SATURN HELIUM BOTTLES

CONTRACT NAS 8-11555

FINAL REPORT

ER 14012

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I. INTRODUCTION

The design, development and qualification of high pressure helium storage bottles for the Saturn S-1C was carried out by the Martin Company under NASA Contract NAS 8-5151. Upon successful completion of that program, NASA-MSFC awarded a production contract, NAS 8-11555, to the Martin Company. It is the purpose of this report to present and discuss the activities associated with the production program.

The basic production contract for 10 units was awarded in October 1963. In June 1964 the contract was amended to include 5 additional units for a total production of 15.

The first 5 units were shipped on schedule in July 1964. Two of the second 5 units were shipped on schedule in September 1964. The three remaining units in this lot, S/N 0022, 0024, 0014 were held at the Martin Company because excessive volumetric expansion had been encountered during acceptance testing.

During October and November 1964 it was established that a heat treat problem existed and additional process controls were established including a hardness acceptance criterion for the bottles. All seven bottles, previously delivered, were sent back to Martin-Baltimore in December 1964. The final hardness criterion was agreed upon during January 1965. It was further agreed that six of the ten units would be reprocessed starting with heat treatment and four units would be leak tested, cleaned and shipped. Three of these four, S/N 0016, 0017, 0020, did not meet the newly established hardness criterion but were accepted "as is". The contract schedule was revised and the 15 units were shipped on schedule as shown in Table 1.

TABLE 1

Summary of Shipping Dates

No. of Units	S/N	Shipping Date
4	0013, 0015, 0016, 0020	1-26-65
3	0014, 0017, 0027	2-26-65
3	0023, 0025, 0026	3-5-65
4	0018, 0021, 0022, 0024	6-8-65
1	0019	6-29-65

The program and the problems mentioned above are discussed in this report. Detailed information can be found in References 1-4.

II. CONTRACT DOCUMENTATION

The basic documents which control the manufacture of the helium bottles are listed in Table 2 together with the revision applicable to the basic contract and the revisions made during the life of the contract. The changes which were made in these documents are summarized in Table 3 and discussed herein.

A. DRAWING 88-4000500, HELIUM STORAGE BOTTLE

1. Change D

The primary purpose of this change was to revise the thread protector used for shipping purposes. The old protector was a cap and dessicant holder which screwed on to the bottle external threads. This protector design was used during the development program and found to be undesirable for several reasons: a) dust from the dessicant entered the bottle interior, b) the bottle could not be installed in the vehicle without exposing the clean interior to atmospheric conditions, c) in one instance, the thread protector on one end froze and had to be sawed off. The new design eliminated these undesirable features. A teflon plug is used to seal the bottle interior. These plugs screw into the bottle internal threads. One plug contains a pressure fitting and the bottle is shipped with the interior pressurized to 10 psi with dry nitrogen. The external threads are protected by a close fitting teflon sleeve on each end. The internal plugs do not have to be removed when the installation in the vehicle is made.

2. Change E

The hardness acceptance criterion which was established during the program was added by this change. This change states that after heat treatment and aging the hardness of the bottle shall be measured in accordance

TABLE 2

Contract Documentation

Doc. or Dwg. No.	Revision Appl. to Basic Contr.	Title	Revisions Made During Contract
88-4000500	C	Helium Storage Bottle	D, E
88-4000510	E	Machining of Extrusion	None
88-4000520	A	Helium Bottle Extrusion	B
MBX-106	2	Manufacturing Plan	3
MBX-107	Basic	Acceptance Test Plan	1, 2, 3
ER 12777	Basic	Quality Program Plan	1
MP 50066	1	Cleaning Procedure	Supplement I
PS 28	A	Heat Treat Procedure	B, C

TABLE 3

Contract Documentation Changes

Doc. or Dwg. No.	Revision	Reason
88-4000500	D	Update for production, add new thread protector
88-4000500	E	Add hardness acceptance criteria
88-4000520	B	Increase minimum mechanical properties
MBX-106	3	Update for production
MBX-107	1	Update for production
MBX-107	2	Revise proof pressure required
MBX-107	3	Add end closure requirements
ER 12777	1	Update for production
MP 50066	Supplement 1	Update for production
PS 28	B	Increase minimum mechanical properties
PS 28	C	Add additional process controls

with a specific procedure and the results shall be such that on the Rockwell B-scale the minimum shall be greater than or equal to 67; the average shall be greater than or equal to 73; and no more than 2 readings shall be less than 70.

B. DRAWING 88-4000520, HELIUM BOTTLE EXTRUSION

1. Change B

The purpose of this change was to reflect an agreement reached with the Aluminum Company of America regarding the guaranteed mechanical properties of the helium bottle extrusions. Prior to the fabrication of the first extrusions under the original development contract, Alcoa guaranteed the following properties:

	Longitudinal	Transverse
UTS (psi)	60,000	54,000
YS (psi)	50,000	40,000
Elongation (%)	5	2

Based upon the data accumulated during the development program (12 extrusions) and the data accumulated on 11 extrusions from this contract, the Martin Company requested the following as guaranteed values:

	Longitudinal	Transverse
UTS (psi)	70,000	68,000
YS (psi)	63,000	61,000
Elongation (%)	8	3

After evaluation of our request, Alcoa agreed to guarantee the following:

	Longitudinal	Transverse
UTS (psi)	66,000	63,000
YS (psi)	56,000	54,000
Elongation (%)	6	2

These values were accepted by the Martin Company and are the present guaranteed minimums.

C. MBX-106 MANUFACTURING PLAN

1. Revision 3

This revision was of a general nature to reflect the fact that a qualified article was now in production.

D. MBX-107, ACCEPTANCE TEST PLAN

1. Revision 1

Testing during the development program was performed at the Martin-Denver facility. This revision was of a general nature to reflect the fact that production testing would be performed at the Martin-Baltimore facility.

2. Revision 2

The purpose of this revision was to reflect a change in the proof pressure. NASA-MSFC directed that the proof pressure be changed from 5000 psi to 4500 psi.

3. Revision 3

The purpose of this revision was twofold; first, to specify the method of closing the ends of the bottle for test purposes, and second, to clarify the description of the method of leak testing. The end

closures specified by NASA-MSFC are in conformance to the actual installation. The closures consist of K-seals in accordance with NASA Standard MC 252 and fittings in accordance with NASA Standard MC 178. Installation torques are specified as 1800 inch-oounds minimum and 2000 inch-pounds maximum for the -24 boss and 2100 inch-pounds minimum and 2300 inch-pounds maximum for the -28 boss.

E. ER 12777, Quality Program Plan

1. Revision 1

This was a general revision reflecting the fact that the program was in a production status.

F. MP 50066, CLEANING PROCEDURE

1. Supplement 1

This was a general revision reflecting the fact that the program was in a production status.

G. PS 28, HEAT TREAT PROCEDURE

1. Revision B

The vendor performing the heat treat operations had always guaranteed to meet the minimum mechanical properties guaranteed by Alcoa for the basic extrusion. This revision reflected the increase in guaranteed values discussed in paragraph B above.

2. Revision C

The purpose of this revision was to reflect the process changes necessitated by the heat treat problems encountered during the program.

This problem and the changes made will be discussed in Section III of this report. Briefly stated, the revision included the addition of more control thermocouples, the addition of test bars placed inside the bottle and the inclusion of the hardness acceptance criterion.

III. FABRICATION

Each major step in the bottle fabrication process will be discussed herein. Pertinent data will be presented and the problems encountered will be discussed.

A. BASIC EXTRUSIONS

The basic extrusions were supplied by the Aluminum Company of America, the supplier of the original extrusions used in the development program. The extrusion quality was excellent and no problems were encountered in their fabrication. The mechanical property data for all 15 extrusions is presented in Table 4. The percent stretch achieved in the stress relieving operation is also shown. The desired stretch of 1% was not always achieved but the minimum of 1/2% was. All of the extrusions met the Class A ultrasonic inspection standard exceeding the Class B requirement.

B. MACHINING OF THE EXTRUSIONS

The vendors who performed these machining operations in the development program declined to bid on the production program. A contract was awarded to the Pennsylvania Forge Co. of Philadelphia. This Company has excellent facilities and equipment and extensive experience in close tolerance machining of large steel parts. They had little experience with aluminum. The machining of the extrusions was accomplished without any major difficulty. The finished parts met all requirements. The surface finish of the internal bore was excellent.

TABLE 4

SUMMARY OF EXTRUSION DATA

S/N	YS-KSI L	YS-KSI T	UTS-KSI L	UTS-KSI T	Elong - % L	Elong - % T	Percent Stretch
0013	69.9	65.0	76.1	70.9	10.0	7.0	0.75
0014	69.5	65.2	75.4	70.6	9.0	7.0	1.18
0014	70.5	66.8	76.1	72.1	10.0	7.0	
0015	67.4	62.7	73.1	70.6	9.0	7.5	1.42
0015	68.4	64.6	74.3	73.4	9.5	8.0	
0016	70.3	64.9	76.1	69.9	9.0	5.0	1.00
0016	70.5	65.6	76.3	70.9	10.0	5.0	
0017	70.0	65.6	75.0	71.8	10.0	7.5	0.94
0017	70.3	65.6	76.0	72.1	10.0	8.0	
0018	70.2	64.6	75.6	70.1	9.5	4.0	0.97
0018	71.4	66.8	75.9	70.6	9.5	5.0	
0019	71.1	67.7	76.2	70.7	9.0	3.0	1.10
0019	71.8	67.6	77.2	72.2	9.0	5.0	
0020	70.2	64.6	75.9	70.1	9.0	4.5	1.11
0020	70.9	65.8	76.6	70.9	9.0	5.0	
0021	70.1	66.2	75.4	71.9	9.5	7.0	1.28
0021	70.2	67.4	75.5	72.7	9.5	7.0	
0022	69.0	64.1	74.3	69.3	9.0	6.0	0.80
0022	69.5	65.6	75.4	71.3	9.0	6.0	
0023	71.1	65.8	76.9	71.6	10.0	6.0	0.85
0024	70.2	65.0	75.9	69.4	9.0	3.5	1.00
0024	70.5	66.2	76.4	72.6	9.5	7.0	
0025	70.5	65.2	76.2	71.4	9.5	5.5	0.88
0025	69.3	64.5	76.2	70.7	10.0	6.0	
0026	70.2	64.6	76.9	71.1	9.0	5.5	0.74
0026	69.6	63.3	75.9	69.9	9.5	5.5	
0027	70.5	64.6	75.6	69.9	10.0	3.5	1.10
0027	68.6	62.1	75.1	69.1	10.0	6.0	

C. FORMING OF THE ENDS

Forming of the ends of the bottles was accomplished without any major problems. Minor problems were encountered in the form of equipment breakdowns; the bolts holding the punch in the drop hammer failed periodically and were replaced with a larger internal wrenching bolt, the air cylinder driving the feed mechanism required a complete overhaul. These items are considered to be in the maintenance category. Wear of the die is, of course, progressive and wear plates were added periodically as required.

Immediately after completion of the forming of the 15 units required under this contract, forming operations started under a Boeing Purchase Order for 35 units. Two major equipment breakdowns were encountered during the forming of the first lot of Boeing bottles. First, one of the side rails, attaching the drive mechanism to the drop hammer, failed. Second, the main gear in the drive mechanism failed. The side rail was spliced and beefed-up in the critical area. The other side rail was reinforced in the same manner. A new gear box was designed, built and installed in the drive system. Approximately 20 units have been formed since these repairs and no trouble has been encountered.

D. INTERNAL MACHINING OF THE ENDS

The tools and techniques developed, during the prior contract, for removing the forming folds by internal machining were employed successfully on this program. The internal tracking tool required routine maintenance and one complete overhaul. The most critical operation is the machining after the second forming step. Sufficient material must be removed to get below the root of any fold. At the same time, however,

removal of too much material will result in an oversize hole after final forming. The standard procedure is to face-off the end so that the OD is 5-1/4", then bore the ID to 2". The location of folds is clearly visible before boring and the locations are marked. A visual inspection of these locations is made after boring. If fold roots are seen the bore is increased in 1/16" increments. If there is any doubt about the existence of a fold, a light swab etch will be conclusive. It was often necessary to proceed in this manner to a 2-1/4" bore and on one occasion the bore went to 2-1/2". Even at the 2-1/2" bore, the final forming and machining was successfully completed.

E. HEAT TREATMENT

The subcontract for the heat treatment of the bottles was awarded to the METLAB Co. of Philadelphia, the same company that processed the development units. The initial units under this contract were processed with the same fixtures and procedures as were originally employed. Several problems were encountered, which will be discussed herein, which necessitated changes in both the fixture and the procedure.

1. Damage to the Bottle External Surface

The first two units processed under this contract (S/N 0017, 0018) were received from the vendor with abraded areas and rust particles imbedded in the exterior surface. The rust particles came from the steel fixture which evidently was not cleaned sufficiently when the heat treat operations were resumed. The fixture was cleaned by sand blasting. The rust particles were removed from the bottle surface by local grinding. This grinding resulted in several small areas of each of the units which

were below the minimum wall thickness of 0.89 inches. A DAR was submitted for each of these units and the deviation was accepted. The basis for acceptance was the fact that one of the qualification units had a somewhat more severe local thickness deviation which did not effect the burst strength.

The cleaning of the fixture did not solve all of the surface abrasion problems. The way in which the fixture was constructed was such that during quenching there was relative motion between the bottle and the support rings which were an integral part of the fixture. It was felt that the surface abrasion could be eliminated by eliminating the relative motion between the bottle and the support rings. This was accomplished by clamping aluminum rings to the bottle so that the relative motion was between the new rings and the old support rings. The rings which clamp to the bottle are approximately 1/4-inch thick and 10-inches wide. They are made as two semi-circular pieces and contain a number of 1-inch holes to allow good quenching. The two halves are clamped to the bottle by wrapping the rings with a length of wire and simply twisting the ends of the wire. This method of attaching the rings offers very little restriction to any radial expansion of the bottle.

2. Underheating

The first indication of a problem came in July 1964 when the fourth unit (S/N 0013) in the first lot of five experienced a permanent volumetric expansion of 443 cubic inches. The maximum allowable expansion is 225 cubic inches. An investigation was started and the following possible causes were analyzed:

a. Incorrect volume measurement

b. Overpressurization during test

c. Improper heat treatment

d. Low strength extrusion

The volume both before and after proofing had been measured twice and the probability of an error here was very small. The final volume was checked again, however, and the result did not change. The indicated test pressure was 5000 psi and a dead weight calibration of the gage indicated zero error at 5000 psi. The heat treat temperature recordings showed that the temperatures were within the specified limits. The laboratory report on the test bars showed that the mechanical properties exceeded the minimum requirements. The records for the extrusion indicated that all requirements were met. Three days later, 7-16-65, the fifth unit in this lot was tested and the volumetric expansion was 31 cubic inches. No reason for the anomalous behavior of the one unit could be found.

The second lot of five units were tested between 8-14-65 and 9-16-65. Three of these units, the first, fourth and fifth (S/N 0022, 0024, 0014), exceeded the allowable volumetric expansion. At this point in time the following actions were taken:

a. A stop order was issued on the third lot of bottles.

b. The vendor was requested to survey his furnace.

c. The vendor was requested to calibrate his control, measuring and recording system.

d. The heat treat logs for all units, including the development units, were reviewed.

e. All delivered units were returned to the Martin Company so that hardness measurements could be made.

These actions resulted in the following findings:

a. The furnace survey revealed a cold spot in the furnace which, due to a heat leak, ran 40-50°F colder than the remainder of the furnace.

b. The control, measuring and recording equipment were within the specified calibration limits.

c. The heat treat logs revealed that the development units had, on the average, a significantly longer furnace time (300-400 minutes) than the present units (200-250 minutes).

d. Preliminary hardness measurements showed that the bottles which expanded had signiciantly lower hardness values than those which did not expand.

As a result of these findings the furnace was repaired and heat treating operations were resumed in November 1964 when the first of the last lot of five units, S/N 0013, was processed. The hardness survey made on this unit showed significantly higher hardness levels than on the expanded units. A hardness acceptance criteria was to be established as soon as data on all the units could be accumulated. The last four units were processed in November 1964 and the hardness surveys indicated good results. The laboratory report of the test bar mechanical properties showed, however, that three units, S/N 0023, 0025, 0026 failed to meet the minimum elongation requirements. It was conjectured that overheating could be the cause and once again the heat treat operations were suspended while an investigation was made.

3. Overheating

After processing unit S/N 0013 the vendor suggested that more uniform heating could be obtained by charging the bottles into a hot furnace (940°F). The Martin Company accepted this suggestion and the last four units were processed in this manner. When the test bar reports were received in December 1964, it was suspected that the low elongation values resulted from overheating. Metallographic examination of these test bars confirmed that they had been overheated. Permission was obtained from NASA-MSFC to remove material from the ends of each of these bottles. Metallographic analysis of these samples did not reveal any evidence of overheating.

At this time, a spare bottle was available from the Boeing contract. It was decided to instrument this unit extensively and make two trial runs. The first run was made starting with a cold furnace and the second was made starting with a hot furnace. Both runs were made during January of 1965. The data generated from these tests is presented and discussed in Ref. 3, wherein it is concluded that additional process controls are required to eliminate the effects of variations in furnace operator technique. It was further concluded that units S/N 0023, 0025, 0024 were not overheated, the overheating was confined to the test bars.

4. Process Changes

As a result of the problems and investigations discussed above, the vendor process was revised to reflect additional controls and acceptance criteria. This revision is reflected in METLAB process PS#28-C. The additional controls imposed are:

a. In addition to the three external bottle surface thermocouples, the test bars at either end of the fixture are instrumented with thermocouples.

b. Four test bars with thermocouples attached are inserted inside the bottle along its length.

c. Furnace controller settings are not to exceed 950°F at any time during the cycle.

d. Bottles will be charged into the furnace not exceeding 350°F.

During December 1964, the previously delivered units were returned to the Martin Company together with one unit available from the development contract. Hardness data was accumulated on all these units. In addition, the remains of the burst test units from the prior contract were available at Martin-Denver and hardness data was taken from these units. All of these data were submitted to NASA-MSFC and during January 1965, the following criteria was established:

> After heat treatment of the bottles, Rockwell B hardness measurements shall be made in accordance with Martin QEL 10.1.007. Acceptance shall be based upon:
>
> no reading less than 67
>
> average reading greater than 73
>
> no more than 2 readings less than 70

2. Final Disposition of the Units

Based upon the hardness criteria established in January 1965, six of the fifteen units (S/N 0013, 0015, 0023, 0025, 0026, 0027,) were acceptable and nine (S/N 0014, 0016, 0017, 0018, 0019, 0020, 0021, 0022, 0024) were not. NASA-MSFC agreed to accept S/N 0016, 0017 and 0020 "as is" and the Martin Company agreed to reprocess units 0014, 0018, 0019, 0021, 0022, 0024 starting with the heat treat operation. DR's for units

0016, 0017, 0020 were submitted and accepted. Regarding units 0023, 0025, 0026, NASA-MSFC did not agree with the Martin conclusion that these units had not been overheated. Before further evidence could be accumulated, a need for some non-flight hardware arose and NASA-MSFC agreed to accept these units "as is" for non-flight use. DAR's were submitted covering the low elongation and also documenting the fact that these units had no surface finish and had not been acceptance tested. The reheat treat operations on the six units were completed in February 1965. Tables 5 and 6 summarize the hardness and mechanical property data for all units.

TABLE 5

Summary of Hardness Data

Rockwell B-Scale

S/N	Minimum	Maximum	Average	No. Readings Less than 70
0013	73	83	79	0
0014*	53	78	63	44
0014**	70	84	79	0
0015	70	83	76	0
0016	67	81	73	5
0017	68	80	72	7
0018*	57	81	67	32
0018**	70	85	80	0
0019*	55	76	66	35
0019**	78	84	82	0
0020	64	82	74	1
0021*	61	78	68	31
0021**	76	85	82	0
0022*	50	78	60	47
0022**	72	86	80	0
0023	77	86	82	0
0024*	51	79	62	33
0024**	77	85	78	0
0025	76	85	81	0
0026	77	81	79	0
0027	76	85	80	0

* After original heat treat

** After reheat treatment

TABLE 6

Summary of Mechanical Properties
After Heat Treat

S/N	YS-KSI L	YS-KSI T	UTS-KSI L	UTS-KSI T	Elong.-% L	Elong.-% T
0013*	71.1	68.7	76.9	73.2	9.5	7.0
0013	71.3	68.1	76.7	73.1	9.5	6.5
0014	66.9	62.9	75.6	72.4	13.0	10.0
0014	74.8	70.2	79.1	73.9	11.0	6.5
0014**	68.4	67.2	74.0	71.3	10.0	9.0
0014**	72.1	70.3	76.7	74.6	10.0	8.0
0014**	73.2	-	77.4	-	9.0	-
0014**	72.5	-	77.1	-	9.5	-
0015	71.1	64.5	76.9	71.5	8.0	7.5
0015	64.6	68.0	73.1	73.2	8.0	7.0
0015	62.9	68.7	72.7	73.8	11.0	8.0
0016	71.9	67.5	77.3	71.6	8.0	4.0
0016	71.2	66.0	77.0	71.0	8.0	4.0
0017	72.0	68.7	78.2	74.1	9.0	7.0
0017	72.1	68.5	77.2	74.5	9.0	8.0
0017	71.7	68.8	78.0	74.7	9.0	7.0
0018	70.3	71.1	78.3	75.0	10.0	4.0
0018	74.5	67.8	80.6	72.1	10.0	4.5
0018**	69.5	68.3	75.2	72.0	7.5	3.5
0018**	68.0	65.2	74.1	67.0	7.5	3.5
0018**	70.8	-	75.7	-	7.0	-
0018**	70.8	-	75.9	-	7.5	-
0019	71.4	64.9	79.2	72.6	10.0	6.0
0019	66.8	64.0	75.1	71.5	10.5	6.0
0019**	71.8	70.1	78.4	73.8	8.0	5.0
0019**	70.3	66.7	75.6	70.0	10.0	3.0
0019**	74.5	-	78.4	-	9.0	-
0019**	73.3	-	78.1	-	9.0	-
0020	71.0	66.3	78.7	72.1	10.0	4.0
0020	74.0	69.5	80.5	74.4	9.5	3.0

* Center thermocouple reached only 912°F
** After reheat treatment

TABLE 6 (continued)

S/N	YS-KSI L	YS-KSI T	UTS-KSI L	UTS-KSI T	Elong.-% L	Elong.-% T
0021	73.9	69.8	78.7	74.9	8.0	7.0
0021	66.5	68.0	74.2	73.7	10.0	7.5
0021**	71.8	69.2	76.6	74.1	9.0	5.5
0021**	72.1	66.9	77.2	71.5	8.5	5.5
0021**	73.6	-	78.2	-	7.5	-
0021**	73.6	-	78.4	-	7.5	-
0022	73.9	68.0	78.7	73.7	8.0	7.5
0022	66.5	69.8	74.2	74.9	10.0	7.0
0022**	71.8	67.2	78.4	73.3	8.0	4.5
0022**	70.3	64.9	77.6	70.3	9.5	5.0
0022**	70.3	-	77.4	-	8.0	-
0022**	70.1	-	76.6	-	8.0	-
0023	75.2	71.5	81.2	75.1	6.0	1.5
0023	76.0	71.9	81.3	75.7	5.5	1.5
0024	65.6	68.2	75.8	74.8	9.0	4.5
0024	59.5	60.4	73.6	71.7	12.5	7.0
0024**	71.2	66.3	76.6	71.3	8.5	6.0
0024**	70.2	70.1	76.7	72.8	8.5	4.5
0024**	71.0	-	77.2	-	8.5	-
0024**	70.0	-	76.1	-	10.0	-
0025	73.6	71.6	77.8	75.4	5.5	4.0
0025	73.2	72.5	79.6	76.8	6.5	4.0
0026	69.4	71.8	76.3	76.4	5.5	4.0
0026	71.4	69.0	77.3	74.2	6.0	5.5
0027	71.0	67.3	77.5	70.9	6.0	2.5
0027	70.1	70.4	76.3	73.8	9.5	2.0

** After reheat treatment

F. INTERNAL SHOT PEENING

The contract for shot peening of the bottle interior surface was awarded to the Metal Improvement Company. This vendor performed the same operations during the prior contract. No problems were encountered in any of the bottles processed.

The six units which were reheat treated were also reshot peened. These units had completely machined ends, threaded both internally and externally. Precautions had to be taken so as not to damage the threads. Normally bottles are shot peened before the ends are threaded. Internal and external thread protectors were used and no difficulties were encountered.

G. FINAL MACHINING OF THE ENDS

The final machining of the ends of the bottle is a critical but straightforward lathe operation. No difficulties were encountered in meeting the various tolerance and concentricity requirements. An operator error was made on unit S/N 0027 however. The proper hole was bored for the -24 boss but the first thread cut was at 8/inch pitch instead of 10/inch. Several possibilities for salvage of this unit were discussed with NASA-MSFC. It was finally agreed to machine this unit with the incorrect 8 threads/inch and the Martin Company furnished two MF 1819 fittings with special matching threads. This deviation was documented by a DAR.

H. SURFACE FINISHING

Anodizing of the exterior surface and conversion coating of the interior surface was performed by the J. W. Hox Co., the vendor who had previously performed these operations. No problems were encountered in these operations.

I. ACCEPTANCE TESTING

Acceptance testing was performed at Martin-Baltimore in facilities provided for this program. All previous test operations had been performed at Martin-Denver. The only difference in test procedure was in the method of obtaining the required proof pressure. At Denver the bottles were filled with liquid nitrogen and pressurized with gaseous helium. This was easily accomplished at Martin-Denver because a large capacity 5500 psi helium supply was available. This same procedure was attempted in Baltimore using a small capacity helium compressor. The compressibility of the liquid nitrogen and the heat losses were such that the small compressor was not capable of pressurizing to the required level. A 6000 psi liquid nitrogen pump was purchased and the test procedure was changed to permit direct pressurization with liquid nitrogen.

The only problem encountered during the test operations occurred on unit S/N 0014. A steel plate screwed onto the external threads is used to support the bottle in the vertical fixture. On this unit the plate at the upper end could not be unscrewed after testing. The plate was sawed off but damage to the next to the last thread was incurred. The damaged area on this one thread was about 2 inches long. It was cleaned up and X-rayed to insure that there were no cracks. A DAR was filed and the unit was accepted since the nature of the vehicle installation is such that no axial load is carried by the external threads at the upper end.

Acceptance test data is reported in Ref. 4.

J. CONTAMINATION CONTROL CLEANING

The final contamination control cleaning is accomplished just prior to packaging for shipment. As with the prior contract, these operations are carried out at Martin-Baltimore in accordance with Martin Process MP 50066. No major problems were encountered in meeting the required cleanliness levels.

IV. SUMMARY AND CONCLUSIONS

Table 7 summarizes the bottles delivered under this contract. Those which were reheat treated are denoted by the letter R after the serial number.

The vendors contributing to the program were:

ALCOA	Extrusion Fabricator
Pennsylvania Forge Co.	Machining
METLAB Co.	Heat Treatment
Metal Improvement Co.	Shot Peening
J. W. Rex Co.	Surface Finishing

With the exception of the METLAB Co., the performance of these vendors was excellent. The METLAB Co. must be criticized for not discovering the equipment deterioration which led to the furnace cold spot. On the other hand, the data accumulated shows that this cold spot aggravated but did not cause the problems encountered. In retrospect it is easy to say that the process controls were inadequate. The minimum controls were established by the Martin Company, approved by NASA-MSFC, and implemented, without question, by the METLAB Co. In this sense, then, all parties share the responsibility. This responsibility was, in fact, accepted by all concerned and the problems were resolved. The personnel of the METLAB Co. were entirely cooperative and contributed much effort toward the resolution of the problems. Acknowledgement is also made of the cooperation and assistance of the NASA-MSFC personnel concerned namely, D. A. Marshall, D. E. Henry, M. Olsen, P. Mueller.

In conclusion, it can be stated that all of the bottles ultimately delivered were the equivalent of those qualified under the development contract.

TABLE 7

Summary of Bottles Produced

Serial Number	Weight (lb)	Int. Vol. (ft^3)	DAR's Against	Reason
0013	1180	31.10	-	-
0014R	1170	31.20	HB 0014-1	Thd. damage
0015	1180	31.13	-	-
0016	1175	31.19	HB 0016-1	Did not meet hardness crit.
0017	1180	31.16	HB 0017,0017-1	Did not meet hardness crit., wall thick. below min.
0018R	1170	31.38	-	-
0019R	1170	31.42	HB0019,0019-1	Did not meet hardness crit., wall thickness below min., oversize volume
0020	1155	31.13	HB 0020-1	Did not meet hardness crit.
0021R	1180	31.15	-	-
0022R	1185	31.58	HB 0022-1	Oversize volume
0023	-	-	HB 0023-1	Not anodized, tested or cleaned
0024R	1170	31.47	HB 0024-1	Oversize volume
0025	-	-	HB 0025-1	Not anodized, tested or cleaned
0026	-	-	HB 0026-1	Not anodized, tested or cleaned
0027	1185	31.12	HB 0027-1	Incorrect thds. on one end

V. REFERENCES

1. Monthly Progress Reports, Numbers 1 to 20.

2. Quarterly Progress Reports, Numbers 1 to 6.

3. Report on Problems Associated with Heat Treatment, ER 13796.

4. Production Acceptance Test Report, ER 13562.