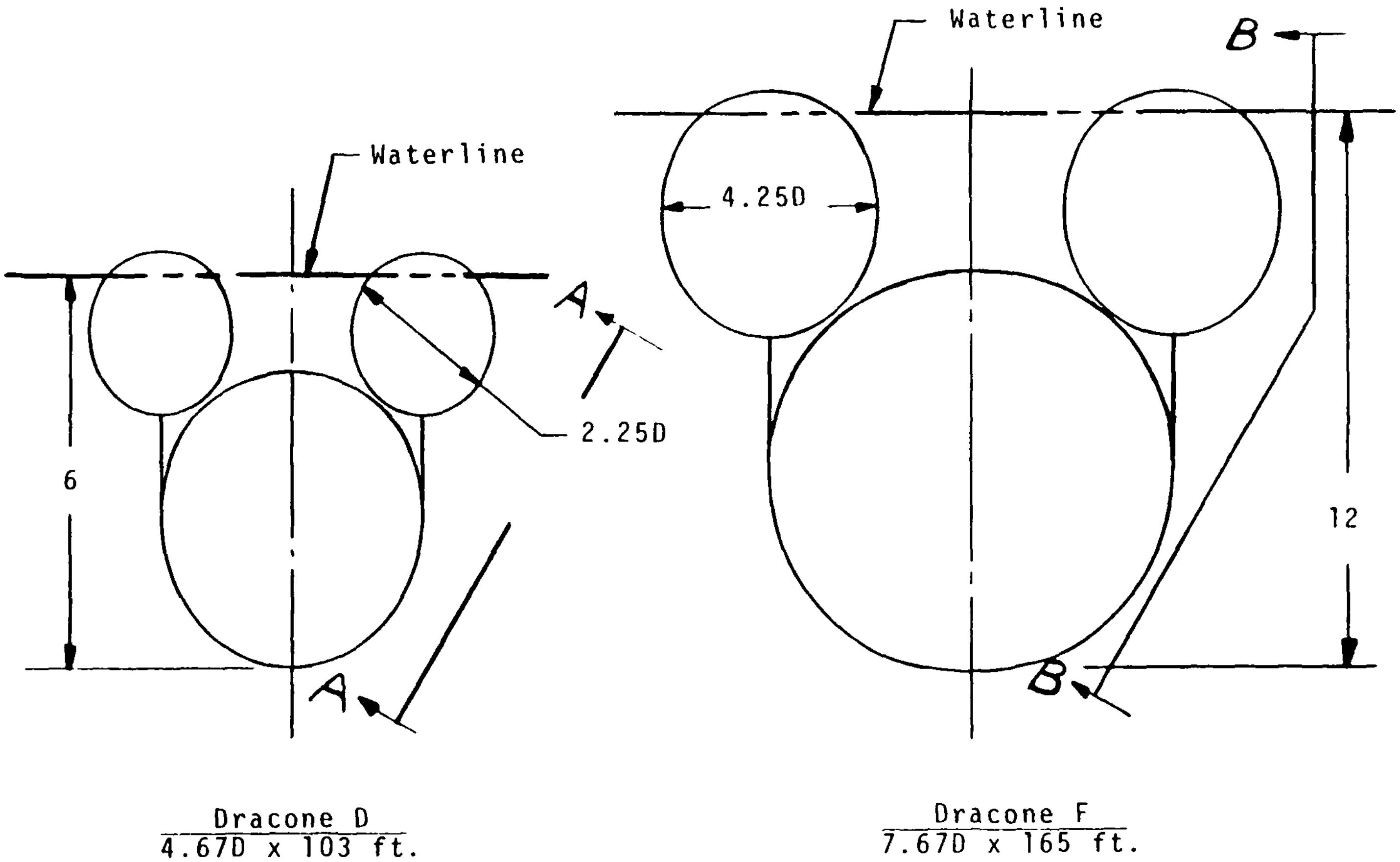
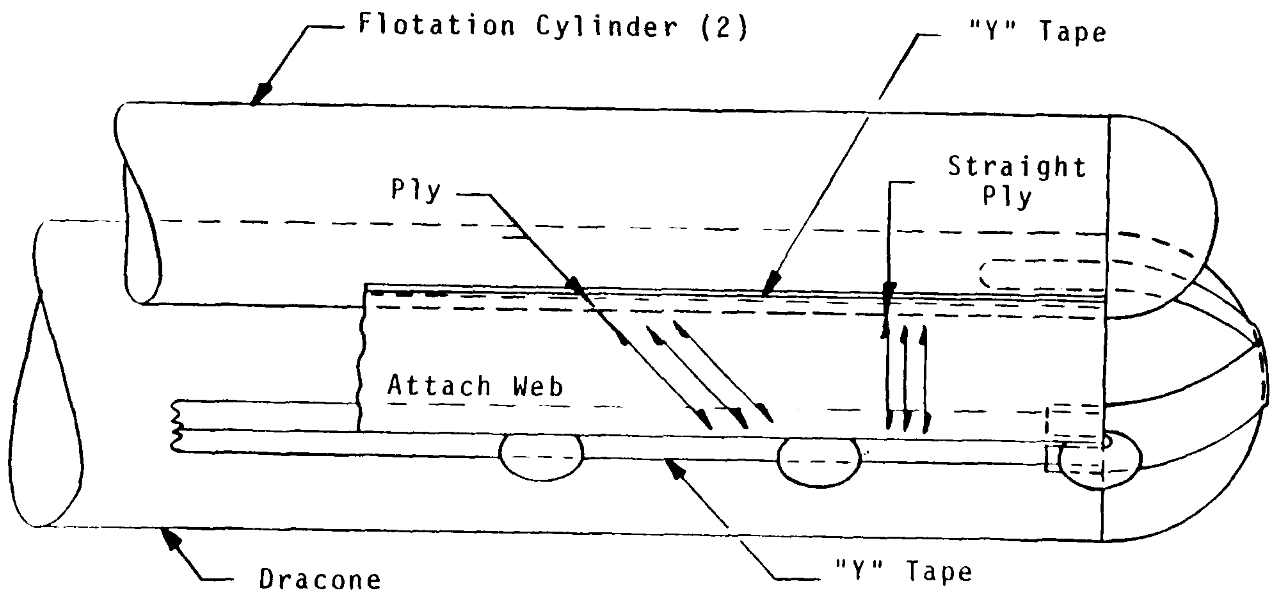


FIGURE 48--MODIFICATION TO PRESENT FLEXIBLE CONTAINERS BY ADDING TWIN FLOTATION CYLINDERS



Sections A-A and B-B

FIGURE 49--ATTACHMENT OF TWIN CYLINDERS TO DRACONES

d. Towing Drag

The towing drag of the modified containers consist of the drag of the basic container plus the drag of the twin buoyancy cylinders, including any interference factor. The total drag of the concepts are:

1) Modified Dracone D

$$D_{Total} = \left[\left(C_{D_{CC}} \times S_{CC}\right) + \left(XC_{D_{BC}} \times S_{BC}\right)\right] q$$

$$= \left[(.78 \times 17.1) + (1.1 \times .78 \times 9)\right] 284 = 5{,}993 \text{ pounds}$$

Where:

$C_{D_{CC}} = .78$; $X = 1.1$; $C_{D_{BC}} = .78$; $S_{CC} = 17.1$ sq. ft.

$S_{BC} = 9$ sq. ft.; $q = 284$ PSF @ 10 kts.

2) Modifed Dracone F

$$D_{Total} = \left[\left(C_{D_{CC}} \times S_{CC}\right) + \left(XC_{D_{BC}} \times S_{BC}\right)\right] q$$

$$= \left[(.78 \times 46) + (1.2 \times .78 \times 28.4)\right] 284 = 17{,}739 \text{ pounds}$$

Where:

$C_{D_{CC}} = .78$; $X = 1.2$; $C_{D_{BC}} = .78$; $S_{CC} = 46$ sq. ft.

$S_{BC} = 28.4$ sq. ft.; $q = 284$ PSF @ 10 kts.

e. Performance Limitations Based on Design Strength of Materials

1) Limiting Wave Height

The Dracone D has a diameter of 4.67 feet, is 103 feet long, and is made of fabric with an ultimate tensile strength of 1,000 pounds/inch and a limit stress of 250 pounds/inch with a design factor of 4. The limiting wave height can be calculated considering the limit stress, the static differential pressure, the design factor, the dynamic differential pressure, the shape, and other factors.

$$\text{Limit Stress} = \sigma = F_{tu}/DF = (\Delta P_S + \Delta P_D H)\ 2.335$$

$$\frac{1{,}000}{4} = (128 + 192.2H)\ 2.335 \text{ and } H = 6.02, \text{ feet.}$$

Where: $\Delta P_S = 2(64) = 128$ PSF; $\Delta P_D = 2 \times 1.54 \times 62.4H = 192H$,PSF

The Dracone F has a diameter of 7.67 feet, is 165 feet long, and is made of fabric with an ultimate tensile strength of 1,400 pounds/inch and a limit stress of 350 pounds/inch with a design factor of 4. The limiting wave height can be calculated in the same manner.

$$\text{Limit Stress} = \sigma = F_{tu}/DF = (\Delta P_S + \Delta P_D H)\ 2.335$$

$$= 1{,}400/4 = (144 + 192H)\ 2.335 \text{ and } H = 4.95 \text{ or } 5 \text{ feet.}$$

Where: $\Delta P_S = 2(64) = 128$ PSF; $\Delta P_D = 2 \times 1.54 \times 62.4H = 192H$,PSF

2) Flotation Cylinders for Operation and Limiting Wave Height

The buoyancy force required to float the D container filled with a chemical with a specific gravity = 1.54 is 580 pounds per ft. The nominal diameter of each of the twin flotation cylinders is 2.25 feet, and the total surface area of the two is 1,554 square feet.

The selected operating pressure in the cylinders is based on the wave height and the distance the apex of the cylinder is underwater; ie, (6 + 3)64 = 576 PSF. From this operation pressure and the buoyancy force, the shape and tension (T) in the fabric was calculated, Appendix D.

$$T/64 = 10.38 \text{ PSF or } T = 10.38\left(\frac{64}{12}\right) = 55.4 \text{ lb/inch}$$

Considering dynamics, $\sigma = \alpha T = 111$ lb/in; $\alpha = 2$

Ultimate Strength = 4.8 x 111 = 532 lb/inch

The buoyancy force required to float the F container filled with a chemical with a specific gravity = 1.54 is 1,047 pounds per ft. The nominal diameter of each of the twin flotation chambers is 4.25 feet and at the total surface of the two is 3,976 square feet.

The selected operating pressure in the cylinders is 7 x 64 = 448 PSF. From this pressure and the buoyancy force, the shape and tension (T) in the fabric was calculated, Appendix D.

$T/64 = 13.08$ PSF or $T = 13.08\left(\frac{64}{12}\right) = 69.8$ lb/inch

Considering dynamics, $\mathcal{T} = \alpha T = 140$ lb/inch; $\alpha = 2$

Ultimate Strength = 4.8 x 140 = 670 lb/inch

f. Weights and Packed Volumes

The estimated weights and packed volumes for the modified containers are presented in Table 36. The weights of the basic container and towing hose were determined from published information. The weights of the buoyancy cylinders and attachments were calculated considering the strength and weights of Nitrile/Nylon cloth fabric materials. The weights and packed volumes are well within the requirements for the smaller unit. The weight of the larger unit is approximately one half the weight limit.

g. Deployment Sequence and Equipment

The major elements in the selected sequence for the modified units include:

1) Deploying the system by faked it into the water using a crane. The weight of the folds are less than the capability of a crane with a 1,000-pound capacity.

2) The foam enclosed in the buoyancy cylinders provides initial buoyancy.

3) Air is added to the twin buoyancy cylinders until they are filled and pressurized to the design operating pressure using an auxiliary air supply.

4) Chemical is pumped into the central container expanding it.

5) Towing is conducted.

6) The chemical is pumped out, collapsing the basic container.

7) The air cylinders are deflated.

8) The container is faked board for refurbishment, repacking, and reuse.

TABLE 36--WEIGHTS AND PACKED VOLUMES OF PRESENT FLEXIBLE CONTAINERS MODIFIED TO CARRY CHEMICALS WITH A SPECIFIC GRAVITY = 1.54

Components	Modified Dracone D		Modified Dracone F	
	Weight, lb.	Packed Vol, cu. ft.	Weight, lb.	Packed Vol., cu. ft.
Container	2,440	165	6,350	295
Flotation Cylinder	300	20	1,000	67
Towing Hose	175	45	175	45
Totals	2,915	230	7,525	407

The twin buoyancy cylinders are pressurized to maintain their volumes under wave actions. The total buoyancy cylinder volumes are based on containers filled with chemicals having a specific gravity of 1.54.

1) Modified Dracone D Cylinders, total

PV = 576 x 933 = 537,400 lb/ft; P = 576 PSF; V = 933 cu. ft.

$$\underset{\text{One Hour}}{\text{Horsepower}} = \frac{PV}{33{,}000 \times 60} = .27$$

2) Modified Dracone F

PV = 448 x 2,700 = 1,209,600 lb/ft.; P = 448 PSF; V = 2,700 cu. ft.

$$\underset{\text{One Hour}}{\text{Horsepower}} = \frac{PV}{33{,}000 \times 60} = .61$$

Thus, a relatively small air supply system can inflate the cylinders in one hour.

h. Summary of the Physical Characteristics of Present All-Flexible Containers Modified for Chemicals with a Specific Gravity = 1.54

The major physical characteristics of container concepts consisting of modified present all-flexible containers are presented in Table 37.

The smaller container carries less than the required 25,000 gallons. The other container can carry more than 25,000 gallons.

The towing drags correspond to the all-flexible containers discussed as design Approach 1, considering size and the specific gravity of the chemical used for design.

Survivability limits are reduced for these containers because of the present fabric strengths for the container.

The packed weights and volumes are within the transportation limits. In fact, several of the modified smaller containers can be transported within the limits of the 3.1 Requirements.

TABLE 37--PHYSICAL CHARACTERISTICS OF PRESENT ALL-FLEXIBLE CONTAINER CONCEPTS MODIFIED TO CARRY CHEMICALS WITH A SPECIFIC GRAVITY = 1.54

CHARACTERISTIC	MODIFIED DRACONE D	MODIFIED DRACONE F
CAPACITY, GALLONS	11,526 (TOWING)	42,534 (TOWING)
TOWING DRAG, LBS. (10 KTS IN 5 FT WAVES)	6,000	17,700
SURVIVABILITY LIMITS, WAVE HEIGHT, FT.	6	5
PACKED WEIGHT, LBS.	2,915 (NET)	7,525 (NET)
PACKED VOLUME, CU. FT.	230 (NET)	407 (NET)
CRANE REQUIREMENTS, LBS.	< 1,000	< 1,000
TIME TO RECEIVE CHEMICAL	LESS THAN 4 HOURS	LESS THAN 4 HOURS
USEFUL WATER TEMP. RANGE, °C	GREATER THAN -2 TO +30	GREATER THAN -2 TO +30
INITIAL FLOTATION, CU. FT. OF FOAM	15	15
DRAFT, FT.	6.3	12

The values for the lifting capacity of the crane, the time to receive chemicals, and the useful range of water temperatures for operating the system all appear to be within the 3.1 Requirements. The draft of the smaller container is 6 feet, while the draft of the larger container is 12 feet, compared to the draft limit of 10 feet.

5. Advantages and Disadvantages for Other Container Concepts Considering Operational and State-of-the-Art Factors

Items selected for describing the advantages and disadvantages of rigid, expandable, and modified all-flexible container concepts are presented in Table 38. The values presented are based on judgments for the operational and state-of-the-art items. The ratings for the operational items are based on how much more difficult it will be to operate these different container concepts than it is to operate an all-flexible container system designed for chemicals with a specific gravity of one. Ratings are from 1 to 5 and ratings of 1 equal the same difficulty; 3 equal several times the difficulty; and 5 equal an order of magnitude increase in difficulty. The operational factors include: transportability, training, deploying (including special equipment), filling, towing, discharging, retrieval, and refurbishing (including repacking).

Transportability is based on the packed weight and the packed volume of the container. Container weights range from two to eight times the weights of an all-flexible container designed for chemicals with a specific gravity of one. The packed volumes are limited by the transportation requirements for the rigid containers. The ratings are associated with the relative weights and bulks of the containers to that of an all-flexible system.

More difficulty in training is associated with teaching any added operations associated with providing bucyancy and controlling its air pressures, filling/discharging, towing, connecting, and refurbishing the containers. All designs require the crew to operate an air system to inflate either a flotation or attitude control system. Training effort is judged to be approximately two times that required for an all-flexible container designed for chemicals with a specific gravity of one.

TABLE 38--ADVANTAGES AND DISADVANTAGES OF CONTAINER CONCEPTS CONSIDERING OPERATIONAL AND STATE-OF-THE-ART FACTORS

Items	Rigid Containers		Expandable Containers		Mod. Pres. Flex Containers	
	Aux. Flotation	Integral Flotation	Single	Multiple	Dracone D	Dracon F
Operational--Relative to a Single Container Designed for a SP GR = 1.0						
--Transportability	5	5	2	2	2	3
--Training	1.5	2	2	2	2	2
--Deploying	4	4	2	2	2	2
--Filling Function	1	1.5	1	1.5	1	1
--Personnel Exposure	1	1	1	1.5	1	1
--Towing Stability	2	4	2	2	2	2
--Operating Partially Filled	1	4	2	2	2	2
--Discharging	1	1.5	1	1.5	1	1
--Retrieving	3	3	2	2	2	2
--Refurbishing	2	1.5	2	2	2	2
Fabrication State-of-Art						
--Construction	1	1	1	1	1	1
--Obtaining Fabric Seam Strengths	2	1	1.5	1.5	1	1
--Retaining Fabric Seam Strengths	1	1	1	1	1	1

The difficulty of deploying the container is associated with placing it into the water, extending it in some designs, and adding all of the air for flotation prior to loading the chemical. The difficulty of placing it into the water is associated with the container's weight, bulk, its flexibility, and the technique used to pack the container. The weight of the heaviest segment was used as the basic criterion. Extending the modified all-flexible container to its length should be of the same order of effort as for other all-flexible containers. Rating for adding air to the flotation cylinders or to the attitude control torus is associated with number and location of fill points.

The difficulty of filling the container with chemicals is associated with the number of fill points and any other operations necessary to accomplish filling. The rigid container concept has a single point for filling. The expandable container can consist of several units; however, a single filling point appears reasonable. Concepts that modify present all-flexible containers retain the single fill point for the chemicals.

The difficulty of limiting the exposure of personnel to the chemicals is associated with the number of hose connections to be made and whether the men might be exposed to spilled chemicals in the water. Containers with single fill points for the air and for the chemical were judged to have exposure potentials equal to the present systems.

Towing difficulty is associated with container drag and stability during tow when it is filled to capacity and when it is partially filled. Rigid container concepts are blunt, have considerable drag, and require testing for towing. The shapes of the other container concepts also require testing to develop the bridle shape and fence shapes for successful towing.

The discharging function is similar to the filling function and the same ratings are repeated.

The relative difficulty in retrieving the containers is associated with the weight of the heaviest segment that must be placed on board with a crane. The ratings are similar to those for deployment.

The relative difficulty for refurbishing the containers is related to cleaning, checking out, repairing, and repacking them considering any special equipment. The difficulty of cleaning the containers may be similar for one large or several smaller containers. Checking out the container's flotation cylinders or attitude control torus will require an air supply system not normally available. Factory air supplies normally are low-volume, high-pressure systems that require long time periods and excessive horsepower to accomplish a check-out task. Repairing the large containers with single compartments will be more difficult than repairing smaller containers. In fact, a badly damaged expandable container unit can be removed from a container train for its operation at a reduced capacity. Difficulty of repacking the containers is associated with weight, bulk, and the amount of items to be repacked.

Fabrication state-of-the-art ratings consider the state-of-the-art for constructing containers of candidate materials, the state-of-the-art for seam strengths, and the state-of-the-art for retaining seam strength after immersion in the different chemicals. The rigid containers use state-of-the-art techniques for the rigid structure. The flotation cylinder fabrics are woven cloth and require seams. The basic fabrication process is state-of-the-art with the fabric materials. Developing good efficiency seams with 2,400 pound/inch fabrics, however, will take engineering efforts. Sewn seams are expected to retain an acceptable portion of their initial load capability after chemical exposure. The rigid portion of the expandable container can be constructed using state-of-the-art techniques that develop and retain high-strength seams and joints. The fabric portion of the container can be constructed using state-of-the-art fabrics that are sewn and bonded together to develop and retain high-strength seams. One pillow tank made from Nitrile (High Vinyl) Nylon fabric and one made from Butyl/Polyester fabric with a liner are candidates for containing all 34 chemicals. The seam strength requirements are 1,700 pounds per inch. Testing will be required to confirm initial and long-term seam strengths immersed in these chemicals.

Modifications to present all-flexible containers are based on their use with 11 chemicals and limited sea state conditions. The basic container material and seam strengths are state-of-the-art. The materials and seam strength requirements for the flotation cylinders are less than for the basic containers. Attaching the flotation cylinders to the basic container using "Y" tapes will require testing to establish efficient bonds.

The values in Table 38 have not been totaled because the relative importance of each of the factors listed has not been established. In general, the expandable or the modified Dracone container concepts appear to be the most desirable.

Physical factors were also used to rate the different container concepts, and the results are presented in Table 39. Ratios were set up for each factor so that values greater than one indicate it is less desirable for that factor than present all-flexible containers, and values less than one indicate it is more desirable.

The first factor is the inverse ratio of the concept's capacity for chemicals with a specific gravity of 1.9 relative to 25,000 gallons. The large numbers for the rigid or a single expandable container indicate their limited capacity. The second factor is the inverse ratio of the concept's capacity for chemicals with a specific gravity of 1.0 relative to 25,000 gallons.

The rating for draft is the ratio of the concept's draft with chemicals having a specific gravity of 1.9 to six feet, which is the draft of a 25,000 gallon all-flexible container designed for chemicals with a specific gravity of one.

The ratings for packed weight and packed volumes are ratios based directly on the values for the weights and volumes of the individual container concepts to hold chemicals with a specific gravity of 1.9 to the corresponding values for an all-flexible container that carries 25,000 gallons of chemicals with a specific gravity of one (1,520 pounds and 110 cubic feet, respectively). Large values are associated with the packed weights and volumes for rigid containers.

TABLE 39--ADVANTAGES AND DISADVANTAGES OF OTHER CONTAINER CONCEPTS CONSIDERING PHYSICAL FACTORS

Factors	Rigid Containers		Expandable Containers		Mod. Pres. Containers	
	Aux. Flotation	Integral Flotation	Single	4 Containers	Dracone D	Dracone F
Capacity, $\frac{25,000}{\text{Gallons @ SG} = 1.9}$	3.1	6.9	5	1.25	2.2*	.6*
Capacity, $\frac{25,000}{\text{Gallons @ SG} = 1.0}$	3.1	4.5	5	1.25	2.2	.6
Draft, $\frac{\text{Ft, SG} = 1.9}{6\text{ Ft.}}$	1.8	1.8	1.6	1.6	1.1	2
Packed Wt., $\frac{\text{Wt, SG} = 1.9}{1,520\text{ Lbs.}}$	5 to 8	4.6 to 7.8	2.3	8.7	2.0	4.9
Packed Vol., $\frac{\text{Vol, SG} = 1.9}{110\text{ Cu Ft}}$	15	15	1.7	7.5	2.0	3.8
Towing Force, $\frac{\text{Force}}{6,200\text{ Lbs}}$	2.9	7.1	1.8	2.9 (Series)	1	2.9
Chem. Carried, $\frac{34}{\text{Number}}$	1	1	1(2 Matl's & Liner)	1(2 Matl's & Liner)	3.1	3.1
Crane Requirements/1,000 Lbs.	7.4 to 12.2	7.2 to 12	3.3	3.3	1	1

*Chemical specific gravity of 1.54 was used in place of 1.9 for designing the system because it is sufficient to carry all 11 chemicals that can be contained by the fabric materials.

Towing force ratings are based directly on the ratio of the container concept's drag to the drag of a 25,000 gallon container designed for chemicals with a specific gravity of one; ie, 6,200 pounds.

Since one of the container concepts cannot carry all 34 chemicals, a rating based on the inverse ratio of the container's capability relative to the other design was included.

The ratings in Table 39 have not been totaled because the relative importance of each of the factors listed has not been established. In general, the expandable container concepts appear to be the most desirable for carrying all of the chemicals. If adding three chemicals to the eight that can be presently carried by the Dracone units is significant, then modifications to those containers also appears as a desirable concept.

6. Operational Hardware Costs for Other Container Concepts

The relative production costs are presented in Table 40 as ratios of the costs to contain 25,000 gallons of chemical with these other container concepts to the cost of single 25,000 gallon containers without liners resulting from design Approach 3A.

TABLE 40--PRODUCTION HARDWARE COST RATIOS
OTHER CONTAINER CONCEPTS/DESIGN APPROACH 3A CONTAINER CONCEPTS

Other Container Concepts	Cost Ratio*for 25,000 Gallons
Rigid	
--Auxiliary Flotation	2.1
--Attitude Control Torus	3.9
Expandable	1.0
Modified Flexible	
--Dracone D	1.2
--Dracone F	1.1

*A value of 1.0 equals a unit cost of approximately 150 thousand 1980 dollars.

The relatively large costs for the rigid containers are associated with stainless steel costs. The lower costs for the expandable are based on pallet and pillow tank technology. The costs of the modified Dracones are based on the costs of the Dracone, the flotation cylinders, and their assembly.

The values for these cost ratios can be directly compared with the cost ratios in Table 30 for the flexible containers investigated in Task 1. Cost ratio'svalues up to 3.3 times the cost of a design Approach 3A container concept are indicated in Table 30. From a cost-ratio standpoint, rigid containers with integral flotation and an attitude control torus are less desirable than any of the flexible containers for holding 25,000 gallons of chemical.

SECTION III--SUMMARY

A. Conclusions

1. The results from Task 1 efforts for determining the feasibility of developing a container to meet the 3.1 Technical and Operational Requirements indicate that:

a. All of the container design concepts presented can meet the technical requirements with different degrees of development risk.

1) Container concepts resulting from design Approach 2 use state-of-the-art tire cord fabrication techniques to develop the required strengths; however, these containers are the heaviest of the three design approaches for all-flexible containers.

2) Container concepts resulting from design Approach 1 require improvement in the state-of-the-art of woven fabric seaming techniques to develop the required seam strengths. One of these container concepts has the least weight.

3) Container concepts resulting from design Approach 3 requires development of the filament winding technique for using elastomers in gum form instead of liquid form. The weights of these container concepts are similar to the weights of container concepts using design Approach 1.

b. The large volumes added for flotations; ie, approximately 25,000 gallons, limit the selection of materials for flotation under waves 12 feet high to contained compressed air.

1) Foams with sufficient strength to displace water at these pressures require excessive packing volumes and are relatively heavy.

2) Foams generated at the site become rigid, costly, and difficult to remove, besides being relatively heavy.

3) Air supply systems can be obtained for providing air inflation in approximately one hour; ie, 5 to 10 horsepower systems.

c. Operation of the containers is similar to that for present all-flexible containers with the addition of those operations associated with filling the buoyancy volumes with air.

1) Operational efforts for container concepts from design Approach 1 are only expanded to include those operations associated with filling the twin flotation cylinders with air.

2) Operational efforts for container concepts from design Approaches 2A and 3A are only expanded to include those operations associated with filling the segments with air through a single hose into a manifold system.

d. All of the chemicals on the U.S. Coast Guard Hazardous List can be contained for 200 hours by using two different fabric materials for the container's structure plus adding a liner within the "acid" container.

1) A Nitrile (high-Vinyl) Nylon cloth fabric container will handle 17 of the chemicals.

2) A Butyl-Polyester cloth fabric structure with a Teflon-Glass cloth fabric liner can handle the other 17 chemicals.

2. The results from Task 1 efforts for determining the feasibility of developing a container with less stringent values for the 3.1 Technical and Operational Requirements and other considerations indicate that:

a. Reducing the specific gravity of the chemical to be carried for design reduces the fabric strength requirements and the weight of the container concepts. However, the effect on the overall feasibility of developing the container is not very significant.

b. Container concepts with internal air buoyancy provisions can carry increasing quantities of chemicals as the specific gravities of the chemicals to be carried decrease from the value used for container design until near unity where the geometric limit of the container is reached; ie, chemical plus air volumes.

c. All container concepts can be partially filled or filled while on a barge.

1) Container concepts resulting from design Approach 1 can be filled to approximately 80 percent of rated capacity.

2) Container concepts resulting from either design Approach 2 or 3 can be filled to rated capacity.

d. Operation at partial fill appears possible for all concepts with some reduction in container operating speeds for container concepts resulting from design Approach 1.

1) Containers resulting from design Approaches 2 and 3 are pressurized, will ride high in water, and can be towed at 10 kts.

2) Containers resulting from design Approach 1 will be limp when only partly filled reducing the allowable towing velocity at some fill conditions.

3. The results from Task 1 efforts for determining the effect of variations in the values of 3.1 Requirements on the feasibility of developing a container indicate that:

a. Wave height and the related dynamic actions determine the required fabric strength when the wave height is greater than 8.75 feet; ie, 2 x 8.75 ft waves = 3.5 x 5.00 ft. waves: where: Amplification factor = 2 for static conditions = 3.5 for towing faster than 5 kts.

b. Drag is the function of the towing velocity squared, a container shape factor, and the maximum cross-sectional area of the container.

c. Advances in the state-of-the-art of the basic materials are not required for container development; however, demonstrating improved seam strengths with woven fabrics or demonstrating the filament winding technique using elastomers in gum form can lead to less weight and bulk systems than design Approach 2.

d. The time for setting up the container to receive chemicals can be varied by the packing arrangement, the manpower available, the size of the air lines and air supply, and the number of connections to be made. A four-hour set up time appears reasonable for simple packing approaches.

4. The results from Task 2 efforts for comparing the risks and costs of candidate container design concepts indicate that:

a. Container concepts resulting from design Approach 2 have the minimal technical and development risk; however, their total development costs are 2.5 to 3 times the costs for the least expensive system, Table 29.

b. Operational hardware production costs for container concepts resulting from design Approach 2 are 3.6 times the costs of that for the least expensive container systems.

c. A listing of risk and relative hardware cost ratios for ten systems indicate that cost increases as risk is reduced; ie:

Concept	1	1A	1B	2	2A	3	3A
Development Risk Rating	2 to 3 (a)	2 to 3 (a)	2 to 3 (a)	1	1	2 to 3 (b)	2 to 3 (b)
Hardware Cost Ratio 5 with liners and 5 without	2.1	1.3	2.0	3.6	3.7	2.5	1.4

Where: (a) Risk ratings are associated with constructing high-strength sewn seams for concepts 1 and 1B. A rating of 2 is associated with attaining seam strengths from 1,400 to 1,900 lbs/inch and a rating of 3 is associated with attaining seam strengths from 1,900 to 2,500 lbs/inch. A rating of 2 to 3 for concept 1A is associated with maintaining the strength of the large bonded lapped seam after immersion in the chemicals.

(b) Risk ratings of 2 to 3 for developing and refining the filament winding techniques for the selected materials are based on a rating of 2 for the Nitrile/Nylon containers and a rating of 3 for the Butyl/Polyester containers. The rating of 2 for the Nitrile/Nylon containers is based on successfully filament winding Neoprene/Nylon decompression chambers on an experimental basis where the Neoprene was in gum form. A rating of 3 for the Butyl/Polyester is based on the softer nature of the Butyl rubber in gum form.

5. The results from Task 3 efforts to investigate the relative attractiveness of other container concepts indicate that:

a. Rigid containers have limited capacity when designed to remain within the dimensions of the air transportation envelope.

1) A container with an 8,000 gallon capacity is possible within an 3 x 8 x 26 feet envelope while meeting most of the other 3.1 Technical and Operational Requirements. Draft is 11 instead of 10 feet, and the lifting requirements for the crane is 7,200 to 12,250 pounds instead of the limiting value of 1,000 pounds.

2) The hardware cost ratios for 25,000 gallons of capacity indicate that rigid containers are two to four times the cost of the least expensive 25,000 gallon flexible container, Table 40.

b. The use of more than one expandable container can provide nearly the required capacity when they are designed to be packed together within the transportation weight and volume limits.

1) A container with a capacity of 5,000 gallons is possible using a "Pillow Tank" and an aircraft pallet. The total weight of the individual container concept is 3,349 pounds. Four individual systems can be carried at one time within the 15,000 pound weight limit. The only other 3.1 requirement not met is requiring a crane with a lifting capacity of 3,350 pounds instead of 1,000 pounds.

2) The hardware cost ratios for 25,000 gallons of capacity indicate that five expandable containers are approximately the same cost as the least expensive 25,000 gallon flexible container.

c. Adding auxiliary flotation cylinders to present all-flexible containers increases the number of chemicals that can be carried from 8 to 11.

1) The container material is not compatible with the other chemicals.

2) Thus, the modification adds a capability for only three more chemicals to present containers.

3) The hardware cost ratios for 25,000 gallons of capacity indicate that present container designs modified to carry these three additional chemicals cost approximately the same as the least expensive 25,000 gallon flexible container of Task 1, Table 40.

B. Open Items

The results from the Task 1 and 2 efforts indicate that there are several open items that affect the risks and costs for developing a container concept including:

1. Demonstrating that the filament winding technique is practical with the materials selected for constructing seamless containers that are less costly and less heavy than container concepts from design Approach 2 and less costly than container concepts from design Approach 1.

2. Demonstrating that the required seam strengths are practical with woven fabrics for less costly and less heavy containers than container concepts from design Approach 2.

3. Demonstrating that a chemically tight flexible seam is practical with Teflon-Glass cloth fabrics for excellent chemical compatibility and reasonable liner costs.

C. Recommendations

1. From the conclusions and the open items relative to the feasibility of developing 25,000 gallon containers to meet the requirements of 3.1, it is recommended that:

a. A program be conducted prior to or as the first part of the Preliminary Design Phase to establish the filament winding technique for constructing chemical container concepts for design Approach 3A. This construction technique has a technical advantage in that it is seamless and its strength is not restricted by the state-of-the-art for seam strengths as are the construction techniques for design Approaches 1, 1A, and 1B. The filament winding construction technique also can lead to the least costly system because it uses machinery compared to the extensive hand labor required for constructing the container concepts for design Approaches 1 and 2.

b. Any consideration for advancing the state-of-the-art for seam strength be contingent on the results of the filament winding program.

c. The demonstration of the chemical tightness of a flexible seam using Teflon-Glass cloth fabrics follow the establishment of the filament winding construction technique.

2. From the conclusions of Task 3 for other containers, it is recommended that:

a. Investigation of rigid containers be limited to the smaller spill sizes;

b. Investigation of expandable containers be included for spill sizes to 25,000 gallons;

c. Investigation of modifications to containers made of Nitrile (Medium Vinyl)/Nylon cloth fabrics be limited as they do not appear to be cost effective since only 11 chemicals can be carried with the modifications compared to eight in their present form.

APPENDIX A

STRESS ANALYSIS AND

SHAPE OF THE SUBMERGED CONTAINER

(Design Approach 1 Concepts)

Summary

1. A numerical method to calculate the submerged shape of the flexible container was formulated and is presented herein.

2. The method is applied to a flexible cylinder filled with liquid having a specific gravity greater than 1. The cylinder may be supported either on each side or at the top center as shown in Figures A-1 and A-2, respectively. The latter case also applies to analysis of the supporting buoyant flexible cylinders that are filled with air.

3. Six foot diameter cylinders for containment of the liquids with an internal over pressure equal to twice the external head at the top of the submerged cylinder was used throughout the study.

4. The cylindrical cross-sections were found to remain essentially circular for 2 foot external head and when filled with liquids of specific gravities from 1.1 to 1.9 (See Figure A-3).

5. The method was applied to design Approach 1 concepts discussed in the body of this report. The shapes were calculated for liquid specific gravities of 1.9 to 1.4.

6. Stresses and required strengths are calculated herein. The amplification factors and design factors discussed in the body of this report are applied.

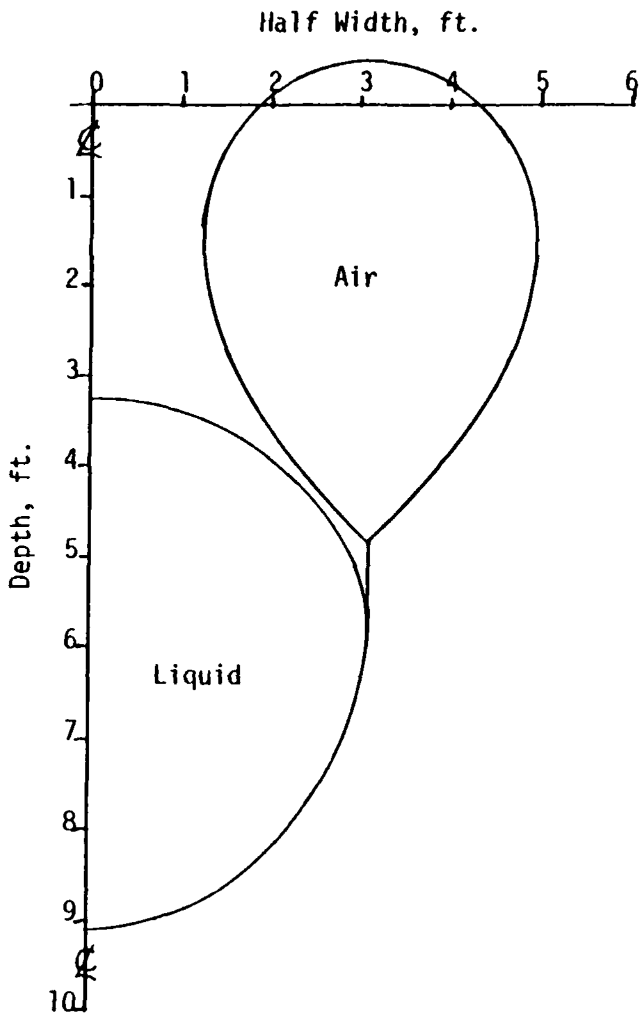


FIG. A-1, Flexible Cylinder Supported By Two Air Chambers (1/2 Section)

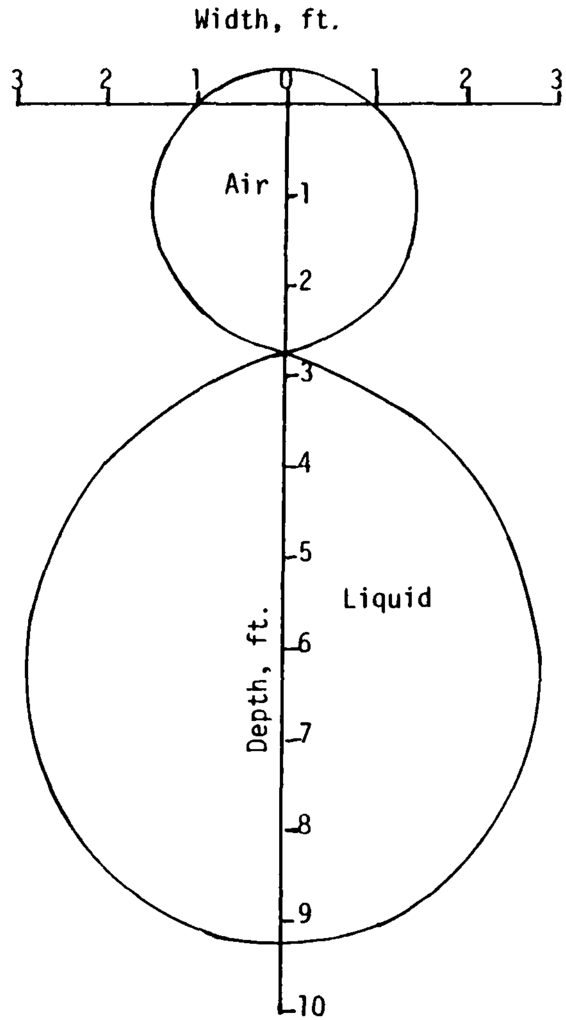


FIG. A-2, Flexible Cylinder Supported By One Air Chamber

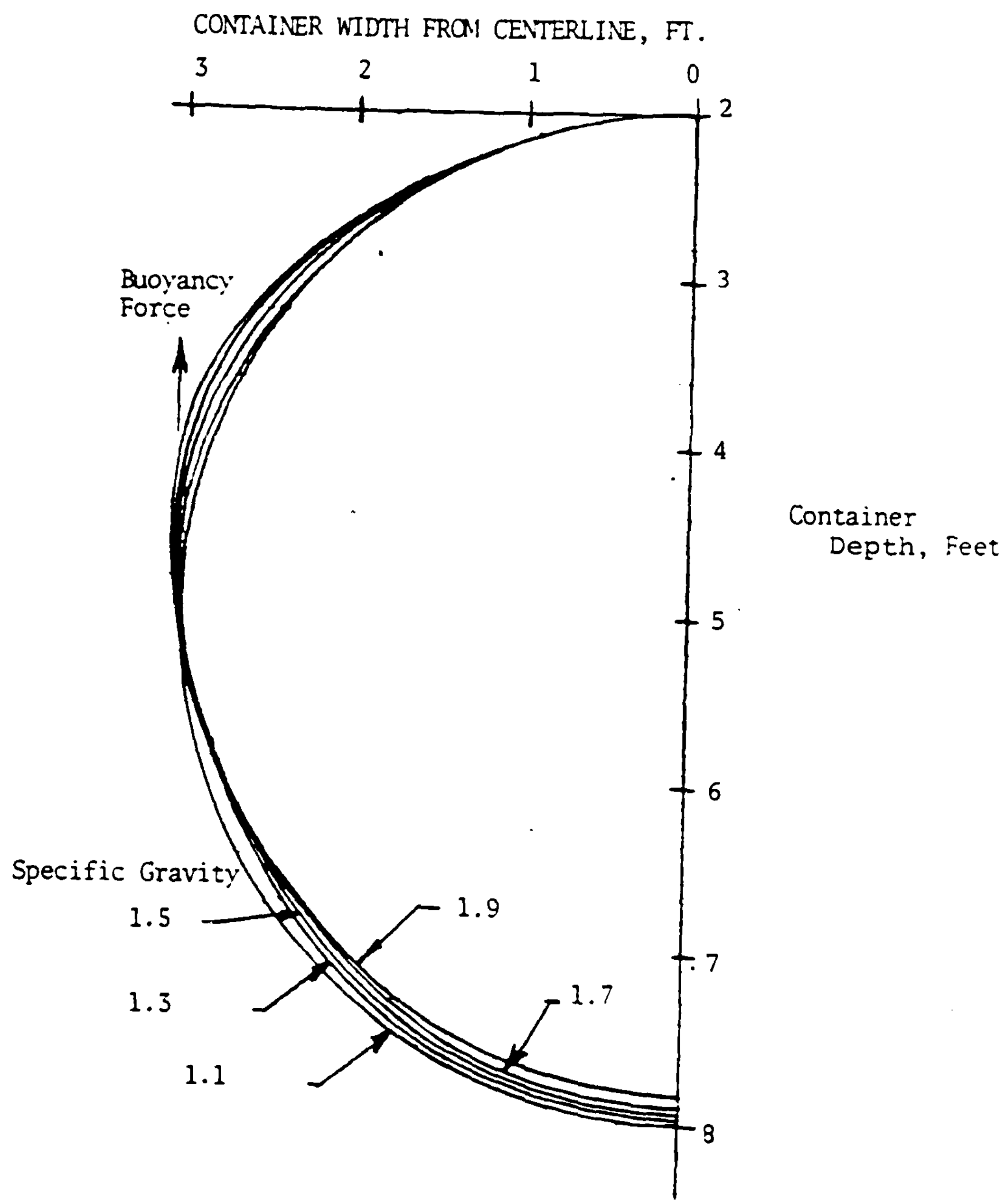


FIGURE A-3 CONTAINER CROSS-SECTIONS WITH LIQUIDS OF SPECIFIC GRAVITIES OF 1.1 THRU 1.9

Numerical Method

An initial boundary value problem is solved whereby a trial value of the membrane tension is made and incremental radii of curvature and arc lengths are calculated starting at $x = y = 0$ and proceeding through the chosen number of increments. Subsequent tension trials are made until the condition of $x = 0$ at the end of the last increment is achieved.

This basic method applies to all shapes of Figures A-1 and A-2 with some variations. The case of the liquid container supported by two air chambers is presented first.

1. Container Supported by Two Air Chambers

Consider the forces acting on one-half the cylinder as sketched in Figure A-4:

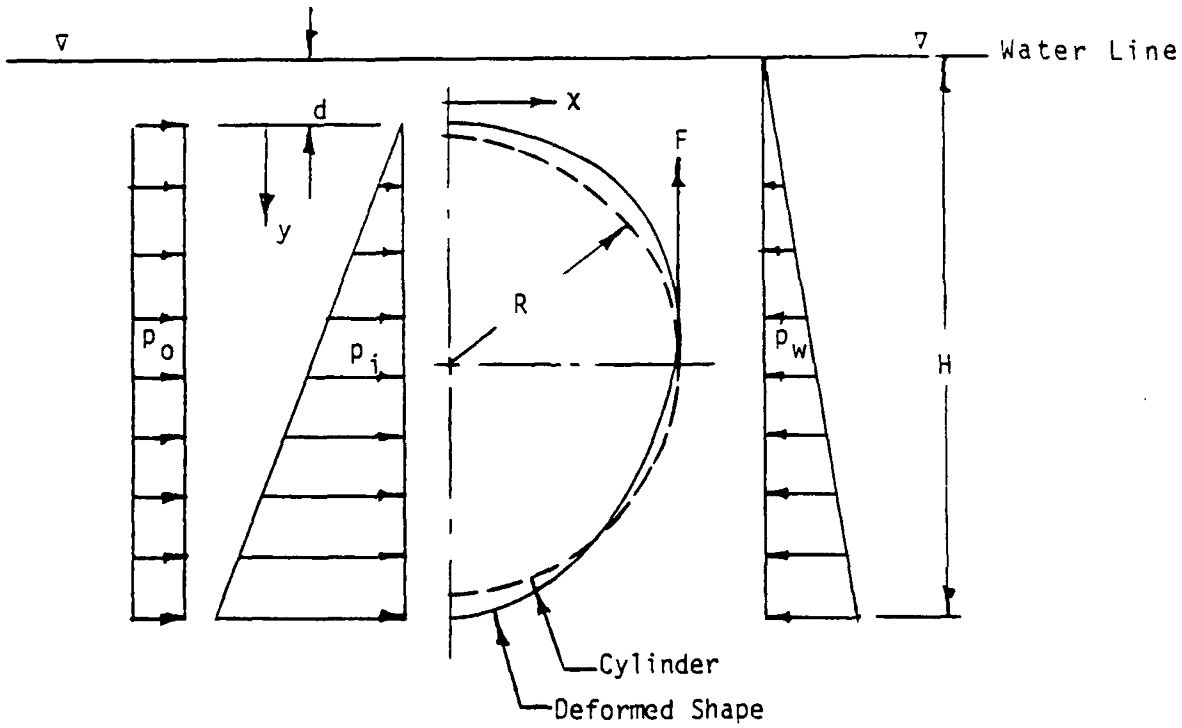


FIG. A-4, Geometry for Two Buoyant Supports

Let:

R = Radius of the undeformed cylinder ~ ft.
F = Buoyancy Force ~ lbs/ft.
H = Draft ~ ft.
d = Depth to top of container ~ ft.
x, y = Coordinates of cross-section ~ ft.
p_o, p_i, p_w = Overpressure, internal pressure and external water pressure, respectively ~ lbs/ft.^2
γ_i, γ_o = Internal and external liquid densities ~ lbs/ft.^3

Because F is unknown in magnitude and in direction, the first step is to solve for the shape in the absence of F. This amounts to placing the force F at $x = 0$, $y = y_F$ as sketched in Figure A-5. Once the solution for this case is found, the force F can be calculated (Eq. 12) and then placed at the equator of the deformed shape. The iterative solution is then repeated to yield the desired shape as sketched in Figure A-6.

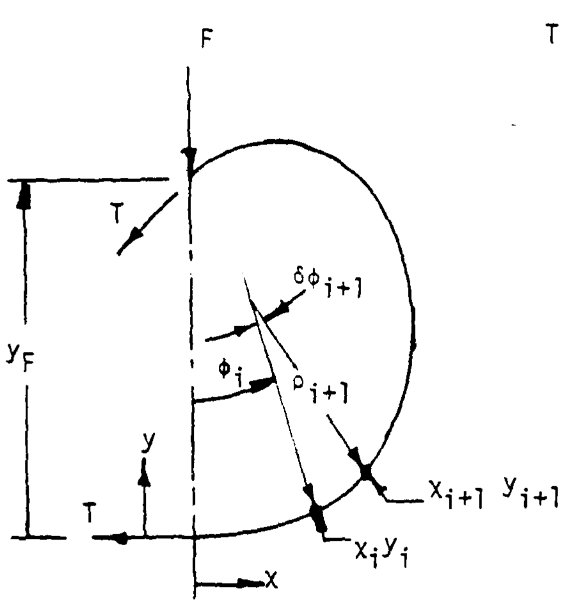


FIG. A-5

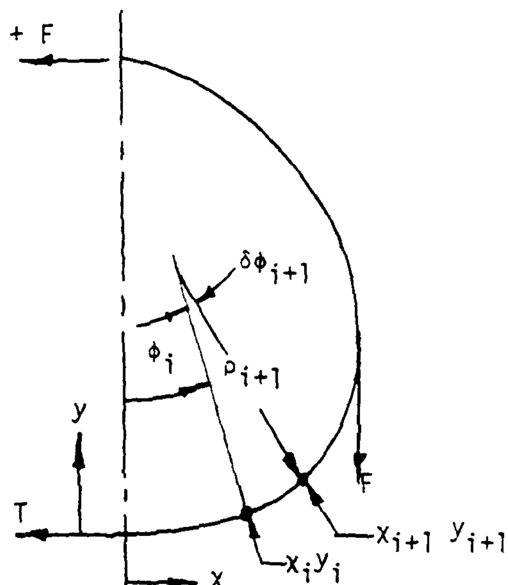


FIG. A-6

In Figures A-5 and A-6, let:

N = Number of increments on the angle, ϕ

$\phi_i, \delta\phi_i$ = Polar angle and incremental angle, respectively ~ radian

ρ = Local radius of curvature ~ ft.

T = Membrane tension ~ lbs/ft.

x_i, y_i = Coordinates of point i on the shape ~ ft.

l_c = Chord length of local arc ~ ft.

The following equations apply:

From Figure A-4, the gage pressure is:

$$\Delta p = p_o + p_i - p_w = p_o + (\gamma_i - \gamma_o) y - \gamma_o d$$

or:

$$\Delta p/\gamma_o = \frac{p_o}{\gamma_o} + \left(\frac{\gamma_i}{\gamma_o} - 1\right) y - d \qquad (1)$$

Consider only the case of: $\dfrac{p_o}{\gamma_o} = 2d$ (2)

$\therefore$

$$\frac{\Delta p}{\gamma_o} = d + \left(\frac{\gamma_i}{\gamma_o} - 1\right) y \qquad (3)$$

The membrane tension is given by:

$$T = \Delta p \rho \qquad (4)$$

or:

$$\rho = \frac{T}{\Delta p} = \frac{T/\gamma_o}{\Delta p/\gamma_o} \qquad (5)$$

By geometry of Figures A-5 and A-6:

$$\delta\phi = \frac{\pi R}{N\rho} \qquad (6)$$

$$\phi_{i+1} = \phi_i + \delta\phi_{i+1} \qquad (7)$$

$$l_c = 2\rho \sin \delta\phi/2 \qquad (8)$$

$$X_{i+1} = X_i + l_{c_{i+1}} \cos\left(\phi_i + \frac{\delta\phi_{i+1}}{2}\right) \qquad (9)$$

$$y_{i+1} = y_i + l_{c_{i+1}} \sin\left(\phi_i + \frac{\delta\phi i+1}{2}\right) \qquad (10)$$

The area of the deformed cross-section is:

$$A = 1/2\ \xi_0^N\ (x_i + x_{i+1})\ (y_{i+1} - y_i) \qquad (11)$$

The required buoyancy force is:

$$F = (\gamma_i - \gamma_0)\ A$$

or:

$$F/\gamma_0 = 1/2\left(\frac{\gamma i}{\gamma_0} - 1\right) \xi_0^N\ (x_i + x_{i+1})(y_{i+1} - y_i) \qquad (12)$$

2. Shape of the Air Chambers

Consider the forces acting on one-half the air chamber as sketched in Figure A-7:

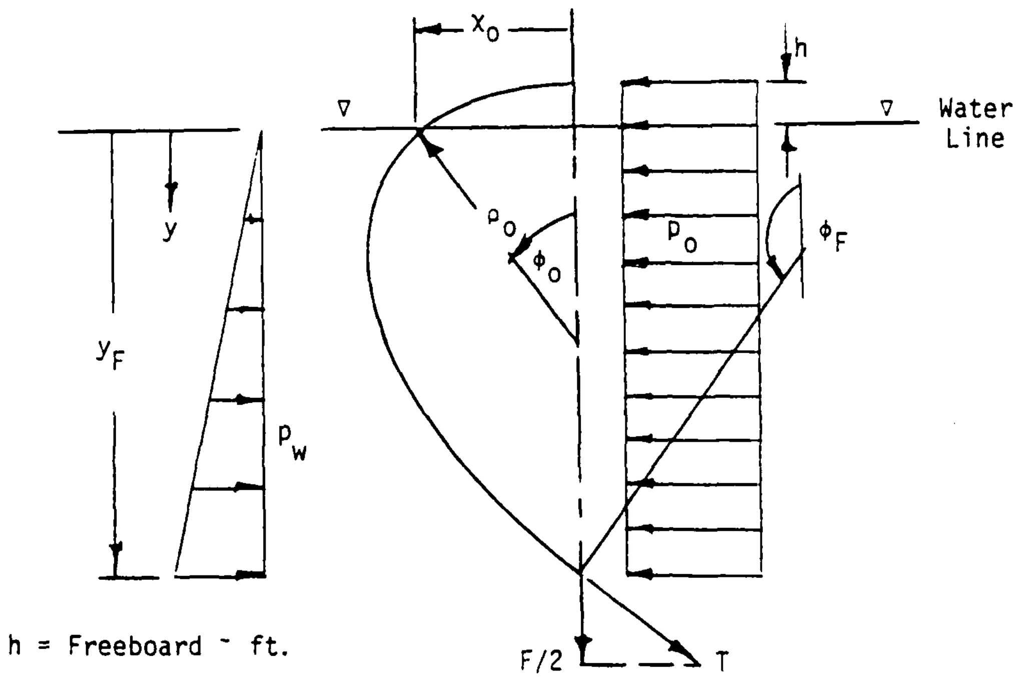


FIG. A-7, Geometry for Air Chamber

The preceeding equations are again applied except the initial values are not x = 0, y = 0. Rather, a freeboard is assumed along with the initial trial tension so that:

$$\rho_o = T/p_o \tag{13}$$

$$\phi_o = \cos^{-1}\left(1 - \frac{h}{\rho_o}\right) \tag{14}$$

and,

$$x_o = \rho_o \sin \phi_o \tag{15}$$

of course,

$$\Delta p/\gamma_o = \frac{p_o}{\gamma_o} - y \tag{16}$$

at $x = 0,\ y = y_F,$

$$F/2 = T \sin \phi_F \tag{17}$$

Resulting Shapes

The submerged shapes of the liquid containers and their buoyancy air chambers for design Approach 1 concepts are presented in Figures A-8 and A-9 for liquid specific gravities of 1.9 and 1.4.

Consider Figure A-8. Two separate shapes for the buoyancy chamber are shown. Either one is valid for calm water. However, the one that is pressurized to a 4.7 foot head, i.e. p_0/γ_0 = 4.7 ft., will collapse under the specified 12 foot wave. Hence, the pressure was increased to a deisgn value of p_0/γ_0 = 16.7 ft., as shown. It is this shape that applies so that, under a 12 foot wave, this chamber may deform and approach the 4.7 foot head contour while still retaining the required buoyancy.

The design conditions for the 1.4 specific gravity of Figure A-9 meet the 12 foot wave requirement.

The submerged shapes for design concepts having a single buoyancy chamber are shown in Figures A-10 and A-11 for liquid specific gravities of 1.2 and 1.5, respectively. Only the former case satisfied the minimum draft limit of 10 feet.

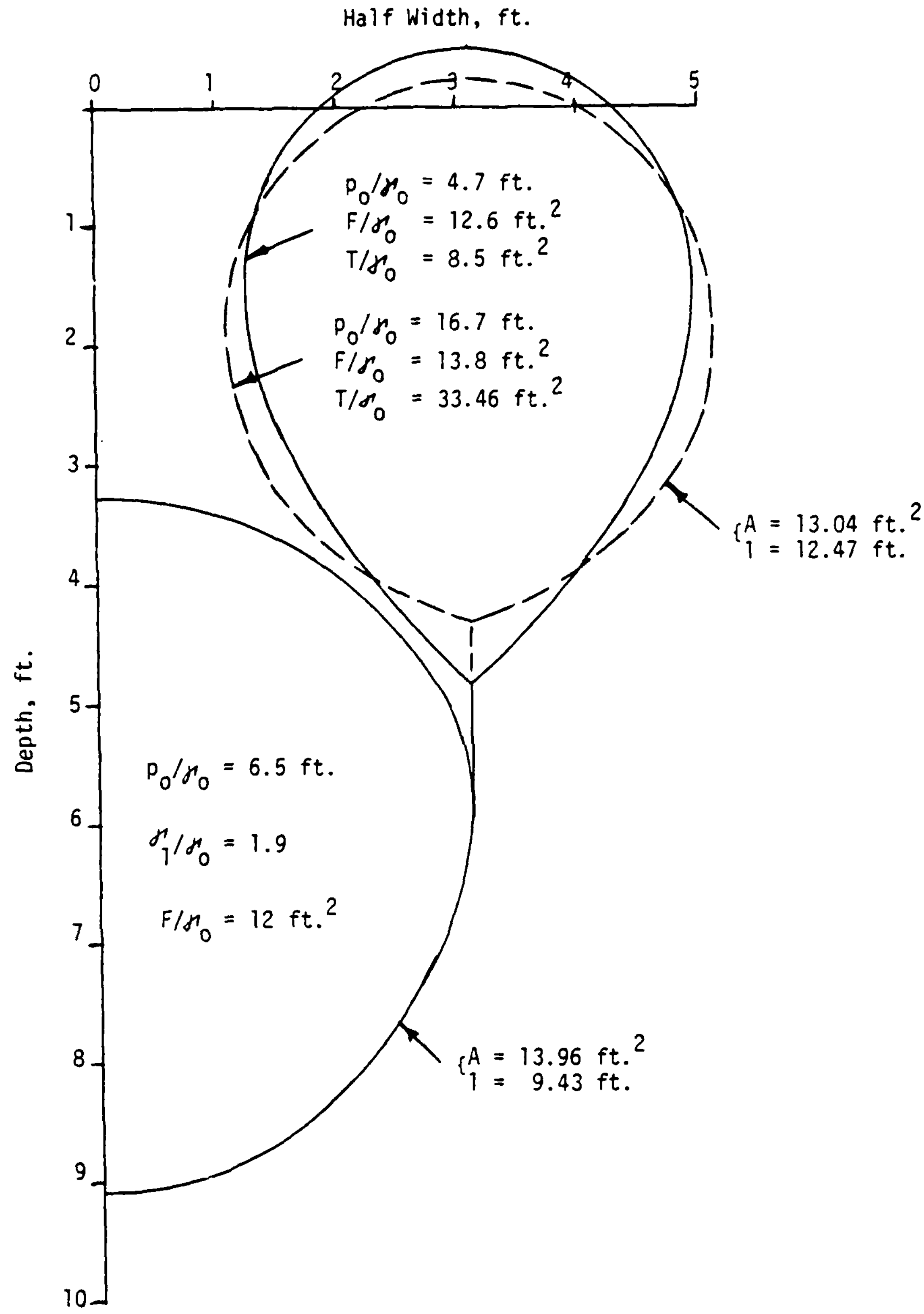


FIG. A-8, Two Air Chamber Configuration for S.G. = 1.9

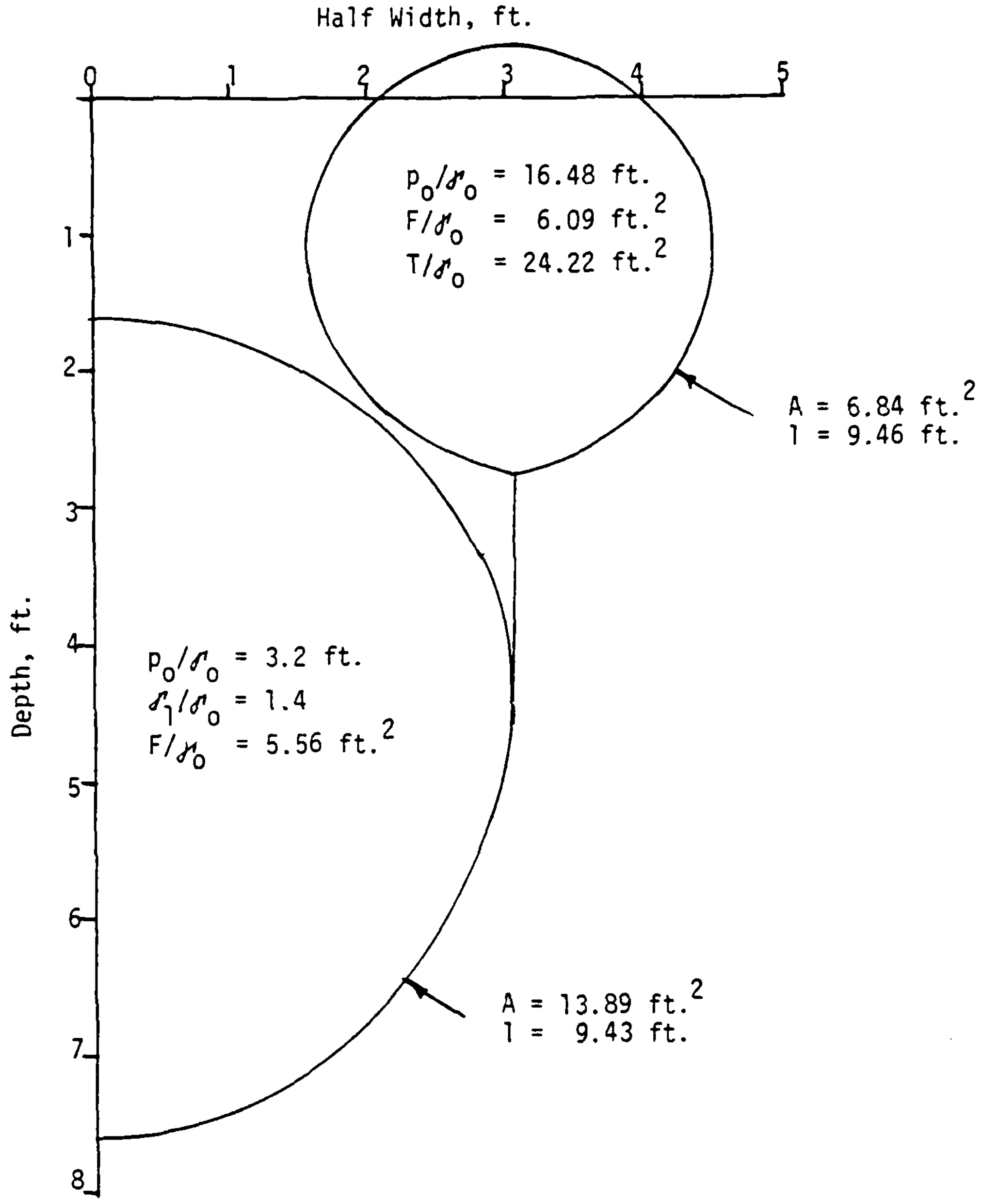


FIG. A-9, Two Air Chamber Configuration for S.G. = 1.4

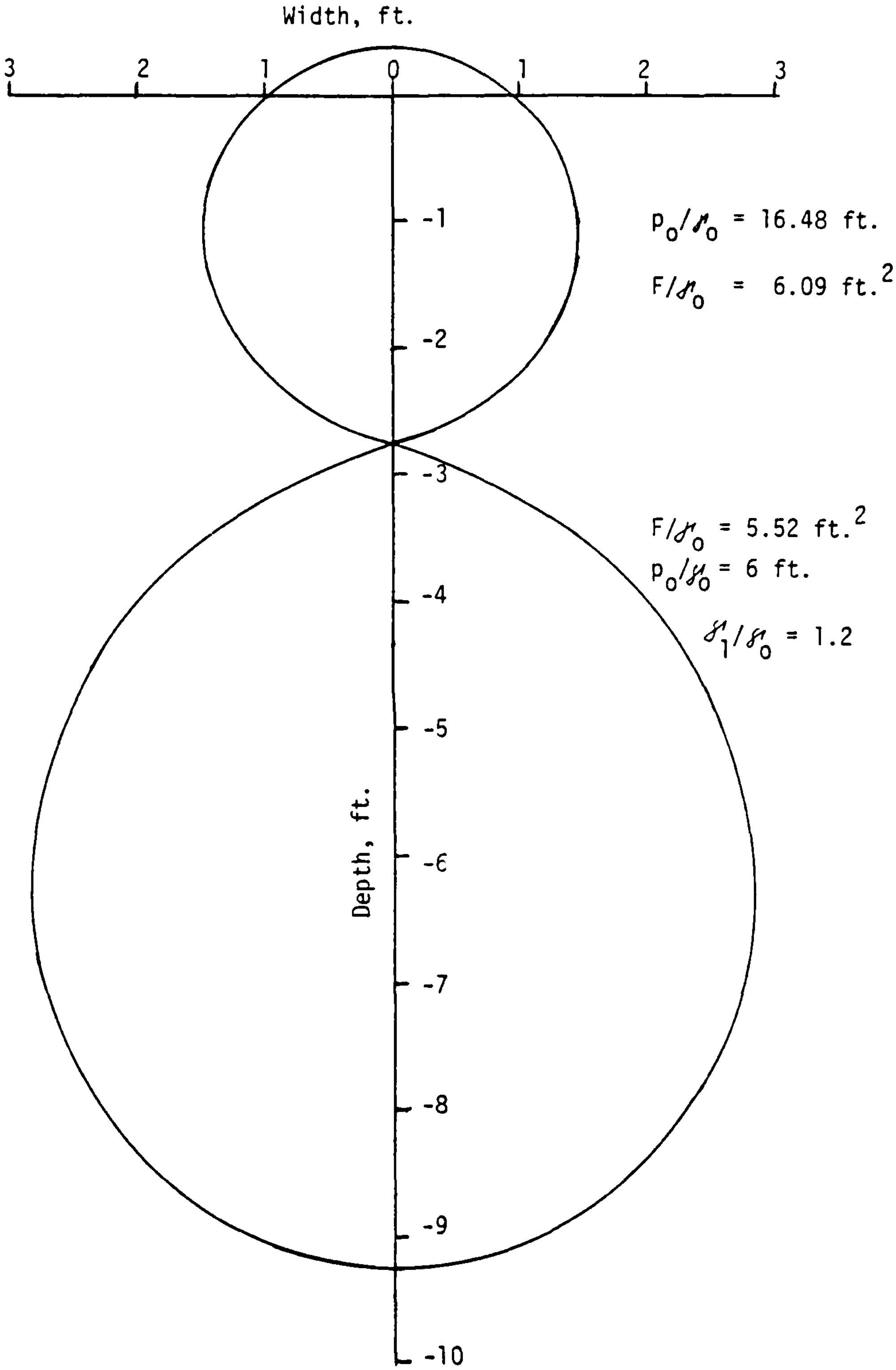


FIG. A-10, Single Air Chamber Configuration for S.G. = 1.2

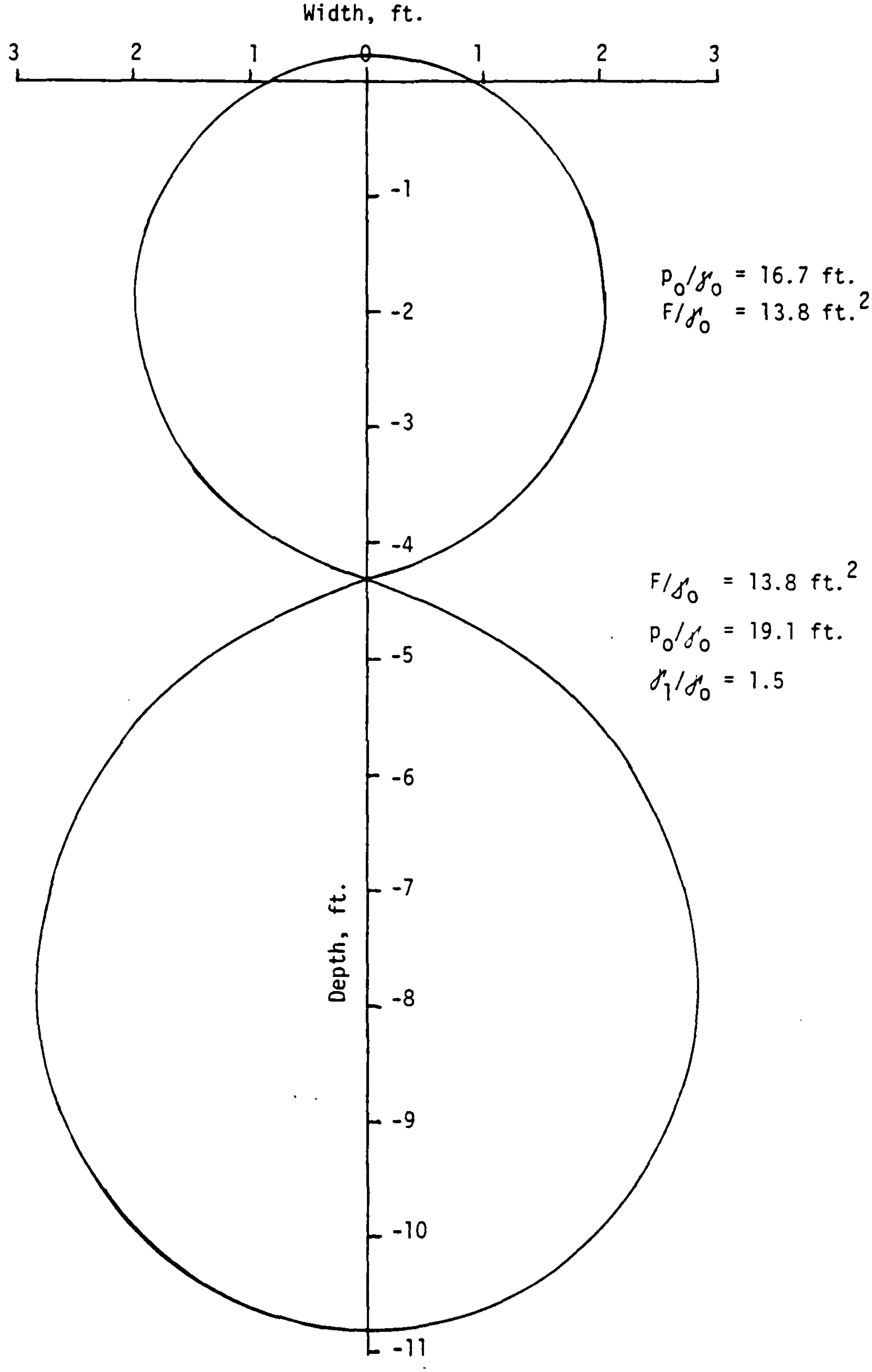


FIG. A-11, Single Air Chamber Configuration for S.G. = 1.5

Stress Analysis

Limit stresses and corresponding required ultimate strengths are calculated for the liquid container, the buoyancy chambers, and their connecting webs. Both the cases for specific gravities of 1.9 and 1.4 are considered.

1. Case 1--S.G. = 1.9

a. The Liquid Container

Per Figure A-8, the operating pressure is:

$$p_o = 6.5\,\gamma_o = (6.5)(6.4) = 416 \text{ PSF}$$

The maximum static differential pressure occurs at the top of the container and is one-half the operating pressure, i.e.,

$$\Delta p_s = 1/2\ \rho_o = h\gamma_o = (3.25)(64) = 208 \text{ PSF}$$

This must be added to the maximum dynamic pressure to give the limit design pressure. This dynamic pressure is discussed in the body of this report where, the expression is found:

$$\Delta p_d = \alpha\gamma\rho H = (2)(1.9)(62.4)(12) = 2{,}845 \text{ PSF}$$

Where:

α = dynamic amplification factor = 2
γ = specific gravity = 1.9
ρ = density of fresh water = 62.4 pcf
H = design wave height = 12 ft.

$$\Delta p = \Delta p_s + \Delta p_d = 208 + 2{,}845 = 3{,}053 \text{ PSF}$$

The limit stress is this differential pressure times the nominal 3 ft. radius, i.e.,

$$\sigma = \Delta pR = 3{,}053\left(\frac{3}{12}\right) = 763.3 \text{ lbs/in}$$

The corresponding required ultimate strength is based on the composite design factor (D.F. = 4) discussed in the body of this report.

$$F_{tu} = \text{D.F.}\,\sigma = (4)(763.3) = 3{,}053 \text{ lbs/in}$$

b. The Buoyancy Cylinders

The operating pressure equals the maximum static differential pressure and from Figure A-8 is:

$$p_o = \Delta p_s = (16.7)(64) = 1{,}069 \text{ PSF}$$

The corresponding static limit stress is given from Figure A-8 as:

$$T = (33.46)\left(\frac{64}{12}\right) = 178.5 \text{ lbs/in.}$$

The dynamic stress is based on an amplification factor of 2, i.e.,

$$\sigma = \alpha T = 2(178.5) = 357 \text{ lbs/in}$$

The design factor is increased from 4 to 4.8 to reflect an estimated reduction in seam efficiency from 90 to 75 percent for the chamber to connecting web joint.

The required ultimate strength is then:

$$F_{tu} = (4.8)(357) = 1{,}714 \text{ lbs/in.}$$

c. The Connecting Web

The limit buoyancy stress from Figure A-8 is:

$$F = 13.8\,\gamma_o = (13.8)\left(\frac{64}{12}\right) = 73.6 \text{ lbs/in.}$$

and, $F_{tu} = (4.8)\ (73.6) = 353$ lbs/in.

2. Case 2--S.G. = 1.4

The above steps are repeated but the proper values as taken from Figure A-9 are applied as follows:

a. The Liquid Container

$$p_o = (3.2)(64) = 205 \text{ PSF}$$

$$\Delta p_s = 1/2\ p_o = 102 \text{ PSF}$$

$$\Delta p_d = \alpha\gamma\rho H = (2)(1.4)(62.4)(12) = 2{,}097 \text{ PSF}$$

$$\Delta P = \Delta p_s + \Delta p_d = 102 + 2{,}097 = 2{,}199 \text{ PSF}$$

$$\sigma = \Delta pR = 2{,}199\ \frac{3}{12} = 549.7 \text{ lbs/in}$$

$$F_{tu} = \text{D.F.}\ \sigma = (4)(549.7) = 2{,}199 \text{ lbs/in}$$

b. The Buoyancy Chambers

$$p_o = \Delta p_s = (16.48)(64) = 1{,}055 \text{ PSF}$$

$$T = (24.22)\left(\frac{64}{12}\right) = 129 \text{ lbs/in}$$

$$\sigma = \alpha T = 2(129) = 258 \text{ lbs/in}$$

$$F_{tu} = (4.8)(258) = 1{,}240 \text{ lbs/in}$$

c. The Connecting Web

$$F = (6.09)\left(\frac{64}{12}\right) = 32.5 \text{ lbs/in}$$

$$F_{tu} = (4.8)(32.5) = 156 \text{ lbs/in}$$

APPENDIX B

STRESS ANALYSIS AND

SHAPE OF THE SEGMENTED CONTAINER

(Design Approach 2 Concepts)

Approach

The structural configuration follows bias ply tire construction. Each segment of the container is laid up of two bias plies of cord type fabric on a barrel shaped form. These plies are wrapped around steel wire tension beads at each end in the same way that beads are formed into a tire. Segments are assembled by mounting on drop center rims as a tire is mounted except that there are two rims per segment (see Figure B-1). These rims are integral to a sandwich bulkhead having stainless steel faces and either foam, balsa, or honeycomb cores.

The bias cord angle and the contour of the barrel shape are chosen so that variation in stress ratios cause small changes in shape. Per Figure B-1, the bias angle is 54 degrees, and the meridian profile is a circular arc of half central angle = 7.614 degrees and radius = ρ_1 = 453.7 inches.

Analysis for S.G. = 1.9

Let:

F = the drag force $\sim$ lbs.

p = internal pressure $\sim$ psig

β = bias cord angle = 54 degrees

ρ_1, ρ_2 = meridian and circumferential radii of curvature, respectively $\sim$ inches

R = radius of the outer rim edge = 45 inches

l = length of one segment = 123 inches

σ_1, σ_2 = meridian and hoop stress, respectively $\sim$ lbs/in

σ_B = stress in one ply of cords $\sim$ lbs/in

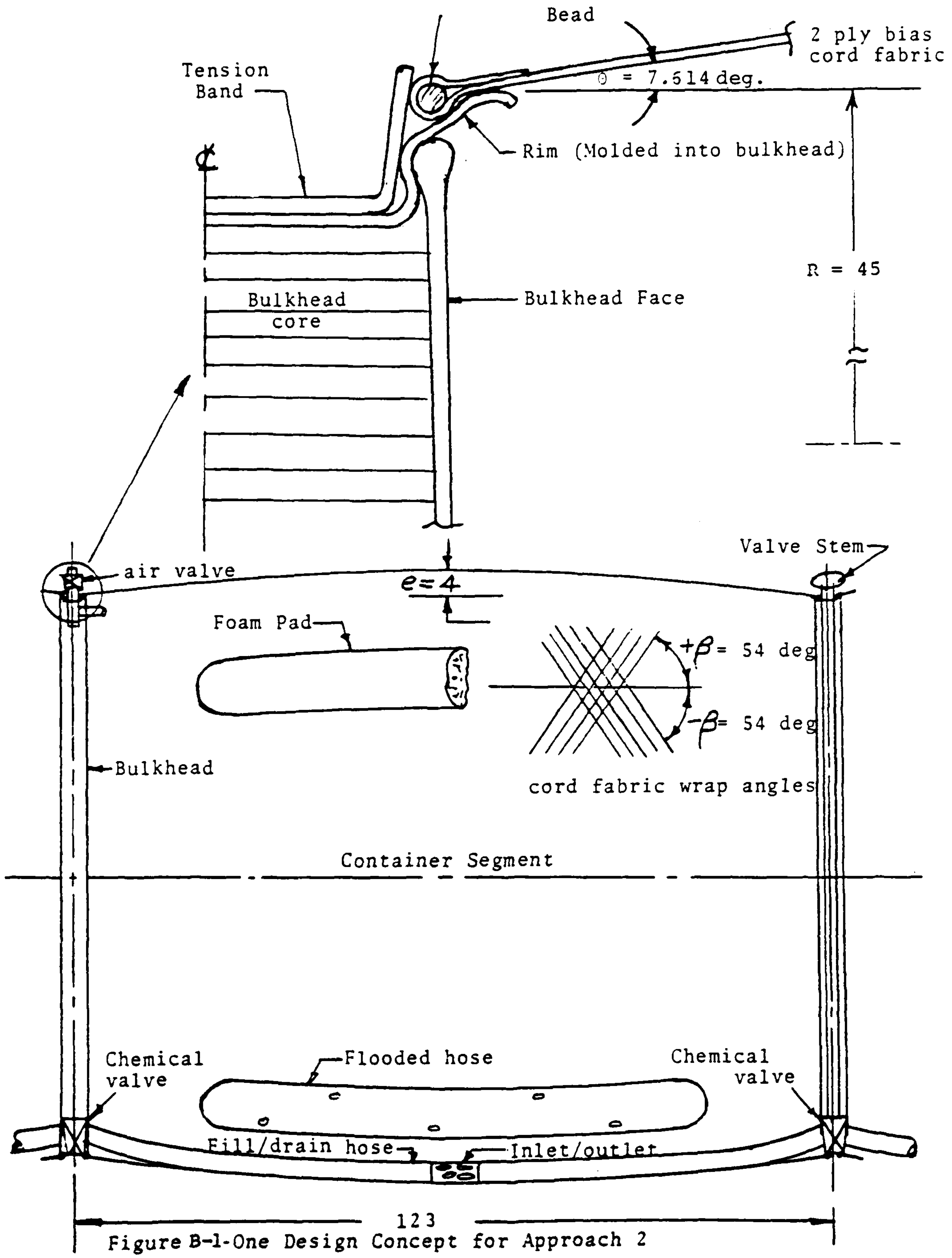


Figure B-1-One Design Concept for Approach 2

Consider the axial forces acting on a cross-section at the mid-length of one segment and let the ratio of the drag force to pressure load be denoted by K; i.e.,

$$K = \frac{F}{p\pi\rho_2^{\,2}} \tag{1}$$

$$\therefore \quad \sigma_1 = \frac{F + p\pi\rho_2^{\,2}}{2\pi\rho_2} = \frac{p\rho_2}{2}(1 + K) \tag{2}$$

$$\sigma_2 = \rho_2\left(p - \frac{\sigma_1}{\rho_1}\right) = \frac{p\rho_2}{2}\left[2 - \frac{\rho_2}{\rho_1}(1 + K)\right] \tag{3}$$

$$\beta = \tan^{-1}\sqrt{\frac{\sigma_2}{\sigma_1}} = \tan^{-1}\sqrt{\frac{2}{1 + K} - \frac{\rho_2}{\rho_1}} \tag{4}$$

$$\sigma_B = \frac{\sigma_1}{2\cos^2\beta} = \frac{p\rho_2}{4}\left(\frac{1 + K}{\cos^2\beta}\right) \tag{5}$$

From the geometry of Figure B-1:

$$\cos\Theta = 1 - \frac{4}{\rho_1} \quad ; \quad \rho_1 = \frac{4}{1 - \cos 7.614^\circ} = 453.7 \text{ in.}$$

$$\rho_2 = R + 4 = 45 + 4 = 49 \text{ in.}$$

<u>For K = 0</u>

$$\beta = \tan^{-1}\sqrt{2 - \frac{49}{453.7}} = 54^\circ$$

$$\frac{\sigma_1}{p} = \frac{\rho_2}{2} = \frac{49}{2} = 24.5$$

$$\frac{\sigma_2}{p} = \frac{\rho_2}{2}\left(2 - \frac{\rho_2}{\rho_1}\right) = 24.5\left(2 - \frac{49}{453.7}\right) = 46.4$$

$$\frac{\sigma_B}{p} = \frac{\rho_2}{4}\left(\frac{1}{\cos^2\beta}\right) = 12.25\left(\frac{1}{\cos^2 54}\right) = 35.5$$

<u>For K = 1/2</u>

$$\beta = \tan^{-1}\sqrt{\frac{4}{3} - \frac{49}{453.7}} = 47.9^\circ$$

$$\frac{\sigma_1}{p} = (24.5)\left(\frac{3}{2}\right) = 36.75$$

$$\frac{\sigma_2}{p} = (24.5)\left[2 - \frac{3}{2}\left(\frac{49}{453.7}\right)\right] = 45$$

$$\frac{\sigma_B}{p} = 12.25\left(\frac{1.5}{\cos^2 47.9}\right) = 40.88$$

In order to seat the beads and to preclude leaking around the rims, the operating pressure must exceed the maximum external pressure. This corresponds to the specified design wave height of 12 feet. A factor of 1.5 is applied so that the operating pressure is:

$$p_o = 1.5\gamma h = 1.5(64)(12) = 1{,}152 \text{ PSF}$$

This must be added to the maximum dynamic pressure to give the limit design pressure. From the body of this report: $\Delta p_d = \alpha \gamma \rho H$. Here, the same values as used in configuration 1 are applied Except for H, the wave height. Since each segment is 10 feet long and is half filled, the maximum possible internal head is 5 feet. This is used for H so that:

$$\Delta p_d = (2)(1.9)(62.4)(5) = 1{,}185.6 \text{ PSF}$$

$$\therefore \quad \Delta p = p_o + \Delta p_d = 2{,}338 \text{ PSF} = 16.24 \text{ psi}$$

This is applied to the preceding equations to give the design limit stress in each of the bias plies of:

$$\sigma_B = 40.88\ (16.42) = 663.7 \text{ lbs/in}$$

The corresponding required ultimate strength for the previously discussed design factor is:

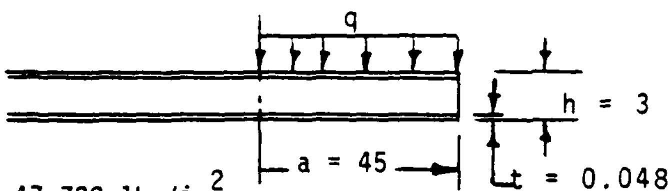
$$F_{tu} = \text{D.F. } \sigma_B = 4(663.7) = 2{,}655 \text{ lbs/in}$$

a. Bulkhead for S.G. = 1.9

Circular flat sandwich plate—uniform pressure. Design limit pressure, q = 16.42 psi

$$M = 0.2067\ qa^2$$

$$\sigma_p = 0.2067\ q\frac{a^2}{ht}$$



$$= 0.2067\ (16.42)\ \frac{45^2}{3(0.048)} = 47{,}728 \text{ lbs/in}^2$$

For Facings of PH15-7MO (RH1050), F_{cy} = 190,000 lbs/in^2

301,302 Annealed, F_{cy} = 40,000 lbs/in^2

1/2 Hard, F_{cy} = 72,000 lbs/in^2

Balsa Core @ 8 to 10 pcf F_{cy} = 1,410 lbs/in^2

F_{cy} = 980 lbs/in^2

<u>Consider</u>

t = 18 gage (0.048") h = 3"

wt = 2.016 lbs/ft^2

$\therefore \sigma_b$ = 47,728 lbs/in^2 -- O.K. for 1/2 Hard

Weight of one bulkhead, W_H

$$W_H = 2(2.016)\,\pi\left(\frac{45}{12}\right)^2 + \frac{\pi}{4}\left(\frac{45}{12}\right)^2(8)$$

= 178 + 88 = 266 lbs.

b. <u>Rim Assembly for S.G. = 1.9</u>

597 lbs/in

σ_1 = 36.75 (16.24) = 597 lbs/in (limit)

1) <u>Bead</u>

70 wraps of d = 0.037 $\begin{cases} +0.002 \\ -0.00 \end{cases}$ Wire

F_{tu} = 270 ksi ht. steel

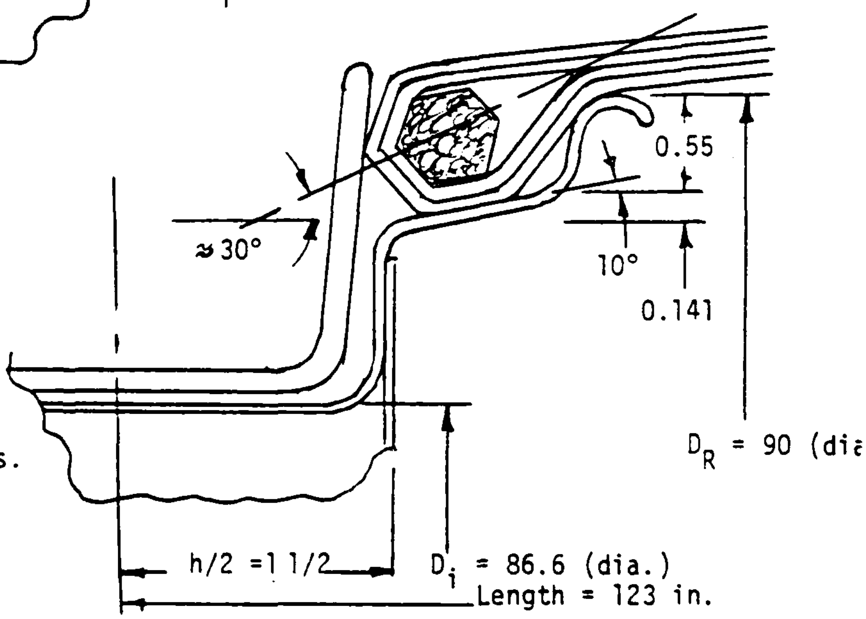
$$AE_{max} = \frac{70\pi}{4}(0.039)^2(29 \times 10^6)$$

$= 2.43 \times 10^6$ lbs.

$$T \approx \sigma_1 \frac{D_R}{2} \sin 30°$$

= (597)(45)(1/2) = 13,433 lbs.

T_u = 20,149 lbs.



2) Rim

Mat'l -- AM-350
AMS 5548 Cond. SCT 850, F_{tu} = 185 ksi
F_{ty} = 150 ksi

t = 12 gage = 0.1054"
w = 4.427 lbs/ft^2 F_{cy} = 158 ksi
F_{su} = 120 ksi

a) Hoop Compression (for 10 psi mounting)

$$\sigma_c \approx \frac{T}{1t} = \frac{\frac{10}{16.24}\ (13,433)\sin 10°}{(0.141)(0.1054)} = 96,649\ lbs/in^2$$

b) Shear

$$\sigma_s = \frac{\sigma_1}{t} = \frac{597}{0.1054} = 5,664\ lbs/in^2$$

3) Retainer t = 14 gage = 0.0751", w = 3.154 lbs/ft^2

$$M = 1/2(90 - 86.6)(36.75)(10)(1 - 0.15 \sin 30°) = 578\ lbs/in$$

$$f_b = \frac{M}{t^2} = \frac{578}{(.0751)^2} = 102,460\ lbs/in^2 \text{ -- O.K. for AM-350}$$

4) Weight of Rim Assy

a) Rim $\pi(86.6)\ (1\frac{1}{2}) + \pi(44.3^2 - 43.3^2) + 2\pi\ (44.3)(0.81)$

$+ \pi(45 + 44.3)(1) = 1,189.3\ in^2$ (1/2 rim)

$$\therefore\ W_{Rm} = \frac{2(1189.3)}{144}\ (4.427) = 73.1\ lbs.$$

b) Retainer

$$(1\frac{1}{2})\pi(86.6) + (90.25^2 - 86.6^2)\ \pi = 2,436"^2 \text{ (1/2 retainer)}$$

$$W_{RET} = 2(2,436)\ \frac{3.154}{144} = 106.7\ lbs.$$

c) Bead $W_B = 70\ \frac{\pi}{4}\ (0.037)^2(90\pi)(0.286) = 6.1$ lbs (1 bead)

Total Assy Weight:

$$W_R = 73.1 + 106.7 + 12.2 = 192\ lbs.$$

Analysis for S.G. = 1.4

The preceding analysis is followed starting with a smaller container. With reference to Figure B-1, the Geometric values now become:

$$l = 116 \text{ in.} \qquad e = 3.76 \text{ in.} \qquad \rho_1 = 426.5 \text{ in.}$$
$$R = 38.25 \text{ in.} \qquad \Theta = 7.614 \text{ deg.} \qquad \rho_2 = 42 \text{ in.}$$

The operating pressure is:

$$p_o = 1.5(64)(12) = 1{,}152 \text{ PSF}$$

The dynamic pressure is based on a half filled segment; i.e.:

$$H = 1/2 \; \frac{116-3}{12} = 4.71 \text{ ft.}$$

$$\Delta p_d = 2(1.4)(62.4)(4.71) = 822.6$$

$$\Delta p = p_o + \Delta p_d = 1{,}152 + 822.6 = 1{,}975 \text{ PSF} = 13.7 \text{ psi}$$

The critical stress and required strength are:

$$\sigma = 40.88\ (13.7) = 560.6 \text{ lbs/in}$$
$$F_{tu} = 4(560.6) = 2{,}242 \text{ lbs/in.}$$

Bulkhead

$$\sigma_b = 0.2067q\, \frac{a^2}{ht} = 0.2067(13.7)\, \frac{\overline{38.25}^2}{3(0.0293)} = 47{,}134 \text{ lbs/in}^2$$

$\therefore$ Use 22 gage (0.0293) -301,302-1/2 hard wt = 1.231 lbs/in^2

Wt. of one bulkhead, W_H

$$W_H = 2(1.231)\ \pi\left(\frac{38.25}{12}\right)^2 + \frac{\pi}{4}\left(\frac{38.25}{12}\right)^2 (8) = 142.42 \text{ lbs.}$$

Rim Assembly

σ_1 = 36.75 x 13.7 = 503.5 lbs/in (limit)

$T \approx \sigma_1 \frac{DR}{2} \sin 30° = \frac{503.5}{4}$ (6.375 x 12) = 9.629 lbs (limit)

51 wraps of d = 0.037; F_{tu} = 270 ksi ht. steel

T_{tu} = 14,806 $\therefore$ F.S. = $\frac{14,806}{9,629}$ = 1.54

$W_B = 51 \ \frac{\pi}{4} \ \overline{0.037}^{\,2}$ (6.375 x 12) π (0.286) = 3.77 lbs.

Rim:

Hoop compression for 10 psi mounting:

$T = \frac{10}{13.7}$ x 9,629 = 7,028 lbs (limit)

$\sigma_c = \frac{T}{1t} = \frac{7028 \sin 10°}{(0.141)(0.090)}$ = 96,170 lbs/in^2

$\therefore$ Use 13 gage (0.090), Wt = 3.780 lbs/in^2

$Wt \approx \frac{6.375}{7.5} \times \frac{3.78}{4.427}$ (73.1) = 53 lbs.

Retainer:

$M \approx 1/2(3.4) \left[(36.75)(10) - 0.15 \times 183.75\right]$ = 578 lbs/in^2

f_b = 102,482 -- Same as for = 1.9

$Wt. \approx \frac{6.375}{7.5}$ x 106.7 = 90.7 lbs.

TOTAL = 90.7 + 53 + (3.77)(2) = 151.25 lbs.

APPENDIX C

STRESS ANALYSIS AND SHAPE

OF INDIVIDUAL CONTAINERS--CABLE CONNECTED

(Design Approach 3 Concepts)

Approach

This configuration is readily suited to filament winding construction. Each container has a central, internal cable assembly connected to fittings at each pole as shown in Figure C-1. These fittings serve as universal joints and are used to connect any number of containers. As such, only these cable assemblies carry the sum total of the drag loads. Each filament wound vessel need only carry its individual pressure and drag loading.

Although a filament wound sphere is indicated in Figure C-1, the vessel is actually a short cylinder with end domes of one of the classical filament wound geodesic ovaloids. The chosen shape is constructed of helix windings at $\alpha_r = \pm 15$ degrees with additional circumferential windings over the cylindrical length.

Geometry (General)

The normalized geometric properties of the dome are presented in Figures C-2 and C-3. Here, the actual pole radius is $X_f = 0.25937$ R although the theoretical pole radius is slightly less and is given by:

$$X_t = R \sin \alpha_r = R \sin 15° = 0.25882 \text{ R} \qquad (1)$$

Between the hole and outboard of the inflection point, the anticlastic curvature is avoided by using a tangent sphere for the shape. Additional woven reinforcement is

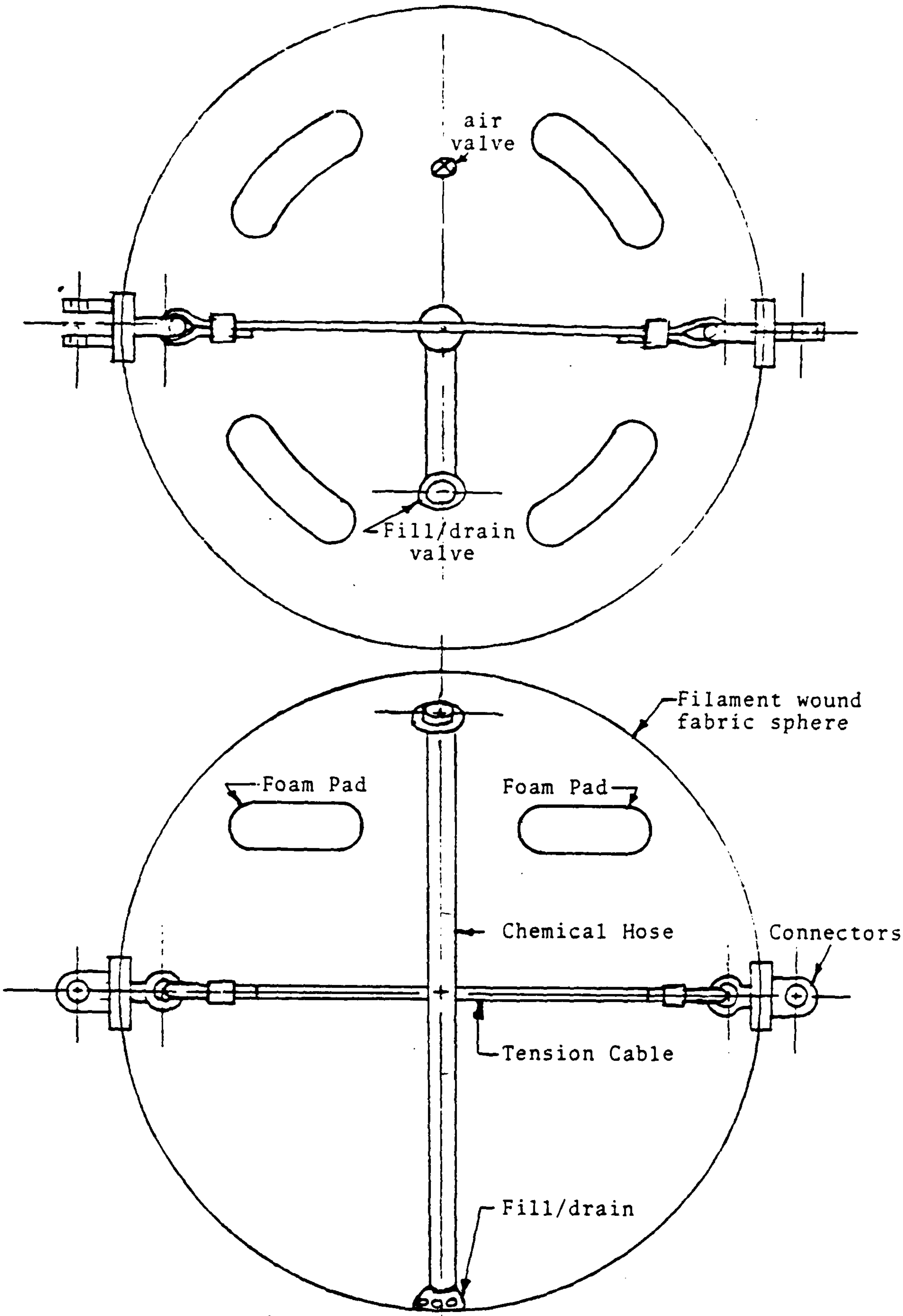


Figure C-1 -One Design Concept for Approach 3