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INDIVIDUAL ALUMINUM FEEDING CONTAINERS

PART II. (FINAL DESIGN) FEEDING CONTAINER ASSEMBLY FOR SPACE FLIGHT

JOHN I. THOMPSON & COMPANY

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FOREWORD

This report was prepared by John I. Thompson and Company, Washington, D. C., under USAF Contract No. AF 33(616)-7080, Project No. 6373, "Equipment for Life Support in Aerospace," Task No. 63121, "Nutritional Support Equipment." The contract was initiated and monitored by the Bio-Specialities Section*, Physiology Branch, Biomedical Laboratory, Aerospace Medical Laboratory of the Wright Air Development Division, Wright-Patterson Air Force Base, Ohio. Dr. Robert E. Hayes and Miss Beatrice Finkelstein were the Project Engineers.

This report is prefaced by WADD Technical Report 60-552(I) which was the engineering evaluation of materials and techniques for fabricating a food container to be used in space flight.

Those who participated in the research and documentation of the report were Mr. C. G. Makrides, Project Administrator; Mr. R. M. Wohlfarth, Mr. A. R. Morse, Project Engineers; and Mr. S. Marks, all from John I. Thompson and Company. Research was started on 1 March 1960 and completed on 31 July 1960.

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ABSTRACT

Designs have been evolved of a container, quick opening device, inner seal, food expelling device, pressure relief method during heating, and mouthpiece for an individual aluminum feeding container for space flight use. The pertinent parameters of these designs are ability to function under zero gravity, and presentation of food in a palatable, acceptable condition. Many designs were conceived and discussed for the various components, and the most feasible designs were selected.

The selected design consists of a rectangular container with a round dispensing end sealed by a foil inner seal and a screw-on cap for quick and easy access and hermetic sealing. The bottom plate also contains a screw-on cap for access to the enclosed expelling plate. The container will be fabricated by impact extrusion from 1100-F aluminum, the other metal components by forming, and casting.

PUBLICATION REVIEW

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INTRODUCTION

Man on extended flights into extreme altitudes will be exposed to many stresses, because of the entirely new environment in which he must live. To aleviate some of the morale problems, it will be necessary to provide facilities which will permit living routines that approach those to which man is accustomed. One specific area which lends itself to this normal environment is that of diet and feeding techniques. However, because of the zero gravity environment, special feeding containers and equipment will be necessary.

This report presents a system for an individual aluminum feeding container in which foods can be processed, stored, heated for serving and for associated equipment for eating directly from the container. The components consist of a container, associated caps and seals, an expelling device, and a mouthpiece to transmit food from the container to the mouth. This system functions under zero gravity and withstands pressures and temperatures peculiar to space travel.

The environmental factors which are applicable to the design of this feeding container are: (1) a condition of zero gravity, (2) a cabin pressure of 1/3 to 1 atmosphere, (3) a cabin temperature of 75°F, (4) an accelerative load factor of 8 g, and (5) a minimum weight and overall volume.

Each component of the feeding system is discussed in a separate section. In each section a recommendation of the best design evolved has been made, as well as a discussion of alternate solutions. The feeding system composed of the most feasible concepts and representing the final design is discussed and illustrated.

CONTAINER

The container fulfills the following design criteria:

1. Be of aluminum.
2. Have a 6 fluid ounce volume with a minimum weight.
3. Be rectangular in shape for convenient storage, handling, and heating.
4. Have sufficient strength to withstand heat processing temperatures and pressures.
5. Have complete sealing to tolerate pressure, temperature, and gravity changes.
6. Be available for filling with one end open and ready for hermetic sealing.

Further factors considered in the design of the container are:

1. A quick opening device to provide access to the food.
2. A pressure relief technique to relieve internal pressure when heating the food.
3. An inner seal to prevent escape of food on release of quick opening device.
4. Provisions for expelling food.
5. Suitable container linings.

The basic container form desired is a square prism with greater length in the vertical than horizontal plane as shown in Figure 1(A). Consideration of materials and fabrication techniques lead to modification, as shown in Figure 1(B), which shows vertical edges rounded to a one half-inch radius.

This change serves to:

1. Improve heat transfer rates.
2. Allow for double roll seam attachment of base plate.
3. Increase structural strength to meet high vacuum requirements.
4. Facilitate the impact extrusion process.

Consideration of feasible methods of quick and easy access to the contents of the container lead to selection of a screw-on cap. This further modification of the basic form is shown in Figure 1(C).

The double roll seam method of attaching the bottom plate is necessary. Although it involves protrusion beyond the container walls, which complicates storage, it does make possible the insertion of the movable expulsion plate, before attaching the base.

The fabrication of a container without a base protrusion would be possible, and perhaps simpler, through the use of continuous seam welding, provided the insertion of the expulsion plate were not required.

In the final design, the expulsion plate and the internal walls and base of the container must be first lined with a protective coating, and the expulsion plate is inserted and the base is attached.

The physical size of the container is dependent upon:

1. Volume required for 6 fluid ounces.
2. Headspace needed for processing.

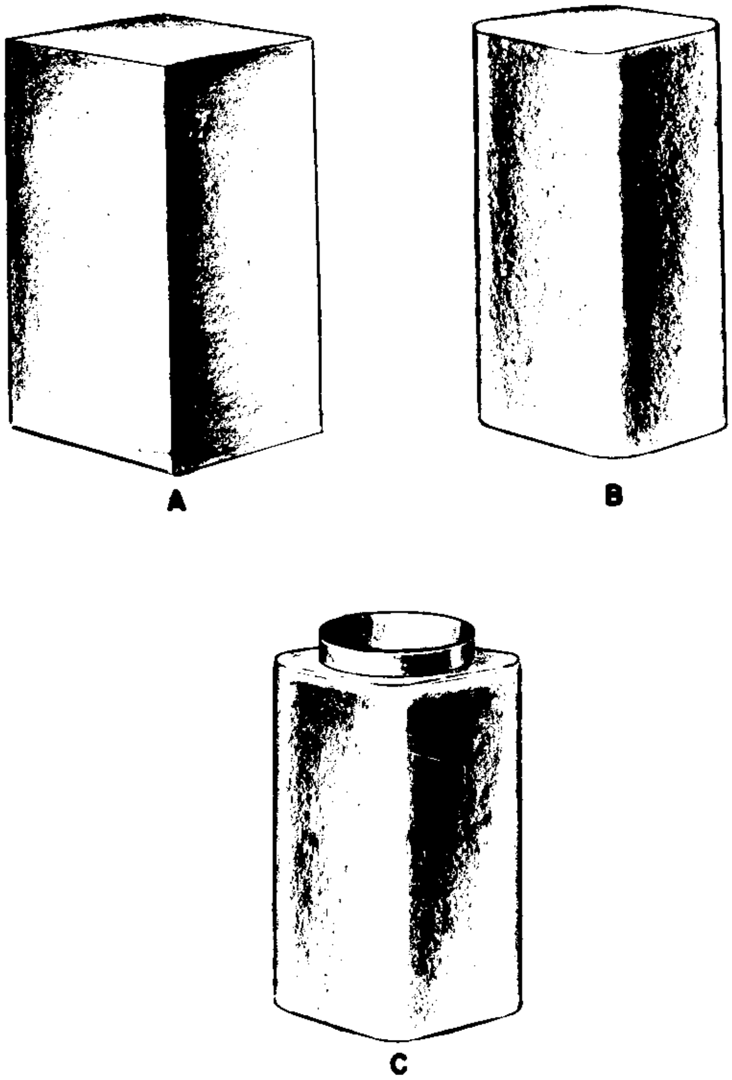


Figure 1

3. Space occupied by the expulsion insert.

4. Selected ratio of container wall width to height.

The volume equivalent to 6 fluid ounces is 10.83 cubic inches. The headspace required for heat processing is approximately 0.95 cubic inches. The resulting internal volume is 11.78 cubic inches, exclusive of any space occupied by an expulsion insert.

While a cubical container has the minimum amount of surface area for a given volume, and the minimum material for a given wall thickness, it does not lend itself to the rapid heating of the food it contains.

The ratio of container wall width to height cannot be selected arbitrarily. A mathematical analysis to determine an optimum solution for minimum weight, rectangular shape, and expulsion plate requirement is essential. For the purpose of analysis (Appendix I) we assumed that wall and plate thickness are uniform, and the analysis becomes an investigation of the relationship between the total surface area of the container, the expulsion plate, and the volume. Therefore where an expulsion plate is inserted in the container, a rectangular form with walls approximately 2 inches wide and 3 inches high fulfills the requirements of minimum weight and rectangular shape.

There are several factors to be considered in deciding on the thickness of the container walls, for the strength and rigidity needed.

1. High vacuum to be resisted.

2. Size of the container.

3. Strength of the construction materials.

For the container fabricating process selected, the most suitable aluminum alloy is 1100-F. This material will allow a minimum wall thickness of 0.020 inches, (see Appendix II). The bottom plate will be of equal thickness to permit proper attachment to the container. A thicker dispensing end is required to allow for machining of rigid threads and to provide for seating the inner seal and mouthpiece.

The containers will be fabricated by the impact extrusion process. This cold working process not only adds strength to the metal, but will simultaneously produce, as an integral unit, walls of minimum thickness, and a dispensing end of sufficient material to allow for secondary operations. These operations include machining of rigid threads for the screw-on caps, and finishing such surfaces as the inside diameter of the circular neck which will hold the inner seal. The bottom plate will be formed from a blank, cut from sheet material of the specified thickness, and a thicker threaded portion, required for later attachment of the expulsion mechanism, will be joined by a brazing process.

The lubricating oil from the extrusion process shall be chemically removed, and a protective coating applied to the container and to the expulsion plate, which shall then be inserted, and the bottom plate attached by a double rolled seam.

The expulsion plate is used to diminish the interior food volume at will, and thus force the food through the dispensing end. Various other methods of food expulsion are mentioned elsewhere in this report.

This plate is so constructed that it will closely fit the square cross-section of the containers, including a cylindrical protrusion to fit the dispensing opening. In perimeter, the plate is slightly less than the inner surface of the container, so that there will be room for a plastic sealing gasket. On the bottom of the plate, set within the cylindrical portion, is a collar which provides a means of moving the plate by an expelling device. This is an integral part of the plate, as the assembly will be fabricated by investment casting. Close tolerances on the plate must be held, because in assembly the plate must not only fit well into the container, but the collar must fit into the access hole in the bottom plate.

The application of a protective coating, or lining, to the interior surfaces of the container is essential to prevent interaction of the food and aluminum. According to standard practices of the canning industry, each food type requires different lining materials in containers made with tinplate.

Manufacturers of coating materials recommend several possible coatings for aluminum containers. These coatings are Stoner-Mudge Company numbers 5-5061 epoxy resin base, S-1367 modified vinyl, and S-6617 modified epoxy. However, they prefer to make detailed recommendations based on tests of the specific foods to be canned and processed. This testing need not be a lengthy procedure, but should be adequate, considering the comparative newness of aluminum food packaging techniques.

Care should be taken that the application of this protective coating provides sufficient coverage of the metal to avoid any minute holes through which chemicals in the food can attack the metal of the container. Some of the new techniques of spray application at reduced pressures may alleviate this difficulty. It is also recommended that if spray is used several applications be given; or a dipping processing substituted, whereby the interior of the container is given a complete and even coverage of the material.

Externally, the containers should be coated with a suitable finish to preserve appearance, and to allow a description of contents.

The aluminum alloys compatible with the impact extrusion process for this design are 1100, 3003, 6061, and 6063. Each has its own properties and advantages, but alloy 1100-F is recommended for this container. Primarily, 1100-F has been chosen because of its workability and its purity, which will allow the minimum wall thickness of fabrication, and give ease of forming. Other alloys are of high strength, but their minimum thickness is greater for this fabrication process.

Material chosen for the gasket of the expulsion plate must, among other things:

1. Be compatible with the food with which used.

2. Withstand the heat and pressure of food processing.

3. Retain its sealing qualities over a period of time.
4. Be compatible with, and adhere to the aluminum.

Of materials investigated, Alcoa A-11 standard gasket liner, Teflon and Rulon appear to best fulfill these requirements.

PRESSURE RELIEF TECHNIQUES AND DEVICES

A pressure relief method or device must be provided on each container to insure against explosion during warming of the food while the container is still sealed. This will permit immediate opening of the container after heating without forcing the food into the cabin atmosphere. If a pressure relief device or method is not employed, an internal pressure great enough to force the contents of the container into the cabin could exist, thereby creating a possible hazard by contamination or injury to the user. In addition, these devices must be designed to prevent the entrance of foreign gases or matter into the container during processing and storage, and to prevent the escape of liquids and solids from the container upon heating for consumption.

The design requirements of the relief valve, determined largely by the container and its intended use, include the following:

1. Lightweight
2. Minimum size, maximum capacity
3. Capable of withstanding an 8g load
4. Capable of functioning at zero gravity
5. Capable of functioning under a pressure of 1/3 to 1 atmosphere at 75°F.
6. Capable of pressure relief by gas expulsion only

Outlined below are four pressure relief methods which will allow the above mentioned requirements to be incorporated into their design.

The differential pressure relief method is one in which the pressure relief valve is designed with the capability of discriminating between the physical states (solids, liquids and gases), and of providing pressure relief by expelling the gaseous matter only.

The inert gas pressure relief method utilizes a relief valve which has the capability of relieving any differential in pressure existing between the cabin atmosphere and a false chamber in the container. This chamber is filled with an inert gas compatible with the cabin atmosphere.

The diaphragm-bladder pressure relief method does not require a valve of any type. The equalization of outside pressure is brought about by the expansion or contraction of a diaphragm within the container itself.

The applied vacuum pressure relief method utilizes a vacuum within the can during the processing operation. Such a vacuum would be of sufficient magnitude so that heating the contents of the container to 185°F for serving, would not cause the pressure within the container to be greater than the cabin pressure.

Investigation of the previously mentioned pressure relief devices indicates the applied vacuum method is the most feasible and readily achieved and has certain advantages which warrant its use over the other devices. Of primary importance is the fact that the vacuum method requires no mechanical parts, which would be true of the diaphragm-bladder method. Also, due to the absence of gravity, it is not possible to predict where the gases in the container will rest. Therefore, since the relief valve methods function by expulsion of the gases in the container, they are unpredictable. The applied vacuum method does not achieve its purpose by equalizing internal and external pressure to increase during warming without becoming greater than the external pressure. Still another advantage of the vacuum method is that it will not impart odor to the cabin atmosphere as relief valves might during the expulsion of gases, since no expulsion takes place in the vacuum method.

Vacuum packing will allow better processing thereby enhancing the contents (food) of the container.

Vacuum packing entails the removal of most of the air from the interior of the container during the canning process. A low oxygen content in the container is desirable, thereby reducing its adverse affects upon the quality of the food, such as oxidation and discoloration. Oxidation may lead to a decrease in the nutritive value of the food.

The preservation of the container itself is aided by vacuum packing, due to the fact that oxygen promotes corrosion of metal containers in the presence of certain foods. By the removal of oxygen from the container, the possibility of corrosion is reduced.

The applied vacuum method has been determined as the most practical pressure relief method, and is incorporated in all the concepts and designs considered in this design study. Therefore all illustrations, drawings, and calculations concern the applied vacuum method rather than pressure relief devices.

In addition to the requirements for a pressure relief device, vacuum packing offers many safety features which are outlined below.

The cabin pressure may be normally maintained at 1 atmosphere. If during flight of the space vehicle, the cabin pressure is decreased to 1/3 atmosphere, the pressure differential and container stresses will decrease.

Most bacteriological spoilage produces gases in the container causing an increase in internal pressure. When cans are vacuum packed the capped ends tend to be drawn in, resulting in a concave shape. Therefore, when the gases given up by bacteriological spoilage increase the internal pressure, the capped ends are bulged out indicating possible spoilage.

The combination of vacuum packing and flexible aluminum foil inner seal over the top of the container offers still another safety feature. Upon removing the cap when the internal and external pressures are normal, the inner seal will curve inward across the opening as in Figure 2-A when a slight vacuum still exists. The position of the inner seal as shown in Figure 2-B is when the container and cabin pressure are equal. If by overheating the internal pressure is greater than the cabin pressure, the inner seal acts as a diaphragm device for pressure relief, thereby increasing the capability of the total pressure relief system. However, the limitation of this system should be realized as the strength of the inner seal. When the internal pressure surpasses that which the inner seal can withstand, the inner seal will fracture allowing the contents to escape.

If the cabin pressure decreases, the container cannot be fully heated. A chart of the extent of safely heating the container at various atmospheric conditions of temperature and pressure for various foods may prove extremely useful in emergencies where cabin pressure is greatly reduced. If the cabin pressure is greatly decreased the container may be opened only without heating or after slight heating in order to allow the user to remove the food.

Vacuum packing in rectangular shaped containers is not as advantageous as vacuum packing in cylindrical shaped containers, due to larger wall thicknesses needed. In order to maintain the wall thickness desired in the rectangular shaped container, a vacuum of 22 inches of mercury was calculated.

In order to determine the increase in internal pressure upon heating the contents of the sealed container, a thermodynamic analysis of the applied vacuum method was performed, as shown in Appendix III. For the purpose of analysis, the sealed container was assumed to be filled with water.

There exists a headspace in the container whose volume is not constant, but will decrease the same amount as the volume of water increases. The increase in water volume is based upon the assumption that the change in weight of the water upon heating is negligible. Application of the perfect gas laws for the air in the headspace will give the air pressure after heating. By the law of partial pressure, the internal pressure after heating may be determined as the sum of the air pressure and vapor pressure at the corresponding temperature in the headspace.

When the contents of the container, at 75°F and 22 inches of vacuum, is heated to 185°F the internal pressure increases to about 1 atmosphere. The increase in internal pressure for increasing temperature is shown in Figure 3. The calculations in appendix III are only an illustration of the thermodynamic processes in the container during heating, since the actual contents will not be water but foods.

In the normal processing of these vacuum packed cans, which will be discussed further, the temperatures approach 240°F. The large increase in pressure due to the temperature rise will be compensated for by the use of retorts in which higher pressures are used.

In support of the theoretical analysis, a laboratory test was performed on a 4 1/2 ounce glass jar of baby food (potatoes). Two sealed jars at 70°F

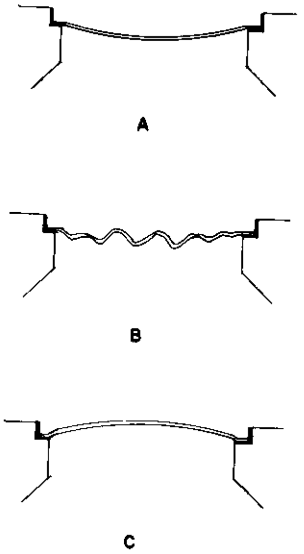


Figure 2

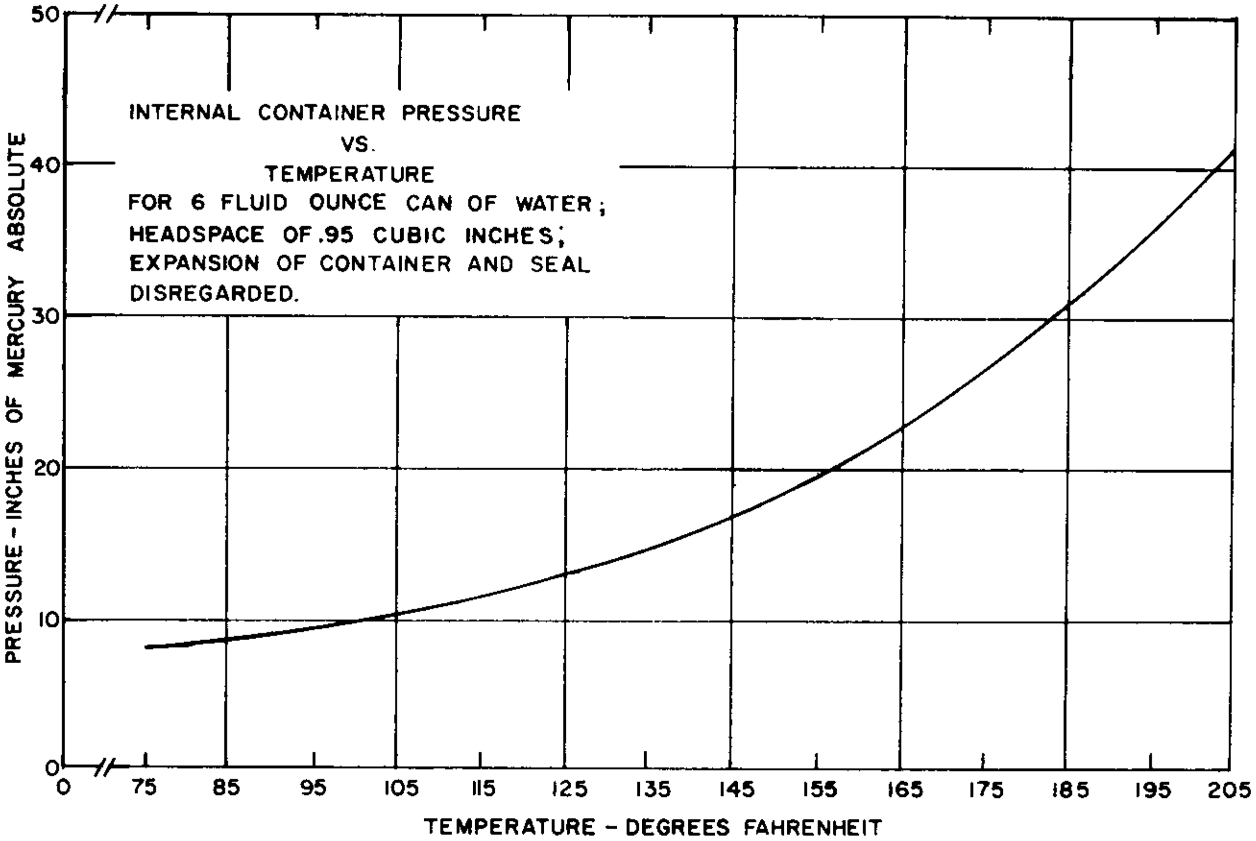


Figure 3

were vacuum tested, and found to be 17 inches of mercury. The third was heated for a half hour at a temperature of 185°F to 190°F. Upon the conclusion of heating, the vacuum in the jar dropped to 8.5 inches of mercury. This illustrates that the thermodynamic process of increasing internal pressure is greater for water than foods, thereby affording a safety factor. However, laboratory tests are recommended to determine whether or not the headspace of the container is adequate for the expansion of the specific foods.

INNER SEAL

The inner seal, located above the food and below the quick opening device at the dispensing end of the container, is used primarily to prevent loss of food upon opening due to reactions in the zero gravity environment of the cabin.

By design, the inner seal will remain intact until the mouthpiece is in place thus preventing loss of food. After partially or fully installing the mouthpiece, the inner seal may be penetrated.

One method for inner seal design considered the use of a polyethylene film seal similar to those used in the vacuum packing of powdered foods. If attached with proper adhesives, it could withstand the pressures involved in food processing. However, subsequent heating and contact with boiling liquids might affect the adhesive and the seal material. In addition, the mouthpiece design requires insertion of the mouthpiece into the neck of the container, therefore, the seal would have to be cup shaped. This presents an additional problem of adequate bonding to the container walls. The merits of this type seal are not enough to warrant further investigation.

Another seal considered was a segmented plastic disk. This seal would be a thick (1/8 inch), flexible, teflon disc that has been sectioned for expelling food (see Figure 4). This seal would restrain food in the container while installing the mouthpiece, but it would not pass the seal retention test specified in the design criteria. Because of this, and its inability to contain and maintain pressures, its use was rejected.

After careful consideration of materials capable of withstanding the pressures and temperatures involved in food processing and subsequent reheating, aluminum stands out as the most desirable material for the container inner seal.

One important reason for the selection of aluminum is that it will maintain the desired pressure within the container as well as the sterile conditions needed for food preservation. Since the seal and container will be of the same material, numerous methods of attachment are available; the best being: cold or pressure welding. Normal aluminum welding processes were eliminated since the required fluxes are toxic.

Pressure welding the inner seal to the rim of the can was feasible until it was decided to mount the mouthpiece inside of the neck of the can rather

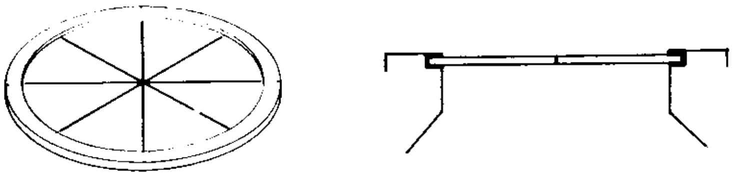


Figure 4

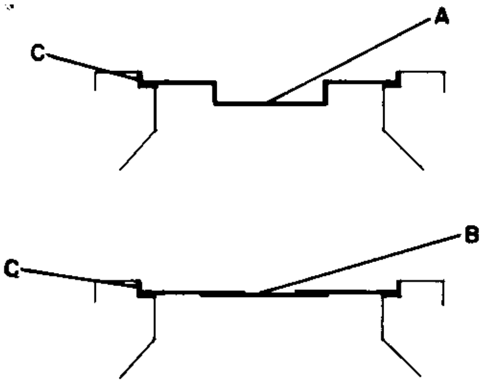


Figure 5

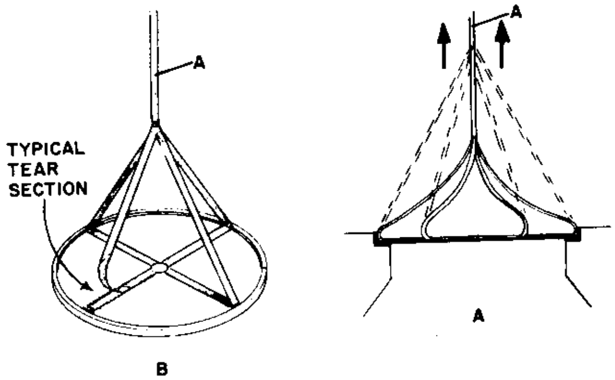


Figure 6

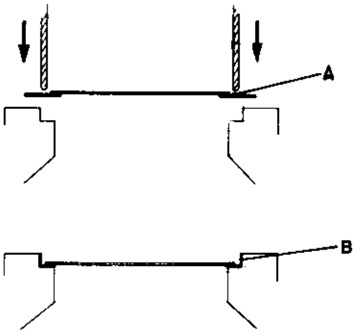


Figure 7

than around the outside. This meant that the inner seal would be broken before the mouthpiece was seated. For this reason the rim mounted seal design was discarded.

Since the mouthpiece design necessitates a recessed inner seal it was decided to design for complete elimination of attachment of a seal to the can, Figure 5. This was accomplished by taking a pan shaped piece of foil (A) that has been compressed into a flat disc (B) and inserting it into an angular cross-section washer (C). The washer's outside diameter would be the same as that of the counterbored notch in the mouth of the can. The width of the washer would be the same as that of the counterbore. In this way the inner seal would be installed without welding or adhesives, be leakproof, and still not interfere with the proper seating of the mouthpiece. It would also prevent the inner seal from being broken before the mouthpiece is partially seated. This compressed aluminum seal would act as a safety device to compensate for any pressure changes.

There are two means to penetrate the inner seal. Both have good points; neither has a serious drawback. In the first method the seal would be the aforementioned circular disc with compressed slack to compensate for pressure change without rupture. Attached to the center of the seal is a pull-strip with a hard tip. This is threaded through the mouthpiece before it is attached. As the mouthpiece is installed, it is rotated just before it has been fully inserted. This tears the seal around the rim in a circle and it can then be drawn through the mouthpiece by the pull strip. The only chance for contamination of the atmosphere could be the food adhering to the seal after it is squeezed through the mouthpiece.

The second aluminum seal is illustrated in Figure 6 (A). This is attached to the container and has the necessary slack to compensate for pressure changes. This method utilizes four tear strips that are attached 90° apart at the circumference of the seal and join at the center. The four ends will join a hard tip (A) which is threaded through the mouthpiece as it is installed. When the mouthpiece is completely installed the tear strip is pulled tearing the seal into four sectors, Figure 6 (B). This method leaves only the thin tear strips to be disposed of thus eliminating the possibility of cabin contamination.

Figure 7 illustrates an alternate method of seal installation that represents the best available design. The method depicted would result in a seal meeting all requirements set forth for the inner seal. In this method, the compressed aluminum foil seal is attached to a flat washer, (A), and the washer is pressed into the counterbored seat, forcing it into the angular cross section shown in (B). This method insures the leak proof seal required between the washer and the can mouth.

QUICK OPENING DEVICE

The general requirements specify that quick opening devices, such as tear strips, be provided for opening containers. The quick opening device must also withstand the temperatures and pressures of thermal processing, and provide hermetic sealing of the container.

Many quick opening devices have been considered, but because they did not meet the above requirements they have been rejected.

The rolled seam type of quick opening device, Figure 8, is found on standard metal food containers throughout the canning industry. It is placed on the container after filling, and is formed by rolling a continuous seam around the perimeter of the can. Aside from consideration of the requirements as previously mentioned, an external removal device is necessary with this type of quick opening method, and this in itself is undesirable. Also, a desired feature but not a requirement, is the ability to re-seal the container after opening, and this is not possible with this concept.

A rectangular container, Figure 9, naturally lends itself most simply to a rectangular opening, so the design was evolved of a rectangular plate that closed the container by fitting closely in two grooves placed on the dispensing end of the container. To remove this quick opening device the plate would be pulled from its tracks, and replaced after consumption to re-seal the container. The problem of hermetic sealing would be considerable with this design as would be the prevention of contamination of the cabin with food particles when the mouthpiece is attached.

The tear strip types of quick opening devices, Figure 10, where a weak portion of the metal is sheared by a stronger portion have been investigated. The types whereby an imbedded piece of wire is used to shear the metal were found troublesome in that the wire could break, pull free, or otherwise malfunction depending upon the angle and speed of force applied. Key operated types of tear strip quick opening devices, as used on coffee cans, also were disregarded due to lack of compatibility with other design parameters and the fact that the container could not be resealed.

A unique and different type of quick opening device, Figure 11, was investigated whereby a round container end, or neck, was sealed with aluminum foil to provide hermetic closure, and covered with a circular cap by virtue of a friction fit. The cap contained a retracted knife edge that could be extended manually, and then rotation of the cap would cut out the foil seal beneath it.

Mechanically operated friction-type quick opening devices, Figure 12, whereby the circumference of the device is diminished by a lever action to give a close fit were also investigated. However, they were found deficient in the ability to hold a hermetic seal, and disregarded.

Circular lids, both friction fitting and threaded, have been evolved for this container. The use of these types of quick opening devices obviously requires a change of container configuration from rectangular to round at the dispensing end. But it is felt that the advantages gained from circular lids are worthwhile. The friction device, Figure 13, was rejected in favor of the threaded version because of the requirement of an opening tool as well as the fact that when removing the cap it could be deformed, if improperly loosened, and then could not be replaced on the container. The friction cap, however, is actually the best of the two opening devices with respect to ease of machining of the container and forming of the cap. It is presently felt though, that the circular threaded cap is capable of withstanding the acceleration load factor of 8 g.

Figure 8

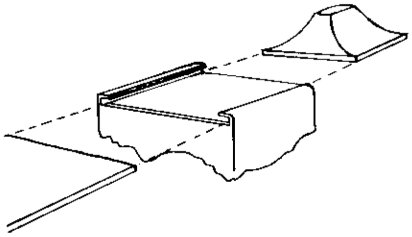


Figure 9

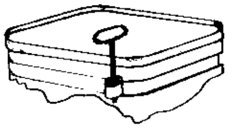


Figure 10

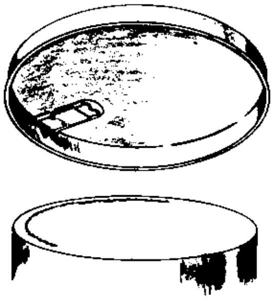


Figure 11

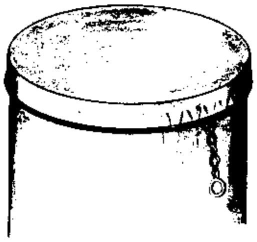


Figure 12

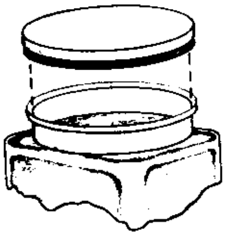


Figure 13

Figure 14

The threaded circular quick opening device, Figure 14, appears to offer the best possibilities for the container design. It has the ability to provide a hermetic seal on the container and can be quickly removed. It is also compatible with the additional parameter that it can be replaced when the food has been consumed to reseal the container. In design, the thread would be so placed to require a small turning arc for operation, yet allow good sealing. A gasket of suitable material is placed on the interior of the cap to insure hermetic sealing. Rubber or suitable plastics could be used as the gasket material as long as it would withstand thermal processing without any adverse effects to the quick opening requirement or the food. The cap itself would be fabricated of aluminum.

The interior portion of the quick opening device, or any part that could possibly come in contact with the food, as when container is resealed, must be lined with the same food protective coating that is applied to the interior of the container.

EXPELLING TECHNIQUES AND DEVICES

The expelling device is used to force the food contents from the container, through the mouthpiece, and into the astronaut's mouth. This device is so designed that the astronaut can hold the can and expelling device, and operate the device, all with one hand.

The basic principle of the expulsion device will be to displace all the contents while simultaneously forcing the remaining food to the area immediately surrounding the outlet.

The simplest method under consideration is a can with a piston in it, Figure 15. After the mouthpiece is installed, a cap (A) is removed from the lower end and the piston (B) pushed upward with the fingers. While the system's simplicity is encouraging, its drawbacks are serious. In order to prevent unequal finger pressure tilting the piston and rapidly disgorging the contents, an extremely long skirt (C) on the piston is required. Also, the operation, of one-handed, would be awkward and uncoordinated; if two-handed, it still remains unsuitable.

One of the first systems under consideration was a screw-type device, Figure 16. This utilizes a screw shaft (A) that would drive a piston (B) along the can's length by turning a knob (C) on the underside of the can. The device could be applied to both liquids and solids. This concept is one of the simplest, but it requires the use of two hands. For this reason, the concept was discarded.

Keeping in mind the basic principle mentioned above, a series of displacement volume systems utilizing inflatable bladders were developed. The first of these methods consisted of inserting a balloon through a hole in the bottom and expanding it to force the contents upward to the mouthpiece. This method had severe limitations as to the amount of the contents that could be removed. For solids, only a fraction of the contents could be removed, in the case of liquids the results were somewhat better but not enough to merit further study. The limiting factor was the hole through which the balloon was inserted.

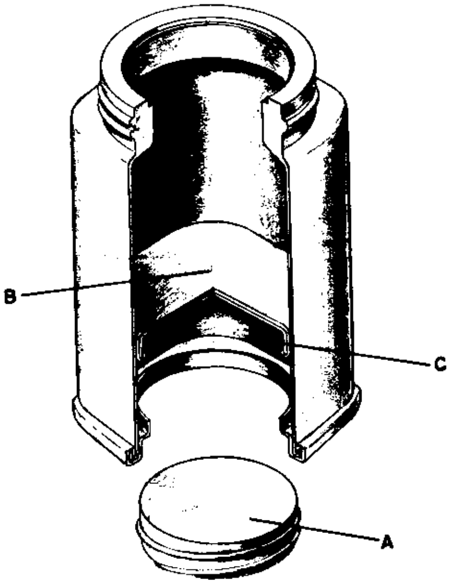


Figure 15

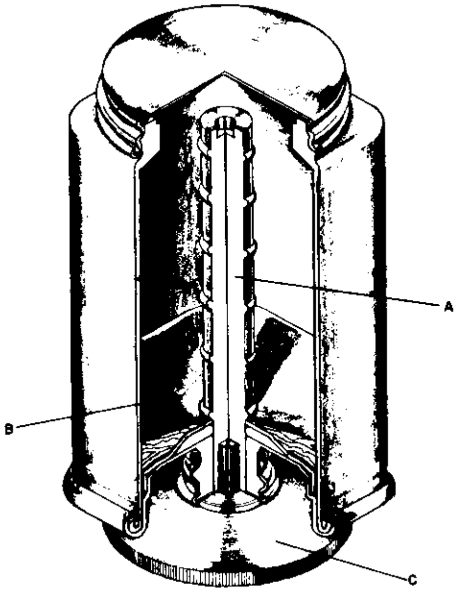


Figure 16

The next idea in this series is a concept that is designed to keep the can a simple, open end extrusion. This simplicity of the can allows it to be sterilized and coated easily. Cooking or processing that is done in the can is less restricted since the absence of gaskets or any other non-aluminum material places no temperature limitations on the can. The force feed will be totally enclosed in the cap and screwed into place, Figure 17. As illustrated in the figure, the cap, mouthpiece and feed control will be a single compact unit that replaces the regular cap. The bulb (A) is the source of air to be used to displace the food. It has two check valves (B_1, B_2) which makes the bulb draw air in at valve B_1, and expel it at B_2, where it inflates the toroid bladder (C). The inflation of the bladder forces the contents to the bottom of the can where it passes into the feed tube D. From here the contents can be drawn up into the mouthpiece which will be at (E). When the contents of the can have been removed, there is still some left in the feed tube and the mouthpiece, then the cap (G) can be loosed admitting air through tube (H), which allows the last remaining contents to be drawn out. When it is desired to remove the entire unit, the knurled nut (F) is loosed which allows the bladder to deflate and fall into the container. The can is now ready to be resealed with its original cap and disposed of.

The most feasible application of the bladder principle is one where the cabin's atmospheric pressure forces the contents from the can. As illustrated in Figure 18 and 19, this system can remove all the liquid from a container with no elaborate equipment, while keeping the can as simple as possible. The device consists of a bladder (A) which has a spring steel reinforced collar (B).

In the center of the bladder is a small reinforced opening (C) through which a drinking straw (D) is secured. This drinking straw contains a one-way valve located at (E) which will obviate the need for a mouthpiece.

When the astronaut wishes to drink he removes the cap and places the collar of the bladder in the seat on the rim of the can. He then installs the ring cap to insure a non-slip hold on the collar. Then, a push on the drinking straw will break the inner seal, and he is ready to drink, Figure 18. He then sucks on the straw to draw the liquid out. The partial vacuum created in the can will draw the bladder and straw down into the can, with the volume ever decreasing around the bottom of the can, Figure 19, with the result that all the liquid is removed and the bladder is stretched against the walls of the container. When the astronaut has consumed the contents of the can, he unscrews the ring cap, bends the drinking straw into the can and reinstalls the cap, thus rendering it disposable.

Another completely different method was arrived at to deal with large chunks of food such as: candy, buns, fruit bars, cubed meats, whole or sliced vegetables, and rolls. The single unit qualifies it as both an expulsion device and mouthpiece. It utilizes a modified fork which is partially enclosed in a clear plastic bag, Figure 20. The significance of the bag becomes obvious when consideration is given to what would happen without the bag. Such a condition would allow juice or gravy, small particles, etc., to contaminate the atmosphere. Also, the chunks not securely impaled or clamped could float off around the cabin. The drawing fully illustrates the principle. By using this method the astronaut will be eating the same food

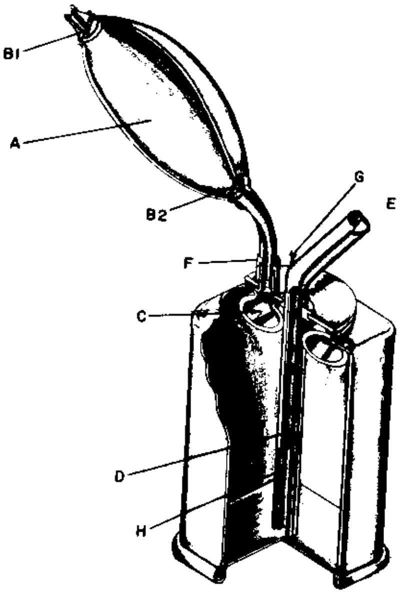


Figure 17

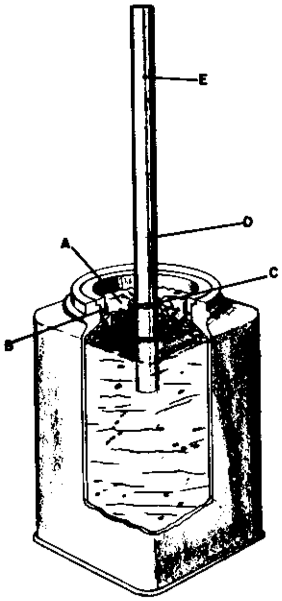


Figure 18

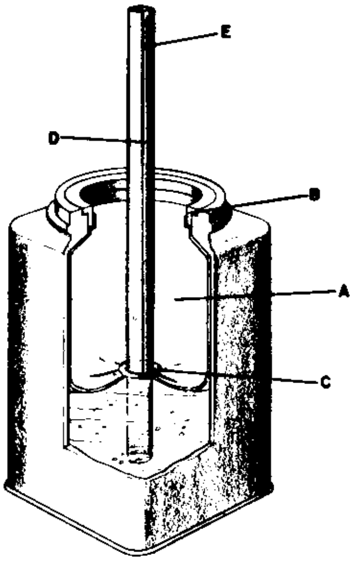


Figure 19

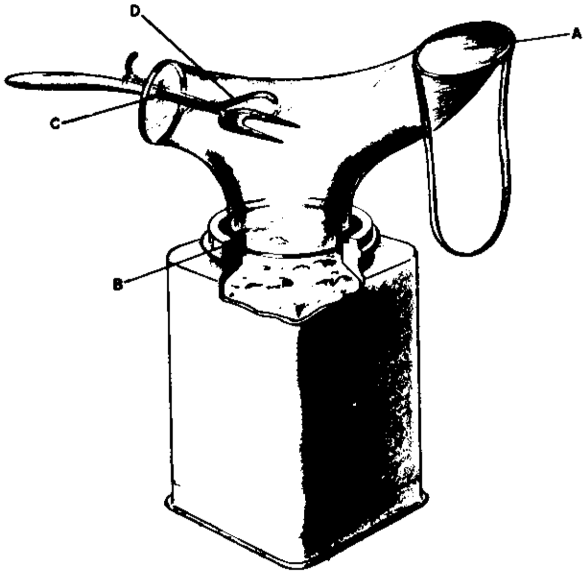


Figure 20

as he is used to in a manner similar to that which he is used to. This method will place no severe size limitations on the food chunks, and will not require him to hold on to the device if he wishes to stop eating due to interruption of his meal. The mouthpiece (A) is a large opening extending from below the nose to under the lower lip, and is held against the face by the strap. The plastic bag will attach to a spring steel reinforced ring (B) that seats inside the rim of the can. The third opening is where the fork is inserted (C). The opening can also be used to wipe the fork upon its withdrawal from the device. The reusable fork will have a third tine (D) that will clamp food that cannot be impaled. The fork may be cleaned with a damp towel containing a sanitizing agent. The only other necessity would be that the can snap into a harness or swivel stand located on the astronaut's chest. In this way the feeding operation remains one-handed, and in emergency both hands could be freed without fear of losing the food container with resultant contamination of the cabin atmosphere.

When the contents of the can are consumed, the astronaut can push the entire bag into the container, except for the snap-on head strap, reinstall the original cap and then have a sealed, disposable can.

The final concept is one that returns to the principle of the moving piston. The piston is driven up by mechanical means from the bottom to the top of the can. This combination of the piston and mechanical drive is considered the most feasible and best suited for the job.

This expelling device can best be described as a hand-gripped, ratchet type device, Figure 21. The entire unit will screw on to the bottom of the can by means of the collar and barrel which are an integral piece (A). The stainless steel plunger (B) then fits snugly into the hole on the underside of the piston. The attachment of the integral collar and barrel to the can creates a rigid member. This rigid member guides the plunger, which fits snugly in the hole in the bottom of the container and into the bottom of the piston. The complete support of the plunger insures that only vertical piston movement will result with no fear of the piston being cocked by the plunger. The plunger has grooves spaced every 3/32 of an inch. The hand grips are held apart by a constant tension spring. By squeezing the hand grips together a spring pawl (C) will engage a groove and drive the piston into the can 3/32 of an inch. The amount of travel per squeeze of the hand grips has been set at a definite length to insure that only a predetermined amount of food can be ingested, usually a mouthful. This is to prevent the astronaut from forcing too much food out by an involuntary or accidental squeeze on the handle. A pawl is used to limit the plunger's travel upward. For re-use the pawl is disengaged and the plunger may be withdrawn by pulling the knurled knob (D) on the end of the plunger.

MOUTHPIECE

The mouthpiece is the final link in the feeding cycle between the food container and the astronaut's mouth. Since the mouthpiece is a limiting factor in space feeding, its design must be a departure from all previously explored concepts. The mouthpiece is designed to attach directly to the can after removal of the cap and before puncture of the inner seal. The sequence

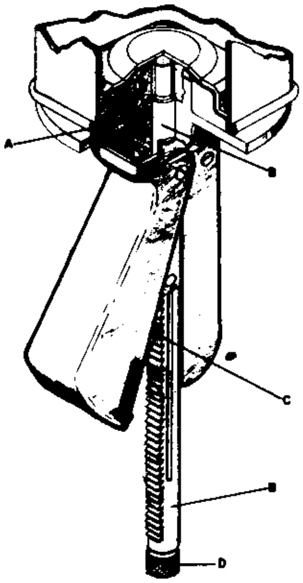


Figure 21

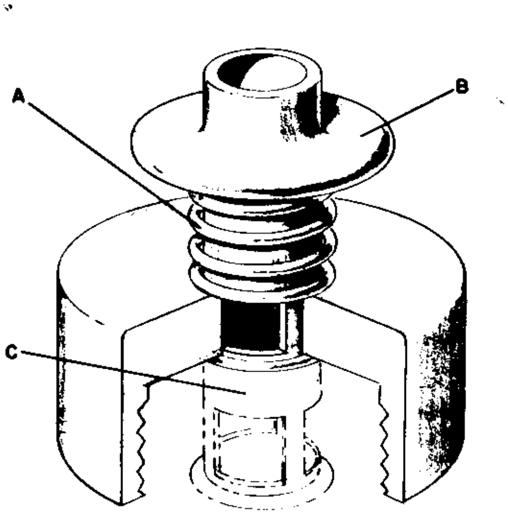


Figure 22

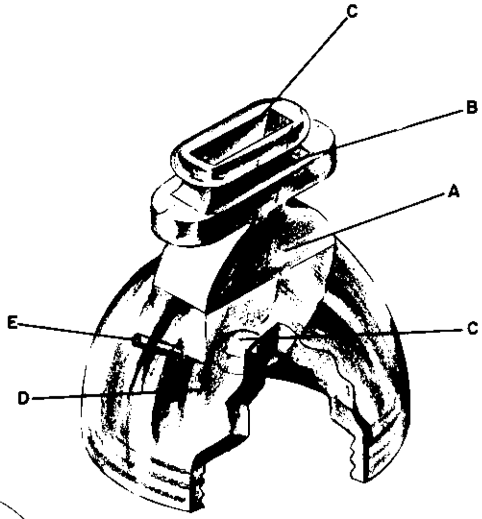


Figure 23

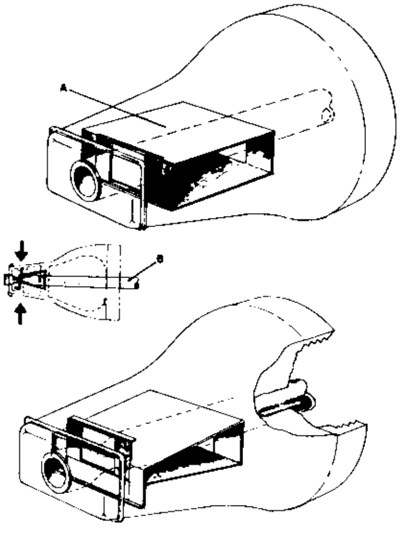


Figure 24

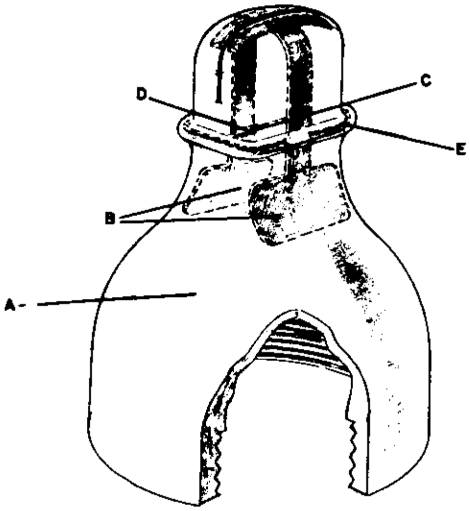


Figure 25

of events is established by design to keep the contents of the can restricted at all times to prevent atmospheric contamination. It will also afford the astronaut a second control on his food supply. The expulsion device provides the force necessary to empty the container; the mouthpiece affords positive on-off control. In addition to meeting all the technical requirements, the mouthpiece has the added necessity of meeting the astronaut's psychological requirements.

The first mouthpiece considered is one that would be suitable for liquids, puddings, and pulverized foods, Figure 22. It relies upon a spring (A) to keep it in a normally closed position and to close it securely after opening. The ring (B) is the piece that the astronaut places his lips against and pushes in. By so doing the tube (C) also moves in exposing the openings in its lower end to the contents which are under pressure by the expulsion device. One of the big assets of this device is that no matter how much the expulsion device is squeezed, thereby increasing the pressure of the contents, the mouthpiece will not open and disgorge the contents.

The next mouthpiece considered is also a positive off-on device, but in this case the astronaut must close the mouthpiece, as it will not return to a closed position, Figure 23. This mouthpiece consists of a round disc (A) with a mouthpiece (B) attached to it. There is a hole (C) through the entire assembly through which the contents flow. This assembly is inserted into a hemisphere (D) to complete the device. When the inner assembly is in an upright position the food can flow through the mouthpiece. When this assembly is turned to either the right or left it closes off the hole and hence the food supply. The hole (E) admits air and allows the contents remaining in the mouthpiece to be sucked out. This device also, when in the off position will not leak or disgorge its contents regardless of the pressure exerted by the expulsion device.

The next mouthpiece is one that is suited only to fluids. It is a positive off-on device that would withstand high pressures before leaking, Figure 24. The heart of the mouthpiece is a spring steel clip (A) which is much like the ordinary pinch clamp used in chemical applications. This steel clip would be potted in the soft plastic enclosure illustrated. The mouthpiece would attach to the can in the normal fashion, and the short extension of hard tubing (B) would puncture the inner seal. The astronaut could then drink by biting down on the mouthpiece, as shown in the cross section, at the arrows. The slight ridge (C) would insure that the pressure of the astronaut's bite would be applied in the proper location. The tube that carries the fluid could be any diameter, depending on the flow desired. A diameter of 1/4 inch is thought to be adequate for all purposes for which this mouthpiece is intended.

The mouthpiece shown in Figure 25 is one of the most feasible of the configurations considered. Its suitability results from the fact that it can be used for solids and liquids, and it is simple, which facilitates cleaning. The mouthpiece will be a soft, pliable, plastic, with the actuating parts imbedded in the body (A). The two levers (B) will be identical and made relatively thin and rigid metal. There will also be a rigid wire hoop (C) surrounding the cavity to which the levers are attached, as illustrated at (D). The ridge of material (E) will insure that the pressure from the astronaut's mouth will be applied at the proper location. In operation the astronaut will bite down on the levers (B) where shown, causing them to pivot on the rigid hoop and force the clamshell opening apart. When the astronaut releases the mouthpiece, the spring tendencies of the wire hoop and the elastic properties of the plastic will return the mouthpiece to its normally closed position.

The final, and most feasible, mouthpiece is the configuration shown in Figure 26. It vaguely resembles a baby bottle nipple and will be made of a material of the same resiliency. Ideally, the mouthpiece would be made of a transparent plastic, meeting the aforementioned qualifications to enable the astronaut to see the next mouthful of food that he would eat. However, such a plastic does not exist and would be difficult to develop. The nearest compound to it is polyvinylchloride which is unsuitable. For this reason it is felt that the mouthpiece should be made of silicone or polysulfide rubber.

The base (A) would be a rigid ring, reinforced with a spring steel hoop, that is inserted into the mouth of the container. The flange (B) would seat on the groove in the mouth where it would be securely seated and clamped in place by reinstalling the ring cap. The ring cap is a screw on cap with an open center section. When installed, the open center section fits over the mouthpiece, and the flange around this open center section bears on the flange of the mouthpiece. The ring cap would insure that the mouthpiece would not be forced off should too much pressure be built up by the expulsion device. It is simple and could be adapted to any mouthpiece to insure its firm seating. The next area (C) acts as a reservoir for the following mouthful of food that the astronaut will take. The slightly enlarged and round area (D) is the next mouthful of food to be taken. The astronaut places his teeth and/or lips where area (C) joins area (D) and forces the food out in a "squeeze-draw" operation. This will force open the slit (E) in the reinforced end section (F). The extremely elastic properties of the mouthpiece material and the fact that area (F) is thicker than other areas causes the slit (E) to return to its normally closed position once the mouthful of food has passed through. By actuating the expulsion device the food in area (C) will fill area (D) and the contents will in turn fill area (C). This cyclic process will continue until the expulsion device has driven the piston to the top of the can and the only remaining food is in the mouthpiece. By manipulation of the mouthpiece practically all of this food could be removed. The astronaut would then force the mouthpiece down into the container, which is facilitated by the reverse curve (G), remove the ring cap, and reinstall the original cap thus rendering the container and mouthpiece sealed and disposable.

A minor variation in this configuration will handle liquids. This mouthpiece would have a longer and smaller cross-section (C) with the elimination of area (D). By biting on a line with the slit (B) in section (F) it would open. Closing would be effected when the pressure is released as in the version mentioned above for solid food.

The last two designs are disposable. This approach is felt to be the ideal way to eliminate the need for the astronaut to remove, clean, store, and reinstall the mouthpiece. It also eliminates the possibility of small quantities of food remaining in the can to escape into the cabin when the mouthpiece is removed.

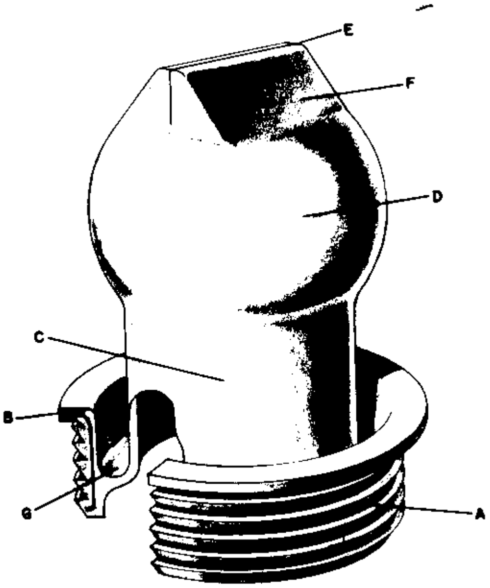


Figure 26

FEEDING SYSTEM - FINAL DESIGN

The feeding system shown in Figure 27 is composed of the most feasible concepts of each individual item, and represents the final design. The individual feeding container, when assembled with its expulsion device and mouthpiece, represents a functional system of integrated parts.

Each individual item in the system underwent an evolution to reach the final stage of design. This evolution was brought about by a constant stream of new ideas and concepts that were unearthed by research. Each concept in the evolution was critically evaluated, and if found unsuitable or not feasible the idea was discarded, and work continued until the final design was established.

The engineering evaluation phase reported in WADD Technical Report 60-522(I) concludes that the most feasible process for fabricating the aluminum container body is impact extruding.

Figure 28 shows the engineering drawing of the feeding container assembly. The container's volume is 11.78 cubic inches, of which 10.83 cubic inches will be food, and approximately 0.95 cubic inches of head space. The bottom of the container is attached to the can by a double roll seam process. Inside the container is an expulsion plate that moves the length of the container. The dispensing end of the container has a threaded cylindrical neck to which is attached its quick opening cap. Beneath this is an aluminum foil tear strip innerseal which prevents the escape of the contents when the cap is removed. This is critical in a zero gravity situation, since food could diffuse and "float" throughout the cabin atmosphere.

The pressure relief technique arrived at was the simplest and most effective. It consists of packing the food under a sufficiently high vacuum so that when the food is heated to serving temperature, the combined gas and vapor pressure within the sealed container will not exceed cabin pressure.

The expelling technique is based on driving the aforementioned expulsion plate the length of the container, thereby forcing the contents out the dispensing end. A hand gripped ratchet device was designed that moves the expulsion plate a set distance with each squeeze of the handles. This is important, since less than a mouthful of food will be forced out per squeeze. This will prevent an uncontrolled spasm or contraction forcing too much food into the crew member's mouth or into the cabin.

Of the many feasible mouthpiece designs evolved, a disposable type was chosen. It is simple in design and construction. There is a design for solid foods and one for liquids. It requires only lip pressure and/or pumping of the expelling device to open the aperture.

In the ready-to-serve configuration, the individual feeding container and its accessories are a functional and attractive piece of equipment that is compact, less than 13 inches square, rugged and lightweight.

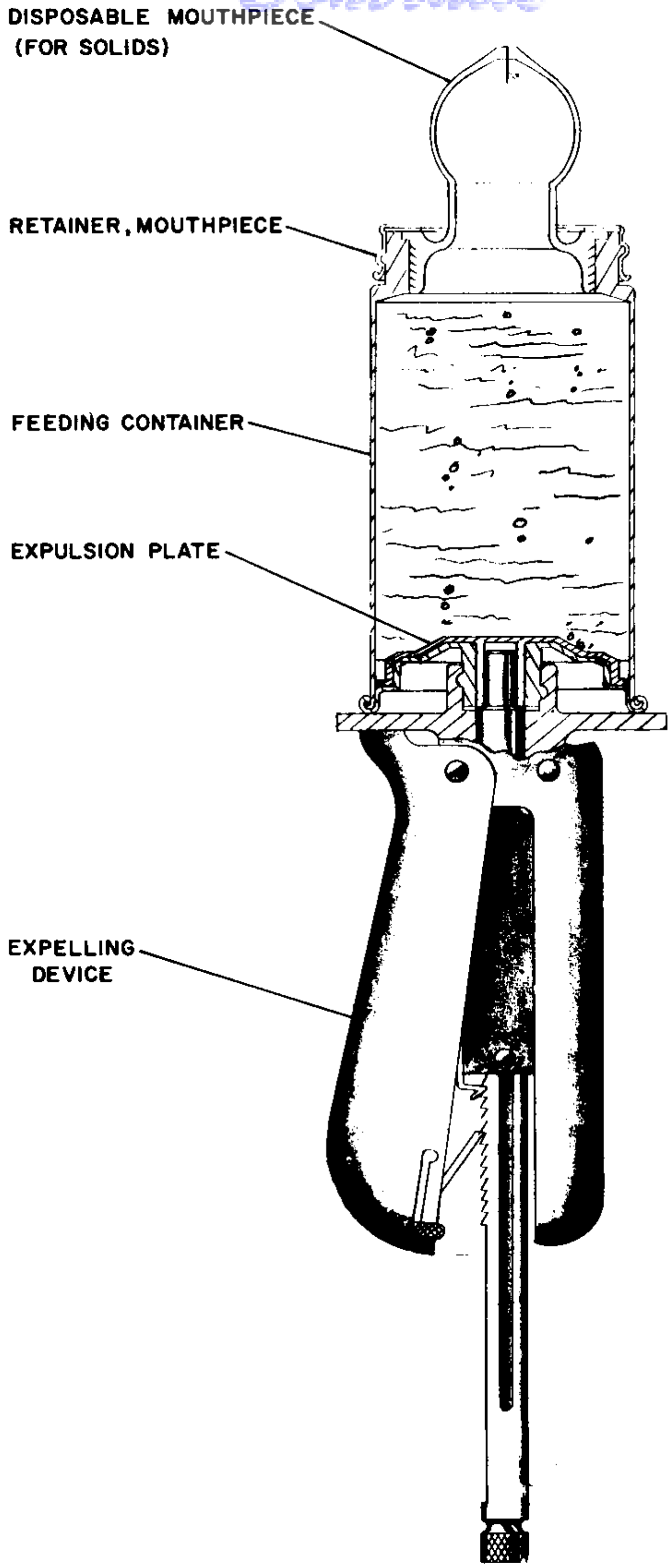
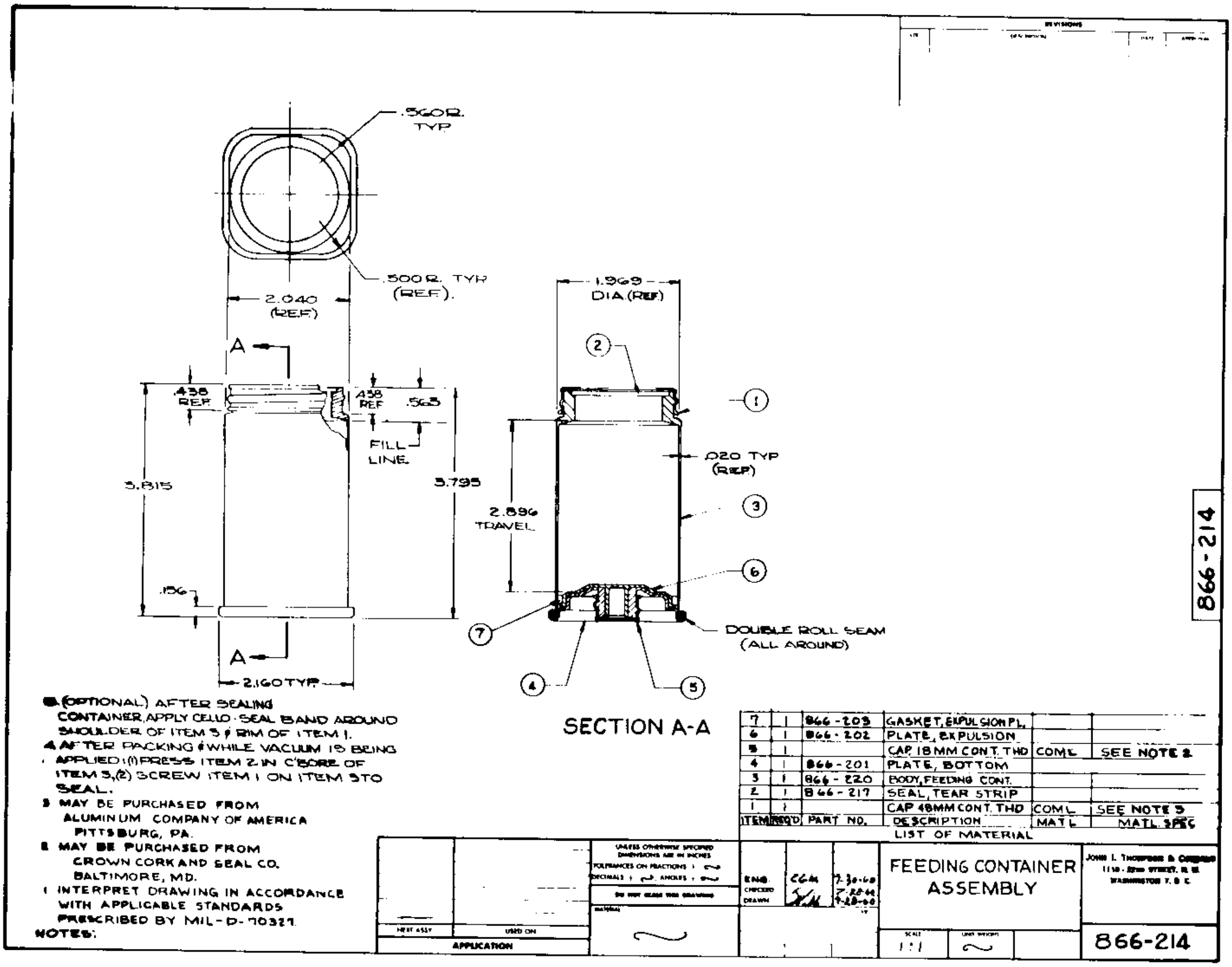

DISPOSABLE MOUTHPIECE (FOR SOLIDS)
RETAINER, MOUTHPIECE
FEEDING CONTAINER
EXPULSION PLATE
EXPELLING DEVICE

Figure 27



5 (OPTIONAL) AFTER SEALING CONTAINER, APPLY CELLO-SEAL BAND AROUND SHOULDER OF ITEM 3 & RIM OF ITEM 1.

4 AFTER PACKING & WHILE VACUUM IS BEING APPLIED: (1) PRESS ITEM 2 IN C'BORE OF ITEM 3, (2) SCREW ITEM 1 ON ITEM 3 TO SEAL.

3 MAY BE PURCHASED FROM
ALUMINUM COMPANY OF AMERICA
PITTSBURG, PA.

2 MAY BE PURCHASED FROM
CROWN CORK AND SEAL CO.
BALTIMORE, MD.

1 INTERPRET DRAWING IN ACCORDANCE WITH APPLICABLE STANDARDS PRESCRIBED BY MIL-D-70327.

NOTES:

7	1	866-203	GASKET, EXPULSION PL.		
6	1	866-202	PLATE, EXPULSION		
5	1		CAP 18MM CONT. THD	COML	SEE NOTE 2
4	1	866-201	PLATE, BOTTOM		
3	1	866-220	BODY, FEEDING CONT.		
2	1	866-217	SEAL, TEAR STRIP		
1	1		CAP 48MM CONT. THD	COML	SEE NOTE 3
ITEM	REQ'D	PART NO.	DESCRIPTION	MAT'L	MATL. SPEC

LIST OF MATERIAL

FEEDING CONTAINER ASSEMBLY

JOHN I. THOMPSON & COMPANY
1118 - 22ND STREET, N.W.
WASHINGTON 7, D.C.

866-214

Figure 28

The operations necessary for feeding have been kept as simple as possible while still allowing the container to meet all the requirements set forth in the specifications. The feeding operation begins when the crew member selects the container of food that he wishes to eat. The container is heated in a special oven to 185° Fahrenheit temperature. When this has been done, the cap is removed and the crew member inspects the inner seal, which is also his pressure warning indicator. The next step is to thread the tearstrip through the mouthpiece and seat the mouthpiece in its groove. The ring cap is then put on, where the original cap was, to insure that the mouthpiece will not pop out if the pressure should become too great in the can while the food is being expelled. The crew member then attaches the expulsion device to the bottom of the can. He then pulls the tearstrip through the mouthpiece, disposes of it, and is ready to eat. He then actuates the expulsion device, which is a one-hand operation, and proceeds to consume the contents of the container. When he has finished the contents of the container, and has also emptied the mouthpiece, he will push the disposable mouthpiece into the container, remove the ring cap, and replace the original cap. Upon removal of the expulsion device and screwing on the bottom cap, he will have a sealed, disposable container. This sequence of events was so set up, by design of components, that the contents of the container will never come into contact with the cabin's atmosphere, which eliminates risking loss to the atmosphere and subsequent contamination.

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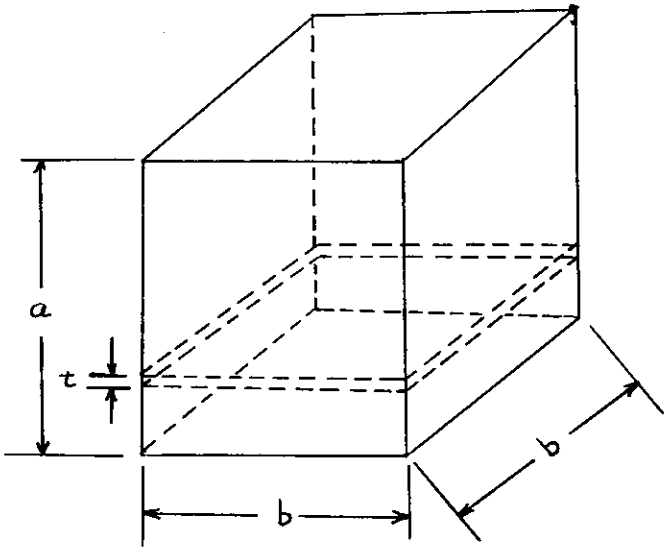
APPENDIX I

ANALYSIS OF MINIMUM SURFACE AREA OF RECTANGULAR CONTAINERS

There are two important requirements that enter into the determination of the container configuration. They are: (1) minimum material, (2) rectangular shape.

Minimum material is self explanatory. The importance of the rectangular shape deals with the heat transfer involved, and the conservation of storage space. The ultimate in heat transfer design is a long thin section. The following is an analytical approach to determine the minimum surface area for the needed volume, and also to determine if the minimum values give a rectangular configuration. The container possesses an internal plate, which acts as a piston for explusion. If it were not for this plate, the minimum surface area would be a cube.



SURFACE AREA = $A = 4ab + 3b^2$ (1) THICKNESS IS NEGLIGABLE

VOLUME = $V = ab^2 - b^2t$ (2) HOWEVER, THICKNESS IS NEGLIGABLE

$\therefore \quad V = ab^2$

$a = V/b^2$ (3)

THE VOLUME IS CONSTANT, THEREFORE FROM EQUATIONS (1) AND (3)

$A = 4b(V/b^2) + 3b^2$

$A = 4V/b + 3b^2$

To OBTAIN A MINIMUM , $\frac{dA}{db} = 0$

$\frac{dA}{db} = 0 = -4\,V/b^2 + 6b$ OR $4\,V/b^2 = 6b$

$6b^3 = 4V$

$b = \sqrt[3]{4/6\ V}$ (4)

FROM EQUATION (3) $a = V/\sqrt[3]{(4/6\ V)^2} = \sqrt[3]{V^3/(4/6\ V)^2}$

$a = \sqrt[3]{36/16\ V}$ (5)

V = 6 FLUID OUNCES ; BUT 0.5541 CUBIC INCHES = 1 FLUID OUNCES

THEREFORE $V = 6\left(\frac{1}{0.5541}\right) = 10.82$ CUBIC INCHES (6)

FROM EQUATIONS (4) AND (6)

$b = \sqrt[3]{4/6\ 10.82} = \sqrt[3]{7.22}$

$b = 1.932$ INCHES

FROM EQUATIONS (5) AND (6)

$a = \sqrt[3]{36/16\ 10.82} = \sqrt[3]{24.4}$

$a = 2.9$ INCHES

$\frac{d^2A}{db^2} = 8\,V/b^3 + 6 = 8\left(10.82/1.932^3\right) + 6 = 12 + 6 = 18 > 0$ ∴ VALUE IS A MINIMUM

As can be seen from the values of (a) and (b) for minimum surface area, the configuration is rectangular thereby meeting requirements of configuration and minimum weight.

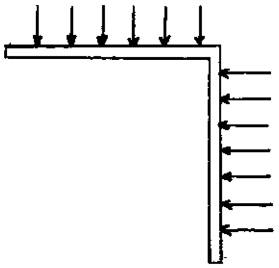
APPENDIX II

STRUCTURAL ANALYSIS OF THIN-WALLED RECTANGULAR CONTAINERS UNDER UNIFORM EXTERNAL PRESSURE

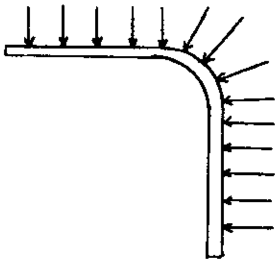
The use of high vacuum, 22 inches of mercury vacuum, having been selected as the pressure relief method, imposes upon the container structure at least three times the acting force usually subjected to conventional cans which have 4 to 6 inches of mercury vacuum. This high vacuum demands that a structural analysis be performed to insure against the container structure failing.

Formulas for determining the stresses in a thin walled container due to internal pressure are not valid for predicting critical stresses due to external pressure, since buckling may occur prior to failure by slip or fracture. Unfortunately, the analysis for thin walled rectangular containers is not available. However, literature is available which indicates buckling will occur in the form of twisting and rippling along the edges at the critical pressure.

Suggested remedies for buckling, which occurs at lower pressures than those causing deformation of the walls, are the addition of angle supports at the edges or thicker walls for the edges, and curving of the edges. Since it would be undesirable to add material to the container, the edges will be curved to replace the square corners, making the container generally a cylindrical shape.



Square Edge



Round Edge

The curvature of the edge offers a stiffening effect, due to the fact that there is less stress concentration on a curved edge than a square edge.

To obtain a rough approximation of the critical stress, the container is considered to be a square prism 2 inches by 3 inches. However, since the edges on the top and bottom plates contain 1/2 inch radii, the flat plate upon which the external pressure acts reduces to 1 inch by 3 inches. From Formulas for Stress and Strain by Roark, the expression for maximum stress for a flat plate with uniform load over the entire surface, and with all edges fixed is used.

$$S = \frac{0.5\,wb^2}{t^2(1+.623\,\alpha^6)}$$; WHERE

S = MAXIMUM STRESS

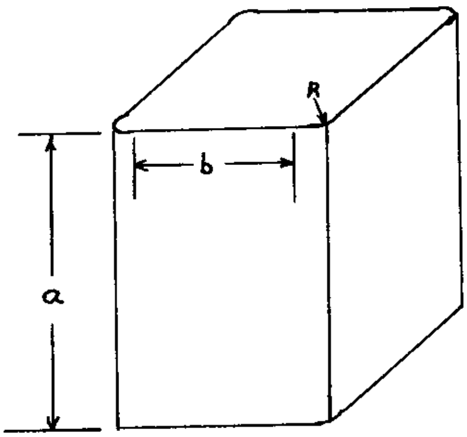
w = EXTERNAL PRESSURE

b = 1 INCH

a = 3 INCHES

$\alpha = b/a = 1/3$

t = THICKNESS



$$t = \sqrt{\frac{0.5\,wb^2}{S(1+.623\,\alpha^6)}}$$

w = 22 INCHES OF MERCURY

$w = 22 \times .491 = 10.8$ PSI

EMPLOYING A FACTOR OF SAFETY OF 1.5 ; $S = \frac{15000}{1.5} = 10{,}000$ PSI

$\alpha = \frac{1}{3}$; $(.623)\alpha^6 = .001352$

$$t = \sqrt{\frac{0.5\,(10.8)\,1}{10{,}000\,(1+.001352)}}$$

$$t = \sqrt{\frac{5.4}{10{,}000\,(1.001352)}}$$

$$t = \sqrt{.000539}$$

$t = 0.0232$ INCHES

It must be emphasized that there is no analysis available to determine whether or not curving of the edges will completely alleviate or aid the problem of buckling. Also, there is little data available for the properties of 1100-F aluminum alloy. That which is available indicates a maximum yield stress of 15,000 psi. Therefore testing of the container is a must in order to determine if the proper wall thickness and edge construction has been employed.

Container manufacturers, upon reviewing the specifications, feel that a container of .020 inches thick would be adequate, in handling up to 22" Hg. The above calculations are only an approximation to get into a feasible area of thickness.

Container manufacturers agree, that tests must be performed on prototype models.

APPENDIX III

ANALYSIS OF THERMODYNAMIC PROCESSES DURING HEATING

CONDITIONS:

P_1 = 8 INCHES MERCURY ABSOLUTE

T_1 = 75° F T_2 = 185° F

V_{1a} = 0.95 CUBIC INCHES

V_1 = 10.82 CUBIC INCHES

P_1 = initial total pressure

T_1 = initial temperature

T_2 = final temperature

V_{1a} = initial volume of headspace

V_1 = initial volume of water

from <u>Thermodynamic Properties of Steam</u>, by Keenan & Keyes

AT 75° F ; P_{1v} = 0.875 INCHES MERCURY ABSOLUTE

v_1 = 0.01607 FT^3/LB

AT 185° F ; P_{2v} = 17.068 INCHES MERCURY ABSOLUTE

v_2 = 0.01654 FT^3/LB

P_{1v} = initial vapor pressure

v_1 = initial specific volume of water

P_{2v} = final vapor pressure

v_2 = final specific volume of water

assuming weight change of water negligible

$$\frac{V_1}{V_2} = \frac{v_1}{v_2} \quad ; \quad V_2 = V_1 \frac{v_2}{v_1}$$

$$V_2 = 10.82 \left(\frac{0.01654}{0.01607}\right)$$

$$V_2 = 11.15 \text{ CUBIC INCHES}$$

V_2 = final volume of water

Increase of volume of water = $V_2 - V_1$

$$V_2 - V_1 = 11.15 - 10.82 = 0.33 \text{ CUBIC INCHES}$$

Decrease of volume of headspace = 0.33 CUBIC INCHES

$$V_{2a} = V_{1a} - 0.33 \quad ; \quad V_{2a} = 0.95 - 0.33 = 0.62 \text{ CUBIC INCHES}$$

V_{2a} = final volume of headspace

from the law of partial pressures

$P_{1a} = P_1 - P_{1v}$

$P_{1a} = 8. - 0.875 = 7.125$ INCHES MERCURY ABSOLUTE

P_{1a} = initial air pressure

from the perfect gas laws

$$\frac{P_{1a} V_{1a}}{T_1} = \frac{P_{2a} V_{2a}}{T_2}$$

$$P_{2a} = \frac{P_{1a} V_{1a}}{T_1} \frac{T_2}{V_{2a}}$$

$$P_{2a} = \frac{(7.125)(0.95)}{(75+460)} \frac{(185+460)}{0.62}$$

$$P_{2a} = \frac{6.76}{535} \frac{645}{0.62}$$

$P_{2a} = 13.1$ INCHES MERCURY ABSOLUTE

P_{2a} = final air pressure

from the law of partial pressures

$P_2 = P_{2a} + P_{2v}$

$P_2 = 13.1 + 17.068$

$P_2 = 30.168$ INCHES MERCURY ABSOLUTE

P_2 = final total pressure