NASA Technical Memorandum

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TESTING AND EVALUATION OF VESPEL UP TO 450°F WHEN USED IN NUTS AND BOLTS AS A SELF-LOCKING ELEMENT

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Science and Engineering

August 1984

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* A DuPont SP-1 polyimide product

16. ABSTRACT

The object of this investigation was to evaluate Vespel for potential application on the Solid Rocket Booster to replace all-metal deformed self-locking nuts and anchor nuts and be used as self-locking elements for bolts and screws. The Vespel self-locking elements were tested for prevailing torque retention at room temperature, after heating to 450°F and exposure for 3 hr, breakaway torque at 450°F and for vibration at a level consistent with the maximum expected on the SRB at lift-off and reentry.

The investigation revealed Vespel has properties that can provide a self-locking capability for threaded fasteners up to 450°F and it can be used in nuts and anchor nuts for installation on the SRB. Vespel elements in bolts did not meet all our SRB requirements for reuse, however, we have defined a design for Vespel elements in nuts/anchor nuts that fully meets all requirements.

It is recommended that No. 10, 1/4 in. and 5/16 in. nuts/anchor nuts be procured for use on the SRB. This system will eliminate the galling problems now encountered and achieve a much higher reuse life than the present deformed nut design.

17. KEY WORDS	18. DISTRIBUTION STATEMENT
Fastener, Bolt, Nut, Anchor Nut, Vespel, Torque, Self-locking, Vibration, Solid Rocket Booster, Tensile Strength, A-286, Inconel 718, MP35N	Unclassified — Unlimited

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TESTING AND EVALUATION OF VESPEL UP TO 450°F WHEN USED IN NUTS AND BOLTS AS A SELF-LOCKING ELEMENT

INTRODUCTION

Self-locking nuts made from A-286 and other corrosion resisting (CRES) materials are widely used on the Solid Rocket Booster (SRB). Because the CRES self-locking nuts are made with a deformed section at the top of the nut there have been numerous cases of seizing or galling after one or only a few times reuse. The severity of the problem is evidenced by the high number of requests for an alternative method to achieve self-locking of the fastener assembly.

The bolts used on the SRB are mostly manufactured from CRES materials and with ultimate tensile strength levels of 180 KSI Ftu and higher. These bolts are made from A-286, Inconel 718, and MP35N and all are subject to seizing from repeated use with CRES self-locking nuts. Military Specification MIL-F-18240, Fastener, Externally Threaded, 250°F, Self-Locking Element For, covers performance levels for non-metallic elements which can be used to provide a self-locking element at temperatures from -65°F to 250°F. An extension of the temperature level to 450°F would be highly desirable. There are no self-locking bolts with non-metallic elements that are qualified to 450°F use temperature.

Self-locking nuts used on the SRB are purchased to conform to a document which requires reuse for 15 installation and removal cycles with each size having a maximum and minimum torque value limit. The document requires reuse cyclic testing to be made without an axial load on the bolt, therefore, it does not simulate actual installation conditions.

We have been convinced the galling problem was the result of interference at the deformed portion of the all-metal nut, therefore, a locking devise could be required on the nut or bolt which would eliminate interference between the nut and bolt thread. One potential material is "Vespel", which is a registered name for a Dupont product and is made from SP-1 polyimide. Parts made from Vespel have high mechanical strength, excellent wear resistance, low creep and low outgassing properties and are highly desirable for non-metallic elements for use in self-locking nuts and bolts. Several vendors can supply Vespel self-locking elements installed in threaded fasteners but its wide use is limited by higher initial cost.

The object of this investigation was to determine if Vespel has a potential to qualify for use as a self-locking element at a temperature up to 450°F. It would provide MSFC with reusable nut and bolt design configurations that use non-metallic self-locking elements up to 450°F and, therefore, would make possible the selection of a fastener system that would eliminate galling and greatly increase its reuse potential.

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* Vespel, a DuPont product made from polyimide resin, Type SP-1.

PROCUREMENT OF FASTENERS FOR THE TESTING INVESTIGATION

The controlling document for bolts used by the Government is Military Specification MIL-F-18240 which covers performance for self-locking elements to be used in bolts and screws. Using this document as a guide, a test program evolved for an investigation of the Vespel element which included most of the performance requirements of MIL-F-18240 plus temperature level raised from 250°F to 450°F and changing vibration to replicate the SRB at lift-off and reentry. The fasteners were changed to A-286 CRES material with threads made to conform to MIL-S-8879, Screw Threads, Controlled Radius Root with Increased Minor Diameter; General Specification For.

Fastener sizes selected for the test program were 1/4, 1/2 and 3/4 in. diameter. Purchased bolts were made from A-286 per AMS 5731 or AMS 5737 and conformed to Standard NAS 1953 through 1970 (Fig. 1) except thread length was longer. Vespel SP-1 self-locking elements were specified for installation and compoiance with MS15981, Fasteners, Externally Threaded, Self-locking, Design and Usage Limitations For, and MIL-F-18240.

Nuts selected to be tested with the self-locking bolts were purchased to conform to Standard NAS 1805 but with a self-locking feature (Fig. 2). The nuts were made from A-286 per AMS 5737 and the dry film lubricant conformed to MIL-L-8937, Lubricant, Solid Film, Heat Cured, Corrosion Inhibiting.

Two lug, floating, regular height, self-locking anchor nuts were procured with nuts made from A-286 per AMS 5732 or AMS 5737 and with a Vespel SP-1 self-locking element and threads lubricated per MIL-L-8937 (Fig. 3). The nut was specified to have 125 KSI minimum tensile strength and comply with MIL-N-25027, Nut, Self-Locking, 250°F, 450°F and 800°F, 125 KSI Ftu, 60 Ksi Ftu and 30 KSI Ftu. (A similar anchor nut made from carbon steel is available on Military Standard MS14179 and it provides minimum tensile strength of 160 KSI and 500 seated reuse cycles.)

TEST PLAN FOR EVALUATION OF VESPEL AS A SELF-LOCKING ELEMENT IN BOLTS

Our test plan (Fig. 4) consisted essentially of the same criteria as given in MIL-F-18240 but with maximum temperature raised to 450°F. A description of the testing criteria is given in the following sections.

Examination of Product

Two types of self-locking elements were evaluated after being installed in three bolt sizes with bare and dry film lubricated threads. The round elements were installed in bare bolts and the two strips were installed in dry film lubricated bolts. A comparison of the round and strip self-locking element sizes given in MIL-F-18240 and those actually tested is given in Table 1.

Tensile Strength

Three bolts each of NAS 1954C50M, NAS 1958C50M and NAS 1962C50M, except with a longer thread, were tested for ultimate tensile strength.

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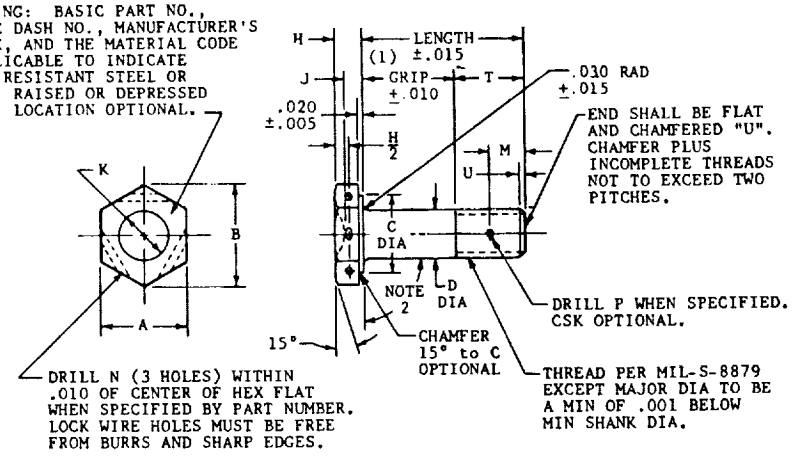

BASIC PART NUMBER	THREAD UNJF-3A	A	(5) B REF	(3) C DIA MIN	(11) D DIA BEFORE PLATING OR COATING	(11) D DIA AFTER PLATING OR COATING	H +.015 -.000	J +.015 -.000	K DIA ±.01	M ±.010	N DIA +.010 -.000	(4) P DIA +.010 -.000	(5) T REF	U REF
NAS1953	.1900-32	.376 .367	.43	.335	.1887 .1881	.1895 .1885	.110	.073	.19	.163	.046	.070	.338	.016
NAS1954	.2500-28	.439 .430	.51	.398	.2487 .2481	.2495 .2485	.125	.083	.25	.178	.046	.076	.425	.018
NAS1955	.3125-24	.502 .492	.58	.460	.3112 .3106	.3120 .3110	.156	.104	.31	.181	.070	.076	.469	.021
NAS1956	.3750-24	.564 .553	.65	.523	.3737 .3731	.3745 .3735	.188	.125	.38	.197	.070	.106	.578	.021
NAS1957	.4375-20	.690 .679	.79	.648	.4362 .4356	.4370 .4360	.219	.146	.44	.201	.070	.106	.594	.025
NAS1958	.5000-20	.752 .741	.87	.710	.4987 .4981	.4995 .4985	.250	.167	.50	.216	.070	.106	.735	.025
NAS1959	.5625-18	.877 .865	1.01	.835	.5607 .5601	.5615 .5605	.281	.188	.56	.218	.070	.141	.840	.028
NAS1960	.6250-18	.940 .928	1.09	.898	.6232 .6226	.6240 .6230	.312	.208	.62	.249	.070	.141	.902	.028
NAS1962	.7500-16	1.064 1.052	1.23	1.023	.7482 .7476	.7490 .7480	.375	.250	.75	.252	.070	.141	1.041	.031
NAS1964	.8750-14	1.252 1.239	1.44	1.210	.8732 .8726	.8740 .8730	.438	.292	.88	.257	.070	.141	1.184	.036
NAS1966	1.0000-12	1.440 1.427	1.66	1.398	.9982 .9976	.9990 .9980	.500	.333	1.00	.264	.070	.141	1.309	.042
NAS1968	1.1250-12	1.627 1.614	1.88	1.585	1.1232 1.1221	1.1240 1.1225	.562	.375	1.12	.357	.070	.141	1.458	.042
NAS1970	1.2500-12	1.815 1.801	2.10	1.772	1.2482 1.2471	1.2490 1.2475	.625	.417	1.25	.389	.070	.141	1.646	.042

LIST OF CURRENT SHEETS

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1	3	4	3
2	3	5	3
3	3		

③ ENTIRE STANDARD REVISED

CUSTODIAN: NATIONAL AEROSPACE STANDARDS COMMITTEE

PROCUREMENT SPECIFICATION	TITLE	CLASSIFICATION
NOTED	BOLT, SHEAR, HEXAGON HEAD, 180 KSI	STANDARD PART
		NAS 1953 THRU 1970
		SHEET 1 OF 5

APPROVAL DATE Dec. 1973 REVISION ① 15 Dec. 1976 ② 15 Mar 1977 ③ 17 Mar 1978

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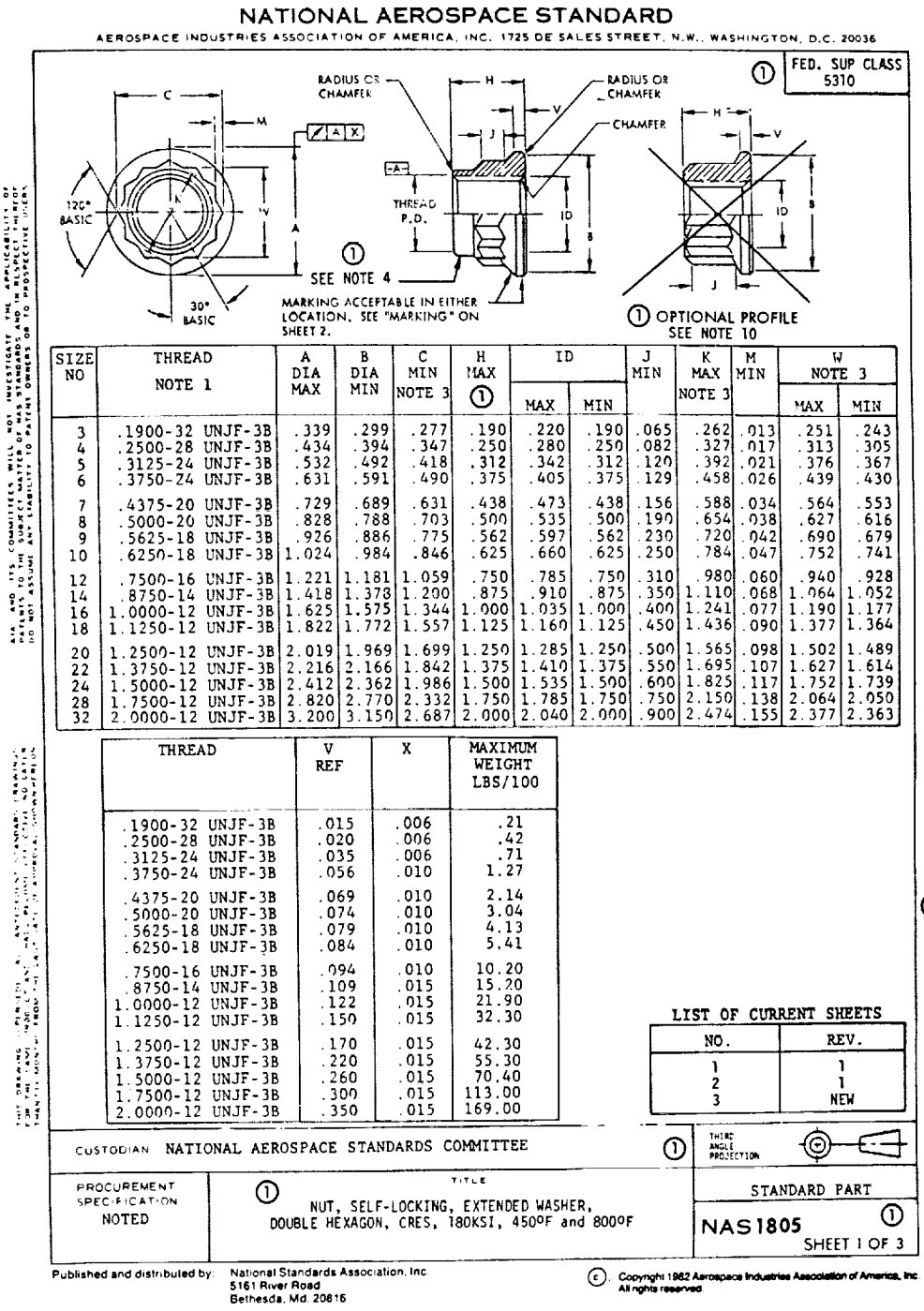
Figure 1. Bolts used for evaluation of Vespel self-locking elements.



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① FED. SUP CLASS 5310

RADIUS OR CHAMFER

RADIUS OR CHAMFER

CHAMFER

120° BASIC

30° BASIC

THREAD P.D.

① SEE NOTE 4

MARKING ACCEPTABLE IN EITHER LOCATION. SEE "MARKING" ON SHEET 2.

① OPTIONAL PROFILE SEE NOTE 10

SIZE NO	THREAD NOTE 1	A DIA MAX	B DIA MIN	C MIN NOTE 3	H MAX ①	ID MAX	ID MIN	J MIN	K MAX NOTE 3	M MIN	W NOTE 3 MAX	W NOTE 3 MIN
3	.1900-32 UNJF-3B	.339	.299	.277	.190	.220	.190	.065	.262	.013	.251	.243
4	.2500-28 UNJF-3B	.434	.394	.347	.250	.280	.250	.082	.327	.017	.313	.305
5	.3125-24 UNJF-3B	.532	.492	.418	.312	.342	.312	.120	.392	.021	.376	.367
6	.3750-24 UNJF-3B	.631	.591	.490	.375	.405	.375	.129	.458	.026	.439	.430
7	.4375-20 UNJF-3B	.729	.689	.631	.438	.473	.438	.156	.588	.034	.564	.553
8	.5000-20 UNJF-3B	.828	.788	.703	.500	.535	.500	.190	.654	.038	.627	.616
9	.5625-18 UNJF-3B	.926	.886	.775	.562	.597	.562	.230	.720	.042	.690	.679
10	.6250-18 UNJF-3B	1.024	.984	.846	.625	.660	.625	.250	.784	.047	.752	.741
12	.7500-16 UNJF-3B	1.221	1.181	1.059	.750	.785	.750	.310	.980	.060	.940	.928
14	.8750-14 UNJF-3B	1.418	1.378	1.200	.875	.910	.875	.350	1.110	.068	1.064	1.052
16	1.0000-12 UNJF-3B	1.625	1.575	1.344	1.000	1.035	1.000	.400	1.241	.077	1.190	1.177
18	1.1250-12 UNJF-3B	1.822	1.772	1.557	1.125	1.160	1.125	.450	1.436	.090	1.377	1.364
20	1.2500-12 UNJF-3B	2.019	1.969	1.699	1.250	1.285	1.250	.500	1.565	.098	1.502	1.489
22	1.3750-12 UNJF-3B	2.216	2.166	1.842	1.375	1.410	1.375	.550	1.695	.107	1.627	1.614
24	1.5000-12 UNJF-3B	2.412	2.362	1.986	1.500	1.535	1.500	.600	1.825	.117	1.752	1.739
28	1.7500-12 UNJF-3B	2.820	2.770	2.332	1.750	1.785	1.750	.750	2.150	.138	2.064	2.050
32	2.0000-12 UNJF-3B	3.200	3.150	2.687	2.000	2.040	2.000	.900	2.474	.155	2.377	2.363

THREAD	V REF	X	MAXIMUM WEIGHT LBS/100
.1900-32 UNJF-3B	.015	.006	.21
.2500-28 UNJF-3B	.020	.006	.42
.3125-24 UNJF-3B	.035	.006	.71
.3750-24 UNJF-3B	.056	.010	1.27
.4375-20 UNJF-3B	.069	.010	2.14
.5000-20 UNJF-3B	.074	.010	3.04
.5625-18 UNJF-3B	.079	.010	4.13
.6250-18 UNJF-3B	.084	.010	5.41
.7500-16 UNJF-3B	.094	.010	10.20
.8750-14 UNJF-3B	.109	.015	15.20
1.0000-12 UNJF-3B	.122	.015	21.90
1.1250-12 UNJF-3B	.150	.015	32.30
1.2500-12 UNJF-3B	.170	.015	42.30
1.3750-12 UNJF-3B	.220	.015	55.30
1.5000-12 UNJF-3B	.260	.015	70.40
1.7500-12 UNJF-3B	.300	.015	113.00
2.0000-12 UNJF-3B	.350	.015	169.00

LIST OF CURRENT SHEETS

NO.	REV.
1	1
2	1
3	NEW

CUSTODIAN NATIONAL AEROSPACE STANDARDS COMMITTEE ①

THIRD ANGLE PROJECTION

PROCUREMENT SPECIFICATION NOTED

① TITLE

NUT, SELF-LOCKING, EXTENDED WASHER, DOUBLE HEXAGON, CRES, 180KSI, 450°F and 800°F

STANDARD PART

NAS1805 ①

SHEET 1 OF 3

AEROSPACE STD MAY 1978 REVISION ① 1 Nov. 1982

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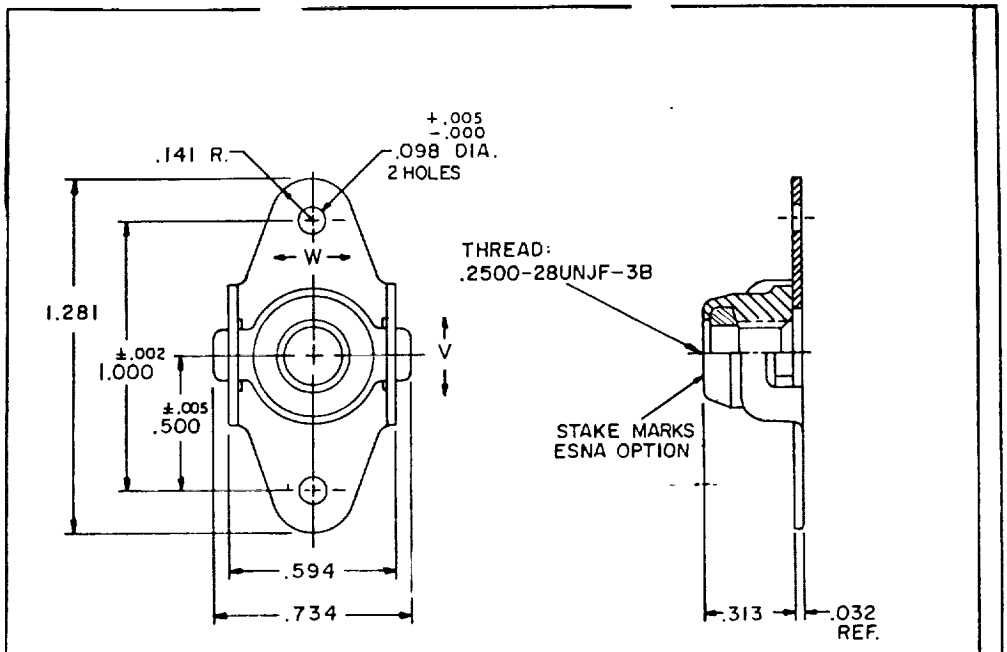
Figure 2. Free running nut used for evaluation of Vespel self-locking elements.



MATERIAL: NUT - A286, AMS 5732 OR AMS 5737
BASKET - STAINLESS STEEL, TYPE 321, AMS 5510

FINISH: NUT - DRY FILM LUBRICATED
BASKET - UNPLATED (PASSIVATED)

LOCKING INSERT: DUPONT POLYMER VESPEL SP-1

THREADS: MIL-S-8879 (PRIOR TO APPLICATION OF DRY FILM LUBRICANT)

MINIMUM TOTAL FLOAT: "V"=.094, "W"=.074

PERFORMANCE: MIL-N-25027

ESNA PART NUMBER: 109VA21-79-048

APPROX. WEIGHT: 1.5 LB/100

ISSUED 03-81 REVISED

TOLERANCES UNLESS OTHERWISE SPECIFIED DECIMALS ± .015 ANGLES ±2° DO NOT SCALE PJ. 2411-79

ESNA DIVISION
Amerace Corporation

NUT—ANCHOR, TWO LUG, FLOATING, VESPEL INSERT

CODE IDENT NO 72962

109VA21-79-048

2-1-1

Figure 3. Anchor nut with Vespel self-locking element.

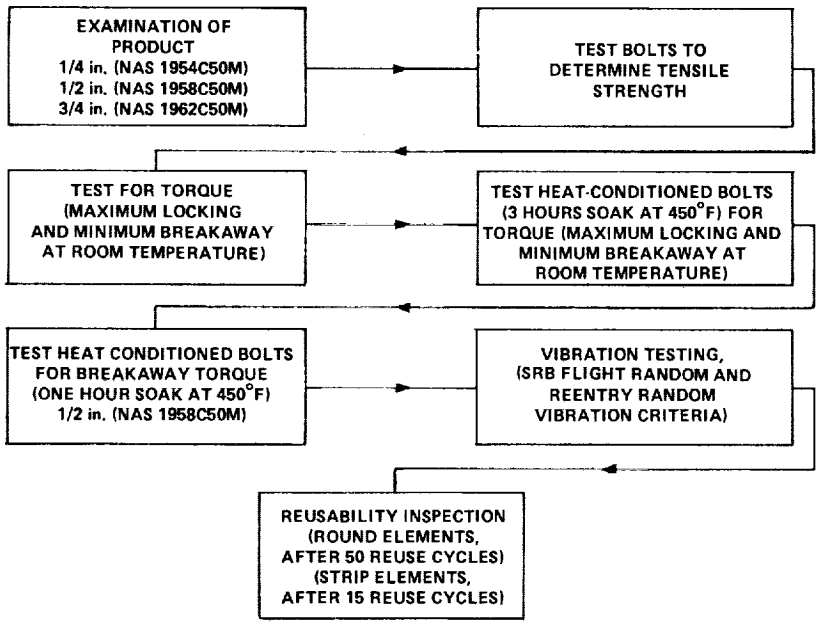


Figure 4. Test and evaluation plan for investigation of Vespel self-locking elements.

Torque, Maximum Locking and Minimum Breakaway

Ten new bolts of NAS1954C50M, NAS1958C50M and NAS1962C50M with round and strip self-locking elements were tested for compliance to the room temperature requirements of MIL-F-18240 (Table 2). Each installation consisted of installing the nut until two thread pitches were exposed. The nut was rotated an additional one-fourth turn and the highest torque level was recorded. Minimum breakaway torque was measured as the torque required to start removal from the installed position.

Torque, Maximum Locking and Minimum Breakaway with Heat-Conditioned Bolts

This test consisted of heating ten new bolts of each size with installed nuts to 450°F, holding for 3 hr, and cooling to room temperature in less than 1 hr. The bolts and nuts were then tested for maximum locking and minimum breakaway torque as specified above.

Minimum Breakaway Torque at 450°F

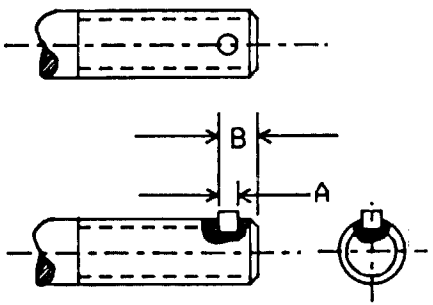
One lot of 10 heat conditioned NAS1958C50M bolts with dry film lubricated threads and two Vespel strips were installed with nuts, heated and tested for breakaway torque after 1 hr at 450°F.

Vibration Tests

A fixture was designed and fabricated to incorporate five bolt and nut assemblies and it was used for vibration testing of NAS 1954C50M, NAS 1958C50M, and NAS 1962C50M bolts made with self-locking elements. The fixture and fastener

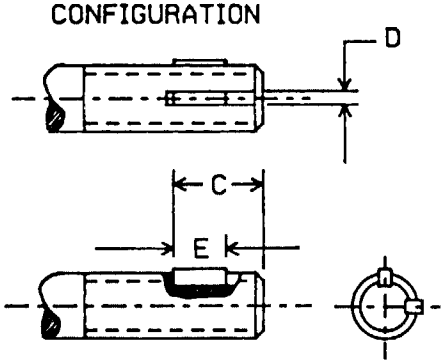
TABLE 1. COMPARISON OF SELF-LOCKING ELEMENT SIZE REQUIREMENTS AND VENDOR SUPPLIED ELEMENTS

ROUND CONFIGURATION



BOLT THREAD SIZE	A^1 MAX INCH	A^1 MIN INCH	A^2 NOMINAL INCH	B^1 MAX INCH	B^1 MIN INCH	B^2 NOMINAL INCH
1/4-28UNF-3A	.144	.098	.100	.231	.191	.214
1/2-20UNF-3A	.166	.146	.147	.301	.261	.291
3/4-10UNF-3A	.235	.209	.220			.377

STRIP CONFIGURATION



BOLT THREAD SIZE	E^1 MAX INCH	E^1 MIN INCH	E^2 NOMINAL INCH	D^1 MIN INCH	D^2 NOMINAL INCH	C^1 MAX INCH	C^1 MIN INCH	C^2 NOMINAL INCH
1/4-28UNF-3A	.437	.267	.275	.025	.080	.437	.267	.361
1/2-20UNF-3A	.684	.375	.440	.035	.105	.684	.375	.550
3/4-10UNF-3A	.999	.416	.440	.055	.105			.665

NOTES:
1. REQUIRED BY MIL-F-18240
2. DIMENSIONS OF VENDOR SUPPLIED ELEMENT
3. MULTIPLY INCH X 0.0254 TO CONVERT TO METER

TABLE 2. TORQUE REQUIREMENTS FOR SELF-LOCKING ELEMENTS
(At room temperature in inch-pounds)

Bolt Size	Maximum Torque (Installation or Removal)	Minimum Breakaway Torque
0.250-28 UNJF-3A	30	3.5
0.500-20 UNJF-3A	150	18.0
0.750-16 UNJF-3A	400	50.0

Note: Maximum locking torque limit can be increased 50 percent on heat-conditioned bolts.

assemblies are shown in Figure 5. The first vibration test was made with round Vespel elements installed in bare bolts assembled with nuts made to conform with NAS 1805 except they were coated with Kaylube dry film lubricant instead of lubricant conforming to MIL-L-8937. Prior to initiation of the test, the nuts were installed and removed four times to expose two thread pitches on each bolt and the maximum locking and minimum breakaway torque was checked for compliance to MIL-F-18240. On the fifth installation cycle the locking torque was checked again and, thereafter, the 1/4 in. nuts were torqued to 60 lbf-in., 1/2 in. nuts torqued to 300 lbf-in., and the 3/4 in. nuts torqued to 800 lbf-in.

Figure 5. Fixture used in vibration tests on bolts installed with Vespel self-locking elements.

The SRB has a wide range of vibration criteria and it was decided to use criteria representing the envelope with the maximum applicable zonal criteria. Therefore, the criteria given in Table 3 was used to simulate conditions the fastener would encounter if used in that specific location. The fasteners were vibrated in accordance with the Flight Random Vibration Criteria to simulate five flights in each of the "X", "Y" and "Z" axes of the SRB. The fasteners were then vibrated in accordance with the Reentry Random Vibration Criteria to simulate five flights in each of the three axes.

TABLE 3. VIBRATION CRITERIA FOR EVALUATION OF VESPEL SELF-LOCKING ELEMENTS

Flight Random	
	20 Hz at 0.22 g^2/Hz
40 Hz to	60 Hz at 0.44 g^2/Hz
109 Hz to	165 Hz at 0.8 g^2/Hz
178 Hz to	240 Hz at 1.0 g^2/Hz
253 Hz to	650 Hz at 1.3 g^2/Hz
750 Hz to	1200 Hz at 1.5 g^2/Hz
	2000 Hz at 0.54 g^2/Hz
Composite = 47.2 g_{rms}	
Test Time = 840 sec	
Reentry Random	
	20 Hz at 1.0 g^2/Hz
60 Hz to	97 Hz at 4.0 g^2/Hz
120 Hz to	200 Hz at 9.12 g^2/Hz
235 Hz to	660 Hz at 4.0 g^2/Hz
1050 Hz to	1440 Hz at 1.0 g^2/Hz
	2000 Hz at 0.33 g^2/Hz
Composite = 68.3 g_{rms}	
Test Time = 210 sec	

A second vibration test, essentially the same as noted, was made using the same fixture but with different fasteners. This time five lubricated 1/4 in. diameter NAS 1954C50M bolts were installed in dry film lubricated anchor nuts, P/N 109VA21-79-048, installed with Vespel self-locking ring elements. Three lubricated and two bare 1/2 in. diameter NAS 1958C50M bolts with two Vespel self-locking strip elements were assembled with lubricated NAS 1805 nuts. Three lubricated 3/4 in. diameter NAS 1962C50M bolts with two Vespel self-locking elements were assembled with lubricated NAS 1805-12 nuts. In order to prevent damage to the vibration equipment two changes were made to the Random Reentry Vibration Criteria. 60 Hz to 97 Hz at 4.0 G^2/Hz was changed to 60 Hz to 97 Hz at 2.0 g^2/Hz and 120 Hz at 9.12 Hz at 9.12 G^2/Hz was changed 120 Hz to 200 Hz at 8.0 G^2/Hz. The second set of fasteners was tested in accordance with the Flight Random Vibration Criteria for 480 sec with equal time in each axis. If inspection of fasteners revealed no failures, they were tested in accordance with the revised Reentry Random Vibration Criteria for 210 sec total with equal time in each axis.

Reusability

After each series of torque tests were completed, the bolts and nuts were examined for damage to the threads or self-locking elements.

TEST PLAN FOR ANCHOR NUTS WITH VESPEL SELF-LOCKING ELEMENTS

The Navy has issued Military Standard MS14179, Nut, Plate, Self-Locking, Floating, Two Lug, Reduced Rivet Spacing, Steel, (Vespel Insert), 500 Cycles Reuse, Replaceable Nut, 160 KSI Ftu, 450°F, but this nut configuration cannot be used on the SRB because it does not have enough corrosion resistance. Since MS14179 was issued on 30 January 1979, one vendor has received qualification approval, therefore, our testing was limited to reuse at room temperature with A-286 bolts and CRES anchor nuts purchased for this investigation. It was decided to torque test the anchor nuts for conformance to MIL-N-25027 for 50 reuse cycles at room temperature without seating plus 10 additional cycles with 90 lbf-in. seating torque.

RESULTS AND DISCUSSION OF TESTS ON FASTENERS INSTALLED WITH VESPEL SELF-LOCKING ELEMENTS

Examination of Product

Ninety of the bare bolts with round Vespel self locking elements were examined for defects and the only deficiency was the presence of excessive burrs and slivers on the periphery of holes for the round elements. Thirty each of the 3 sizes were later modified by removing the round elements and two Vespel strips were installed plus the application of a dry film lubricant per MIL-L-8937 (Kal Gard Type FA). The 1/4 in. NAS 1954C50M bolts were installed with two strips instead of one as required in MIL-F-18240.

Round Vespel elements were removed from three bolts each of the 1/4 in., 1/2 in. and 3/4 in. diameter in order to inspect threads for compliance to MIL-S-8879 using Method "A" gaging methods. All threaded portions of the bolts were inspected with "GO" and "LO" thread ring gages and all failed to pass due to burrs and slivers. After an extensive clean-up, the bolt threads passed the thread inspection check.

Tensile Strength

Three bolts each of NAS 1954C50M (1/4 in.), NAS 1958C50M (1/2 in.) and NAS 1962C50M (3/4 in.) were tested to determine their tensile strength as required in NAS 19531953 through 1970 and MIL-F-18240. Threaded adapters instead of nuts were installed to within two thread pitches of thread run-out and tests were conducted in accordance with MIL-STD-1312, Test No. 8. The tensile strength results of individual bolts are shown in Table 4.

Surprisingly, the 3/4 in. diameter bolts failed to pass the tensile test and it was decided to perform a metallurgical evaluation on all nine bolts. It revealed the cause of head failure in the 1/2 in. and 3/4 in. diameter bolts was due primarily

TABLE 4. TEST RESULTS OF 180 KSI Ftu BOLT TENSILE TESTING

SAMPLE NO.	NOMINAL SIZE	PART NO.	ULTIMATE LOAD		JOHNSON'S 2/3 YIELD		TYPE OF FAILURE
			NEWTONS	LBS.	NEWTONS	LBS.	
1	1/4-28	NAS1954C50M	35,140	7,900	29,090	6,540	BOLT THREAD
2	1/4-28	NAS1954C50M	34,700	7,800	27,020	6,075	BOLT THREAD
3	1/4-28	NAS1954C50M	36,920	8,300	29,490	6,630	BOLT THREAD
4	1/2-20	NAS1958C50M	140,920	31,680	106,760	24,000	BOLT HEAD
5	1/2-20	NAS1958C50M	144,130	32,400	106,090	23,850	BOLT HEAD
6	1/2-20	NAS1958C50M	143,590	32,280	100,090	22,500	BOLT HEAD
7	3/4-16	NAS1962C50M	284,690	64,000	245,550	55,200	BOLT HEAD
8	3/4-16	NAS1962C50M	303,350	68,200	277,580	62,400	BOLT HEAD
9	3/4-16	NAS1962C50M	282,020	63,400	253,560	57,000	BOLT HEAD

NOTES:
1. NAS 1954 MINIMUM TENSILE STRENGTH IS 6,980 LBS.
2. NAS 1958 MINIMUM TENSILE STRENGTH IS 30,900 LBS.
3. NAS 1962 MINIMUM TENSILE STRENGTH IS 71,100 LBS.

to the reduction of hardness and strength in the head to shank area which was caused by the hot heading operation during manufacturing, and secondarily to the head design associated with shear bolts.

Torque, Maximum Locking and Minimum Breakaway

Ten each of the NAS 1954C50M, NAS 1958C50M, and NAS 1962C50M bolts installed with round Vespel self-locking elements and assembled with NAS 1805 nuts were tested for torque at room temperature for 50 cycles or failure. Ten NAS 1954C50M, nine NAS 1958C50M, and one NAS 1962C50M passed the room temperature torque test. A summary of torque test results for the round Vespel self-locking elements is shown in Table 5 and individual results are shown in Tables 7 through 9.

Ten each of the three lubricated bolt sizes installed with two Vespel self-locking strip elements and assembled with NAS 1805 nuts were tested for torque at room temperature for 15 cycles or failure. Ten NAS 1954C50M,, ten 1958C50M, and seven NAS1962C50M bolts passed the room temperature torque test. A summary of results for the strip self-locking elements is shown in Table 6 and individual results are shown in Tables 13 through 15. Figures 6 and 7 illustrate NAS 1958C50M (1/2 in.) bolts with two Vespel self-locking strip elements before and after torque testing for 15 cycles. Figure 8 illustrates all three bolt sizes with two Vespel strip elements installed in the bolt threads.

Torque, Maximum Locking and Minimum Breakaway with Heat Conditioned Bolts

Ten each of the NAS 1954C50M, NAS 1958C50M, and NAS 1962C50M bolts installed with round Vespel self-locking elements and assembled with NAS 1805 nuts were heated for 3 hr at 450°F and, after cooling to room temperature, were torque tested for 50 cycles or failure. Eight 1/4 in., seven 1/2 in., and no 3/4 in. diameter bolts passed the torque test for heat-conditioned bolts. A summary of test results is shown in Table 5 and individual results are shown in Tables 10 through 12.

Ten each of the three lubricated bolt sizes installed with two Vespel self-locking strip elements and assembled with NAS 1805 nuts were heated for 3 hr at 450°F and, after cooling to room temperature, were torque tested for 15 cycles or failure. All three bolt sizes passed the 15 cycle reuse torque test for heat-conditioned bolts. A summary of test results is shown in Table 6 and individual results are shown in Tables 16 through 18.

Torque, Minimum Breakaway Test at 450°F

Ten NAS 1958C50M (1/2 in.) bolts previously tested as heat-conditioned bolts (3 hr at 450°F) were again heated to 450°F and held for 1 hr. At this time the nuts were tested for breakaway torque and all ten bolts passed. The test results are shown in Table 19.

Vibration Testing

Five each of the NAS 1954C50M, NAS 1958C50M, and NAS 1962C50M bare shank bolts fabricated with round Vespel self-locking elements were installed in a vibration test fixture and assembled with dry film lubricated NAS 1805 nuts. These fasteners

Figure 6. NAS 1958C50M bolts with two Vespel self-locking strip elements before torque testing.

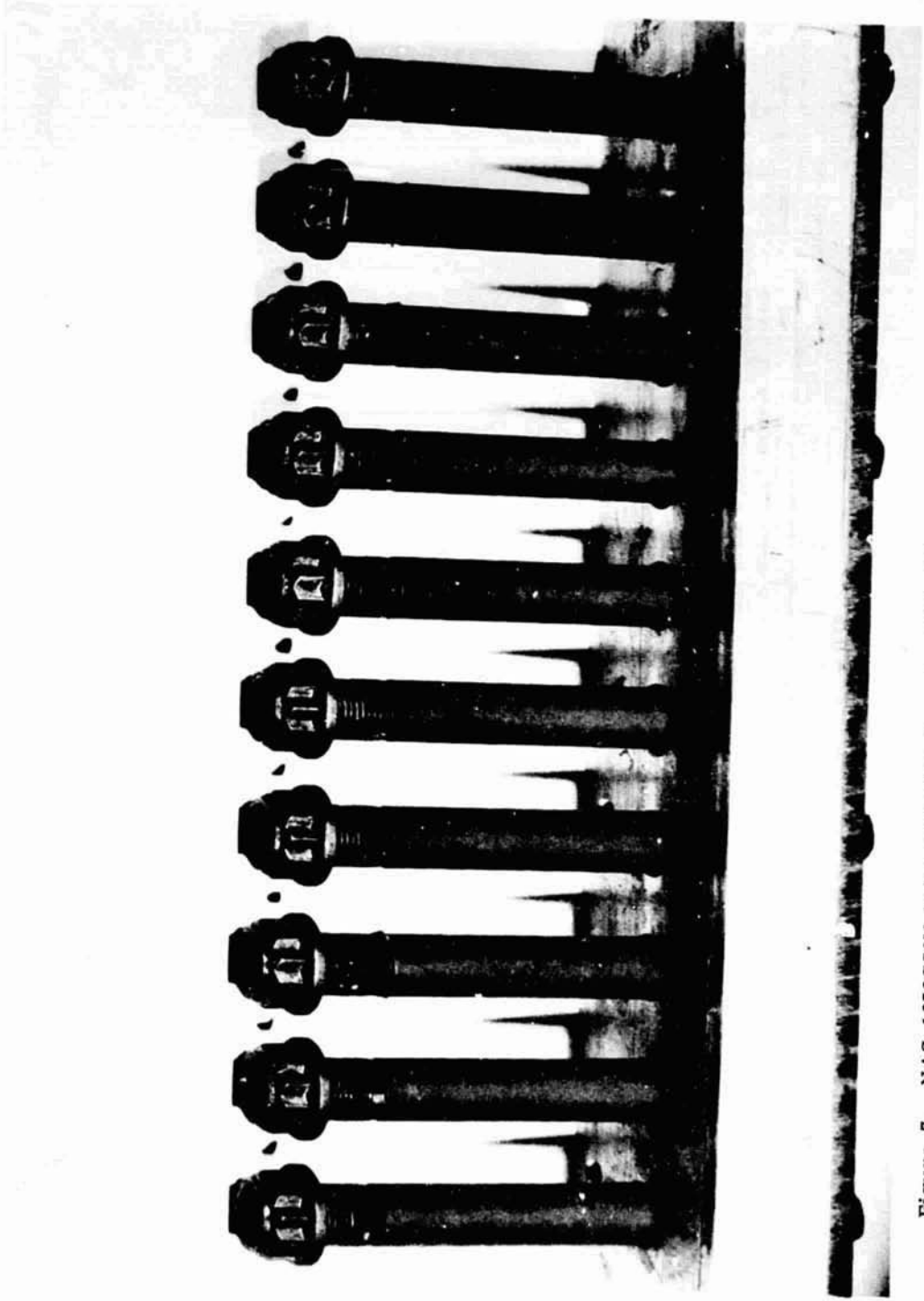


Figure 7. NAS 1958C50M bolts with two Vespel self-locking strip elements after torque testing.

were vibrated to criteria representing a five mission Shuttle flight and all fasteners passed because there was no nut rotation. Figure 9 illustrates the fasteners and fixture mounted on the vibration machine.

When it was decided to use dry film lubricated bolts and nuts, a second round of vibration testing became necessary. This time the fixture included the following:

Item	Quantity	Description
1	5	Bolt, NAS 1954C50M, Lubricated per MIL-L-8937
2	5	Anchor Nut, P/N 109VA21-79-048, Lubricated
3	2	Bolt, NAS 1958C50M, Bare
4	3	Bolt, NAS 1958C50M, Lubricated per MIL-L-8937
5	5	Nut, NAS 1805-8, Lubricated
6	3	Bolt, NAS 1962C50M, Lubricated per MIL-L-8937
7	3	Nut, NAS 1805-12, Lubricated

The second set of fasteners was tested to the same Flight Random Vibration Criteria as the first set but the Reentry Random Vibration Criteria level was reduced which resulted in a composite level of 65.6 g_{rms} instead of 68.3 g_{rms}. This change was required to prevent damage to the vibration machine. The time represented a four mission Shuttle flight. Fasteners were removed and reinstalled four times after completing vibration in each of the three axes. Locking and breakaway torque was measured on each cycle and torque values remained within tolerance. This second lot of fasteners passed the vibration test and nut rotation was not evident on any of the three fastener sizes.

Reusability

After the 15 and 50 cycle reuse torque testing was completed on the bare and lubricated fasteners they were carefully examined for any thread defects or other problems. The nut threads were visually inspected and checked with thread plug gages and no evidence of deformation or galling was revealed in all the nuts. The bolt threads were visually inspected and checked with "Snap" thread gages and no problems were evident. The anchor nut threads were checked with plug gages up to the self-locking element and all five parts passed.

There was a problem with the Vespel strip element. During the reuse torque tests, the strips usually broke within approximately 1/16 in. from the end of the strip. The broken portion was subsequently driven to a position which was determined by how many times the nut was rotated.

The five anchor nuts passed the 50 cycle torque reuse tests without any significant problems (Table 20). The only discrepancy was higher torque values than allowed in documents covering this type of nut. In order to apply some preload the bolts were torqued to 90 lbf-in. for ten additional reuse testing cycles and the Vespel self-locking ring element continued to perform satisfactorily with only a slight reduction in torque values.

Figure 8. NAS 1954C50M, NAS 1958C50M, and NAS 1962C50M bolts showing Vespel self-locking strip elements before torque testing.

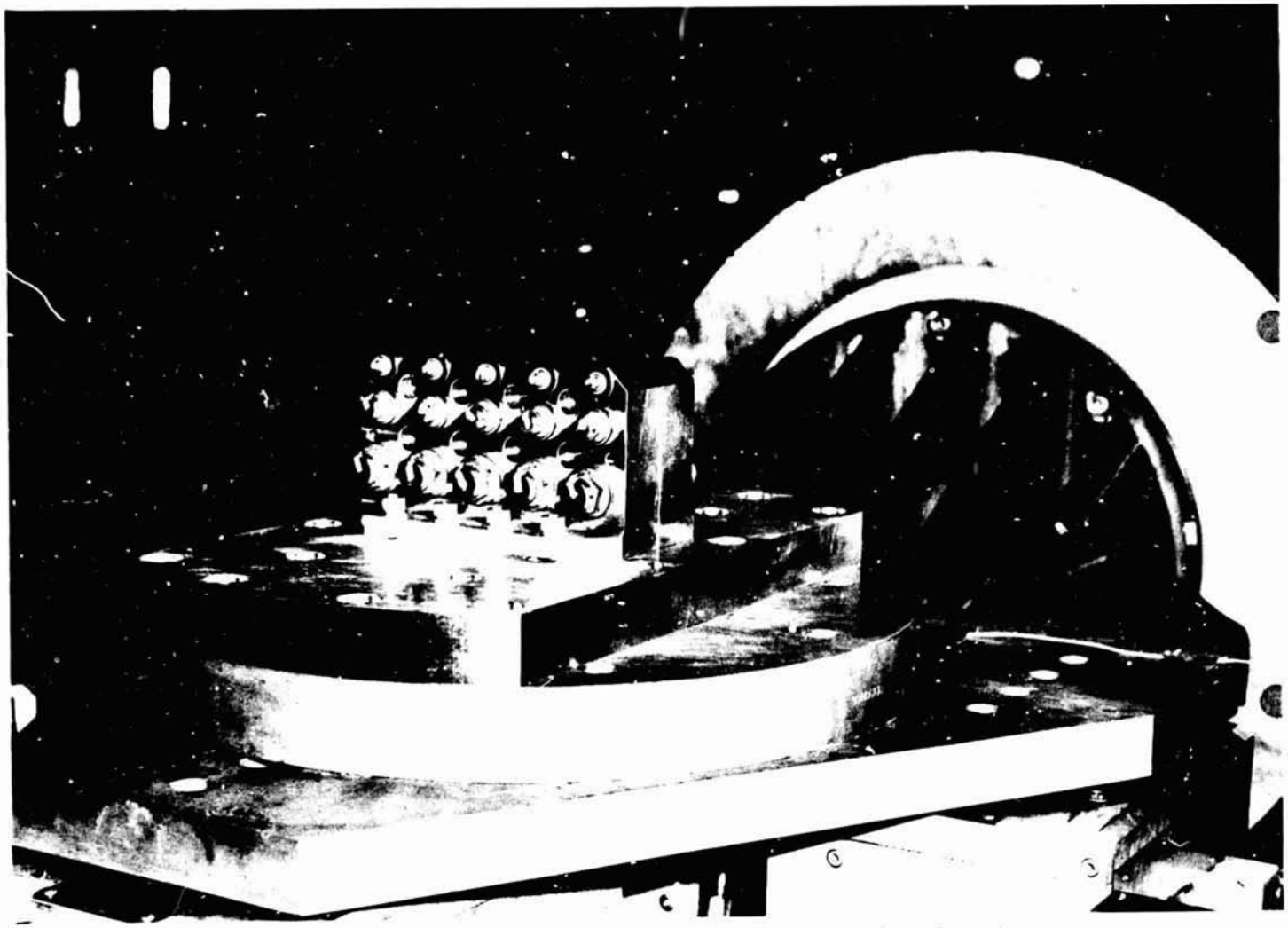


Figure 9. Vibration test set-up for Vespel self-locking elements.

TABLE 5. SUMMARY OF 50 CYCLE TORQUE TEST RESULTS ON 180 KSI A-286 SELF-LOCKING BOLTS WITH VESPEL ROUND ELEMENTS AND NON-LOCKING NUTS AT ROOM TEMPERATURE AND AFTER THREE HOURS EXPOSURE AT 450°F

Bolt Size Nom. Inch	Torque, max. & min. Breakaway lbf-in.	Torque Tests at Room Temperature Fastener No./Cycles Tested or Cycles at Failure to Comply With MIL-F-18240									
0.250	30/3.5	1R 50	2R 50	3R 50	4R 50	5R 50	6R 50	7R 50	8R 50	9R 50	10R 50
0.500	150/18	11R 50	12R 50	13R 50	14R 50	15R 50	16R 50	17R 50	18R 29	19R 50	20R 50
0.750	400/50	21R (6)	22R (4)	23R (12)	24R (13)	25R 18	26R 32	27R 50	28R (8)	29R 38	30R 24
		Torque Tests at Room Temperature After 3 Hours Soak at 450°F Fastener No./Cycles Tested or Cycles at Failure to Comply with MIL-F-18240									
0.250	45/3.5	31R 50	32R 50	33R 50	34R 41	35R 42	36R 50	37R 50	38R 50	39R 50	40R 50
0.500	225/18	41R 50	42R (0)	43R 35	44R 37	45R 50	46R 50	47R 50	48R 50	49R 50	50R 50
0.750	600/50	51R (3)	52R (2)	53R (0)	54R (0)	55R (0)	56R (0)	57R (2)	58R (0)	59R (2)	60R (0)

Notes:
1. Cycles noted ( ) indicates failure to pass 15 cycle reuse requirement in MIL-F-18240
2. Torque values were checked after nut was installed with two thread pitches exposed.
3. Bolts were bare and NAS 1805 nuts were coated with Kaylube dry film lubricant.

TABLE 6. SUMMARY OF 15 CYCLE TORQUE TEST RESULTS ON 180 KSI A-286 SRLF-LOCKING BOLTS WITH VESPEL STRIP ELEMENTS AND NON-LOCKING NUTS AT ROOM TEMPERATURE AND AFTER THREE HOURS EXPOSURE AT 450°F

Bolt Nom. Size inch	Torque Reqd. max. & min. Breakaway lbf-in.	Torque Tests at Room Temperature Fastener No./Cycles Tested or Cycles at Failure to Comply with MIL-F-18240									
0.250	30/3.5	1S 15	2S 15	3S 15	4S 15	5S 15	6S 15	7S 15	8S 15	9S 15	10S 15
0.500	150/18	11S 15	12S 15	13S 15	14S 15	15S 15	16S 15	17S 15	18S 15	19S 15	20S 15
0.750	400/50	21S 15	22S (14)	23S 15	24S 15	25S 15	26S 15	27S (7)	28S 15	29S 15	30S (8)
		Torque Tests at Room Temperature After 2 Hours Soak at 450°F (232°C) Fastener No./Cycles Tested or Cycles at Failure to Comply with MIL-F-18240									
0.250	45/3.5	31S 15	32S 15	33S 15	34S 15	35S 15	36S 15	37S 15	38S 15	39S 15	40S 15
0.500	225/18	41S 15	42S 15	43S 15	44S 15	45S 15	46S 15	47S 15	48S 15	49S 15	50S 15
0.750	600/50	51S 15	52S 15	53S 15	54S 15	55S 15	56S 15	57S 15	58S 15	59S 15	60S 15

Notes:
1. Cycles noted ( ) indicates failure to pass 15 cycle reuse requirement in MIL-F-18240.
2. Torque values were checked after nut was installed with two thread pitches exposed.
3. Bolts were coated with lubricant per MIL-L-8937 (Kal Gard FA)
4. NAS1805 nuts were coated with Kaylube dry film lubricant.

TABLE 7. RESULTS OF 50 CYCLE ROOM TEMPERATURE TORQUE TESTS ON NAS 1954C50M (1/4 in.) BOLTS WITH ROUND VESPEL SELF-LOCKING ELEMENTS

Cycle Number	Bolt Number 1R		Bolt Number 2R		Bolt Number 3R		Bolt Number 4R		Bolt Number 5R	
	Installation (ON) and Breakaway (OFF) Torque, lbf-in.									
	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF
1	19	20	18	21	22	20	18	17	16	16
3	12	14	14	17	15	18	13	15	13	14
6	11	13	11	14	12	14	10	12	10	11
9	11	12	10	13	11	12	8	11	7	11
12	10	11	11	14	10	12	8	10	8	11
15	9	10	10	12	10	12	8	10	8	10
20	9	10	9	12	10	12	7	9	8	10
30	8	8	9	11	10	11	6	8	7	9
40	8	9	9	11	9	10	6	8	6	8
50	7	9	9	11	8	10	5	8	5	6
	Bolt Number 6R		Bolt Number 7R		Bolt Number 8R		Bolt Number 9R		Bolt Number 10R	
1	22	20	20	18	18	17	19	19	32	27
3	12	19	11	13	12	12	13	12	19	21
6	10	7	11	12	10	10	10	10	14	14
9	11	13	12	13	10	12	10	10	12	15
12	10	13	11	13	9	13	10	10	12	14
15	10	12	10	12	7	9	10	10	12	13
20	9	13	10	12	7	9	10	11	11	13
30	9	11	10	12	5	6	10	10	10	11
40	8	11	10	11	6	8	9	10	9	11
50	8	11	11	12	6	6	9	9	9	10

Notes:
1. MIL-F-18240 requirement for torque is 30 lbf-in. maximum ON and 3.5 lbf-in. minimum OFF breakaway.
2. Torque values were checked after nut was installed with two thread pitches exposed.
3. Bolts were bare and NAS 1805 nuts were coated with Kaylube dry film lubricant.

TABLE 8. RESULTS OF 50 CYCLE ROOM TEMPERATURE TORQUE TESTS ON NAS 1958C50M (1/2 in.) BOLTS WITH ROUND VESPEL SELF-LOCKING ELEMENTS

Cycle Number	Bolt Number 11R		Bolt Number 12R		Bolt Number 13R		Bolt Number 14R		Bolt Number 15R	
	Installation (ON) and Breakaway (OFF) Torque, lbf-in.									
	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF
1	45	50	43	42	62	62	75	70	74	72
3	30	35	22	28	30	35	43	38	40	38
6	30	28	23	28	22	28	38	39	31	36
9	24	23	20	22	26	26	41	45	32	33
12	21	21	22	22	23	26	34	41	26	35
15	21	21	23	23	21	22	35	40	28	36
20	21	26	27	26	26	27	33	34	34	36
30	21	24	25	25	24	25	28	32	29	32
40	22	26	21	22	21	24	21	26	22	28
50	18	20	18	19	18	21	18	18	24	25
	Bolt Number 16R		Bolt Number 17R		Bolt Number 18R		Bolt Number 19R		Bolt Number 20R	
1	55	58	58	50	62	60	39	44	50	44
3	32	35	37	40	35	40	26	28	34	31
6	37	36	37	32	33	35	23	28	26	27
9	37	39	33	33	26	31	22	27	24	24
12	34	35	30	31	24	28	23	25	24	23
15	32	34	31	31	23	24	22	26	24	24
20	24	30	31	33	20	21	20	22	26	22
30	24	26	26	25	Failed at		19	21	20	21
40	21	26	22	28	Cycle No. 29		18	21	18	19
50	20	24	19	24			20	20	19	20

Notes:
1. MIL-F-18240 requirement for torque is 150 lbf-in. maximum ON and 18 lbf-in. minimum OFF breakaway.
2. Torque values were checked after nut was installed with two thread pitches exposed.
3. Bolts were bare and NAS 1805 nuts were coated with Kaylube dry film lubricant.

TABLE 9. RESULTS OF 50 CYCLE ROOM TEMPERATURE TORQUE TESTS ON NAS 1962C50M (3/4 in.) BOLTS WITH ROUND VESPEL SELF-LOCKING ELEMENTS

Cycle Number	Bolt Number 21R		Bolt Number 22R		Bolt Number 23R		Bolt Number 24R		Bolt Number 25R	
	Installation (ON) and Breakaway (OFF) Torque, lbf-in.									
	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF
1	100	100	95	75	120	80	155	105	160	100
3	120	90	95	75	85	80	115	110	100	95
6	55	45	45	40	75	80	105	80	125	80
9	48	45	40	40	75	80	85	80	70	65
12	48	45	40	35	45	35	55	50	70	55
15	50	45	55	45	50	45	45	50	60	65
20	Failed at		Failed at		Failed at		Failed at		Failed at	
30	Cycle No. 6		Cycle No. 4		Cycle No. 12		Cycle No. 13		Cycle No. 18	
40										
50										

	Bolt Number 26R		Bolt Number 27R		Bolt Number 28R		Bolt Number 29R		Bolt Number 30R	
1	150	140	112	100	100	100	100	113	190	130
3	140	115	90	80	85	75	80	80	120	115
6	80	90	85	70	70	55	75	75	145	90
9	120	100	80	70	40	40	70	75	70	70
12	100	85	75	75	40	40	60	60	70	60
15	80	70	70	65	40	40	60	60	55	45
20	65	60	80	60	Failed at		60	65	Failed at	
30	70	70	65	65	Cycle No. 8		50	65	Cycle No. 15	
40	Failed at		60	60			Failed at			
50	Cycle No. 32		65	60			Cycle No. 38			

Notes:
1. MIL-F-18240 requirement for torque is 400 lbf-in. maximum ON and 50 lbf-in. minimum OFF breakaway.
2. Torque values were checked after nut was installed with two thread pitches exposed.
3. Bolts were bare and NAS 1805 nuts were coated with Kaylube dry film lubricant.

TABLE 10. RESULTS OF 50 CYCLE ROOM TEMPERATURE TORQUE TESTS ON 450°F HEAT-CONDITIONED NAS 1954C50 (1/4 in.) BOLTS WITH ROUND VESPEL SELF-LOCKING ELEMENTS

Cycle Number	Bolt Number 31R		Bolt Number 32R		Bolt Number 33R		Bolt Number 34R		Bolt Number 35R	
	Installation (ON) and Breakaway (OFF) Torque, lbf-in.									
	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF
1	12	18	9	10	4	4	3	3	8	10
3	14	15	7	8	4	4	3	4	6	6
6	14	16	6	7	4	6	3	4	4	5
9	14	16	6	8	4	5	3	4	4	5
12	12	15	6	8	4	6	3	4	4	4
15	12	16	6	8	4	6	3	4	4	4
20	11	13	6	7	5	7	4	4	4	4
30	11	14	5	8	4	6	4	4	4	4
40	10	14	5	7	4	5	4	4	4	4
50	10	14	5	7	4	4	Failed at Cycle No. 1		Failed at Cycle No. 42	
	Bolt Number 36R		Bolt Number 37R		Bolt Number 38R		Bolt Number 39R		Bolt Number 40R	
1	6	6	6	7	4	4	9	11	4	5
3	5	5	6	7	4	4	7	9	4	5
6	4	5	6	7	4	4	6	7	4	6
9	4	5	5	7	4	4	6	7	4	6
12	4	5	6	7	4	4	5	6	4	6
15	4	6	6	7	4	4	5	6	4	6
20	5	5	5	6	4	4	5	6	4	5
30	5	6	5	6	4	5	4	6	4	6
40	5	6	5	6	4	4	5	5	4	6
50	5	6	4	5	4	5	4	5	4	5

Notes:
1. MIL-F-18240 requirement for torque is 45 lbf-in. maximum ON and 3.5 lbf-in. minimum OFF breakaway.
2. Torque values were checked after nut was installed with two thread pitches exposed.
3. Bolts were bare and NAS 1805 nuts were coated with Kaylube dry film lubricant.

TABLE 11. RESULTS OF 50 CYCLE ROOM TEMPERATURE TORQUE TESTS ON 450°F HEAT-CONDITIONED NAS 1958C50M (1/2 in.) BOLTS WITH ROUND VESPEL SELF-LOCKING ELEMENTS

Cycle Number	Bolt Number 41R		Bolt Number 42R		Bolt Number 43R		Bolt Number 44R		Bolt Number 45R	
	Installation (ON) and Breakaway (OFF) Torque, lbf-in.									
	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF
1	25	25	20	15	20	20	20	25	25	25
3	25	25	10	10	20	20	20	20	25	25
6	20	20	10	10	20	20	20	20	20	25
9	20	20	10	10	20	20	20	20	20	25
12	20	20	10	10	20	20	20	20	20	25
15	20	20	10	10	20	20	20	20	20	25
20	20	20	Failed at		25	20	20	20	20	25
30	20	20	Cycle No. 1		20	20	18	20	18	20
40	21	22			Failed at		Failed at		20	25
50	20	18			Cycle No. 35		Cycle No. 37		18	22

	Bolt Number 46R		Bolt Number 47R		Bolt Number 48R		Bolt Number 49R		Bolt Number 50R	
1	35	30	25	25	25	25	25	25	20	20
3	25	25	20	20	25	30	20	20	20	20
6	25	25	20	20	25	20	20	20	20	20
9	25	25	20	20	25	20	20	20	20	25
12	25	25	20	20	25	20	20	20	20	25
15	25	25	20	20	25	20	20	20	25	25
20	25	30	20	20	20	20	20	20	25	25
30	25	28	20	20	20	20	20	20	25	25
40	26	30	22	21	24	23	22	19	25	21
50	27	27	20	22	25	25	20	18	25	26

Notes:
1. MIL-F-18240 requirement for torque is 225 lbf-in. maximum ON and 18 lbf-in. minimum OFF breakaway.
2. Torque values were checked after nut was installed with two thread pitches exposed.
3. Bolts were bare and NAS 1805 nuts were coated with Kaylube dry film lubricant.

TABLE 12. RESULTS OF 11 CYCLE ROOM TEMPERATURE TORQUE TESTS ON 450°F HEAT-CONDITIONED NAS 1962C50M (3/4 in.) BOLTS WITH ROUND VESPEL SELF-LOCKING ELEMENTS

Cycle Number	Bolt Number 51R		Bolt Number 52R		Bolt Number 53R		Bolt Number 54R		Bolt Number 55R	
	Installation (ON) and Breakaway (OFF) Torque, lbf-in.									
	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF
1	58	60	50	60	40	40	40	51	32	38
3	40	42	40	42	30	32	46	52	35	40
6	38	45	52	60	29	30	32	39	43	48
9	48	48	48	58	40	50	42	48	45	40
11	46	45	52	56	40	45	42	50	59	56
	Failed at Cycle No. 3		Failed at Cycle No. 2		Failed at Cycle No. 1		Failed at Cycle No. 4		Failed at Cycle No. 1	
	Bolt Nnumber 56R		Bolt Number 57R		Bolt Number 58R		Bolt Number 59R		Bolt Number 60R	
1	32	40	52	52	28	30	73	75	30	35
3	40	40	40	40	28	38	32	40	30	42
6	38	37	23	29	30	39	31	41	28	34
9	42	52	29	30	43	50	32	42	32	38
11	52	60	31	36	28	30	40	45	35	42
	Failed at Cycle No. 1		Failed at Cycle No. 2		Failed at Cycle No. 1		Failed at Cycle No. 2		Failed at Cycle No. 1	

Notes:
1. MIL-F-18240 requirement for torque is 600 lbf-in. maximum ON and 50 lbf-in. minimum OFF breakaway.
2. Torque values were checked after nut was installed with two thread pitches exposed.
3. Bolts were bare and NAS 1805 nuts were coated with Kaylube dry film lubricant.

TABLE 13. RESULTS OF 15 CYCLE ROOM TEMPERATURE TORQUE TESTS ON NAS 1954C50M (1/4 in.) BOLTS WITH VESPEL SELF-LOCKING STRIP ELEMENTS

Cycle Number	Bolt Number 1S		Bolt Number 2S		Bolt Number 3S		Bolt Number 4S		Bolt Number 5S	
	Installation (ON) and Breakaway (OFF) Torque, lbf-in.									
	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF
1	19	23	20	20	24	24	20	21	24	25
3	13	14	12	15	14	15	14	16	13	14
6	12	14	12	14	14	15	14	16	13	14
9	12	14	12	14	13	14	14	15	11	13
12	12	12	13	14	12	13	14	16	11	13
15	12	14	13	15	13	14	15	17	11	13
	Bolt Number 6S		Bolt Number 7S		Bolt Number 8S		Bolt Number 9S		Bolt Number 10S	
1	21	25	26	29	30	34	22	23	25	26
3	16	19	13	14	15	16	14	16	15	17
6	16	18	12	13	15	17	15	14	13	16
9	13	16	10	13	13	14	14	16	13	15
12	15	18	11	12	11	13	14	16	14	14
15	15	18	11	14	13	16	14	15	13	14

Notes:
1. MIL-F-18240 requirement for torque is 30 lbf-in. maximum ON and 3.5 lbf-in. minimum OFF breakaway.
2. Torque values were checked after nut was installed with two threads exposed.
3. Bolts were coated with lubricant per MIL-L-8937 (Kal Gard FA).
4. NAS 1805 nuts were coated with Kaylube dry film lubricant.

TABLE 14. RESULTS OF 15 CYCLE ROOM TEMPERATURE TORQUE TESTS ON NAS 1958C50M (1/2 in.) BOLTS WITH VESPEL SELF-LOCKING STRIP ELEMENTS

Cycle Number	Bolt Number 11S		Bolt Number 12S		Bolt Number 13S		Bolt Number 14S		Bolt Number 15S	
	Installation (ON) and Breakaway (OFF) Torque, lbf-in.									
1	140	170	135	160	95	110	130	145	135	160
3	90	110	100	115	65	75	100	115	95	135
6	60	80	65	80	45	55	70	90	65	80
9	60	70	55	60	40	50	60	80	55	70
12	55	70	55	60	40	50	55	70	55	65
15	55	70	50	55	40	50	55	75	55	60
	Bolt Number 16S		Bolt Number 17S		Bolt Number 18S		Bolt Number 19S		Bolt Number 20S	
1	130	150	140	170	145	155	125	140	135	165
3	95	115	95	115	70	80	70	95	65	90
6	80	100	70	90	55	70	45	65	45	80
9	75	95	70	90	50	60	45	55	45	70
12	60	70	70	85	45	55	40	50	45	70
15	75	90	60	75	45	50	40	50	40	65

Notes:
1. MIL-F-18240 torque requirements are 150 lbf-in. maximum ON and 18.0 lbf-in. minimum OFF breakaway.
2. Torque values were checked after nut was installed with two threads exposed.
3. Bolts were coated with lubricant per MIL-L-8937 (Kal Gard FA).
4. NAS1805 nuts were coated with Kaylube dry film lubricant.

TABLE 15. RESULTS OF 15 CYCLE ROOM TEMPERATURE TORQUE TESTS ON NAS 1962C50M (3/4 in.) BOLTS WITH VESPEL SELF-LOCKING STRIP ELEMENTS

Cycle Number	Bolt Number 21S		Bolt Number 22S		Bolt Number 23S		Bolt Number 24S		Bolt Number 25S	
	Installation (ON) and Breakaway (OFF) Torque, lbf-in.									
1	375	375	175	200	400	425	350	375	400	300
3	100	160	75	85	115	175	150	200	140	190
6	80	130	55	70	80	120	120	150	100	140
9	70	100	50	60	75	110	105	145	90	120
12	65	90	50	60	70	110	110	145	110	110
15	65	80	45	55	70	105	85	115	75	100
	Bolt Number 26S		Bolt Number 27S		Bolt Number 28S		Bolt Number 29S		Bolt Number 30S	
1	260	300	185	150	260	175	275	300	140	180
3	115	175	75	100	150	200	100	150	75	100
6	95	140	50	60	115	175	85	120	55	80
9	85	125	40	55	100	160	75	115	40	65
12	85	125	40	55	100	155	75	110	45	65
15	80	115	40	50	95	150	75	100	35	60

Notes:
1. MIL-F-18240 requirement for torque is 400 lbf-in. maximum and 50 lbf-in. minimum OFF breakaway.
2. Torque values were checked after nut was installed with two thread pitches exposed.
3. NAS 1805 nuts were coated with Kaylube dry film lubricant.
4. Bolts were coated with dry film lubricant per MIL-L-8937 (Kal Gard FA).

TABLE 16. RESULTS OF 15 CYCLE ROOM TEMPERATURE TORQUE TESTS ON 450°F HEAT-CONDITIONED NAS 1954C50M (1/4 in.) BOLTS WITH VESPEL SELF-LOCKING STRIP ELEMENTS

Cycle Number	Bolt Number 31S		Bolt Number 32S		Bolt Number 33S		Bolt Number 34S		Bolt Number 35S	
	Installation (ON) and Breakaway (OFF) Torque, lbf-in.									
	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF
1	33	36	26	30	24	27	23	26	33	36
3	20	23	10	10	15	17	18	20	22	24
6	20	21	8	10	14	16	16	18	19	22
9	19	22	9	10	12	15	16	20	19	22
12	19	22	9	10	13	17	18	20	17	22
15	17	22	9	10	11	14	15	19	17	22
	Bolt Number 36S		Bolt Number 37S		Bolt Number 38S		Bolt Number 39S		Bolt Number 40S	
1	20	22	32	35	24	26	19	21	25	28
3	12	13	25	28	14	13	16	16	16	17
6	12	13	20	24	11	12	13	15	14	15
9	11	14	20	24	11	13	13	16	13	16
12	12	15	21	24	10	12	15	17	14	16
15	11	14	21	28	10	12	14	17	12	14

Notes:
1. MIL-F-18240 requirement for torque is 45 lbf-in. maximum and 3.5 lbf-in. minimum OFF breakaway.
2. Torque values were checked after nut was installed with two thread pitches exposed.
3. NAS 1805 nuts were coated with Kaylube dry film lubricant.
4. Bolts were coated with dry film lubricant per MIL-L-8937 (Kal Gard FA).

TABLE 17. RESULTS OF 15 CYCLE ROOM TEMPERATURE TORQUE TESTS ON 450°F HEAT-CONDITIONED NAS 1958C50M (1/2 in.) BOLTS WITH VESPEL SELF-LOCKING STRIP ELEMENTS

Cycle Number	Bolt Number 41S		Bolt Number 42S		Bolt Number 43S		Bolt Number 44S		Bolt Number 45S	
	Installation (ON) and Breakaway (OFF) Torque, lbf-in.									
	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF
1	140	160	155	180	165	190	150	170	180	210
3	70	75	95	110	85	110	75	90	105	140
6	60	75	85	100	70	95	65	80	90	120
9	50	50	65	85	50	65	50	55	75	95
12	55	50	65	70	55	80	55	60	80	90
15	50	50	70	70	60	85	55	60	70	90
	Bolt Number 46S		Bolt Number 47S		Bolt Number 48S		Bolt Number 49S		Bolt Number 50S	
1	165	180	155	180	155	170	130	140	155	155
3	95	110	65	80	80	90	60	80	70	75
6	80	85	60	60	60	70	45	60	60	60
9	50	55	45	55	45	50	35	45	45	60
12	45	50	45	50	40	50	35	45	45	50
15	55	55	50	60	45	50	50	40	45	45

Notes:
1. MIL-F-18240 requirement for torque is 225 lbf-in. maximum and 18 lbf-in. minimum OFF breakaway.
2. Torque values were checked after nut was installed with two thread pitches exposed.
3. NAS 1805 nuts were coated with Kaylube dry film lubricant.
4. Bolts were coated with dry film lubricant per MIL-L-8937 (Kal Gard FA).

TABLE 18. RESULTS OF 15 CYCLE ROOM TEMPERATURE TORQUE TESTS ON 450°F HEAT-CONDITIONED NAS 1962C50M (3/4 in.) BOLTS WITH VESPEL SELF-LOCKING STRIP ELEMENTS

Cycle Number	Bolt Number 51S		Bolt Number 52S		Bolt Number 53S		Bolt Number 54S		Bolt Number 55S	
	Installation (ON) and Breakaway (OFF) Torque, lbf-in.									
	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF
1	300	350	235	250	275	350	375	425	375	435
3	100	135	140	150	125	150	100	125	150	200
6	120	140	115	130	120	160	100	110	150	180
9	100	120	100	110	100	135	80	95	125	150
12	90	110	95	110	100	135	75	90	115	130
15	90	110	95	110	100	135	80	90	115	140
	Bolt Number 56S		Bolt Number 57S		Bolt Number 58S		Bolt Number 59S		Bolt Number 60S	
1	350	410	375	425	350	410	310	375	260	285
3	125	150	125	160	125	150	125	175	90	100
6	110	145	125	145	100	120	120	160	70	90
9	85	120	100	120	80	95	105	135	60	80
12	90	120	95	120	65	90	85	115	55	75
15	85	120	95	120	65	85	85	115	55	80

Notes:
1. MIL-F-18240 requirement for torque is 600 lbf-in. maximum and 50 lbf-in. minimum OFF breakaway.
2. Torque values were checked after nut was installed with two thread pitches exposed.
3. NAS 1805 nuts were coated with Kaylube dry film lubricant.
4. Bolts were coated with dry film lubricant per MIL-L-8937 (Kal Gard FA).

TABLE 19. RESULTS OF BREAKAWAY TORQUE TESTS AT 450°F ON NAS 1954C50M (1/2 in.) BOLTS WITH VESPEL SELF-LOCKING STRIP ELEMENTS

Cycle Number	Bolt Number 41S		Bolt Number 42S		Bolt Number 43S		Bolt Number 44S		Bolt Number 45S	
	Breakaway Torque, inch pounds (Nm)									
	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF
15 (1)	50	50	70	70	60	85	55	60	70	90
16 (2)	29	31	48	60	21	21	-	-	45	52
17 (3)	-	60	-	68	-	41	-	41	-	65
18 (4)	21	20	-	39	-	40	57	52	57	52
	Bolt Number 46S		Bolt Number 47S		Bolt Number 48S		Bolt Number 49S		Bolt Number 50S	
15 (1)	55	55	50	60	45	50	50	40	45	45
16 (2)	33	37	-	-	23	25	22	29	22	30
17 (3)	-	60	-	45	-	59	-	60	-	52
18 (4)	-	30	-	28	30	30	21	-	-	-

Notes:
1. Maximum and breakaway torque values for 450°F (232°C) heat conditioned fastener assembly.
2. Recorded torque values prior to initiation of heat for breakaway torque test at 450°F (232°C).
3. Breakaway torque values at 450°F ± 10°F (232°C ± 5.6°C).
4. Maximum and breakaway torque values after approximately 24 hours.
5. MIL-F-18240 requirement for torque is 18.0 lbf-in. minimum breakaway.

TABLE 20. RESULTS OF 60 ROOM TEMPERATURE TORQUE TESTS ON ANCHOR NUT, P/N 109VA21-79-048, WITH VESPEL SELF-LOCKING RING ELEMENT

Cycle No.	Anchor Nut No. 1		Anchor Nut No. 2		Anchor Nut No. 3		Anchor Nut No. 4		Anchor Nut No. 5	
	Installation (ON) and Breakaway (OFF) Torque, lbf-in.									
	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF
1	34	40	39	38	39	40	46	38	31	31
10	25	34	37	38	26	34	35	39	29	30
20	26	29	33	32	37	38	24	29	30	30
30	26	31	31	34	26	31	24	26	32	33
40	28	30	32	39	31	38	29	32	32	35
50	29	34	38	34	31	34	38	40	34	38
	Bolts Were Torqued to 90 lbf-in. from Cycle 51 through 60									
60	24	20	33	33	28	28	22	27	27	26

Notes: 1. Anchor nut, P/N 109VA21-79-048 was purchased from the Amerace Corporation, ESNA Division, and is a CRES adaption of P/N 22NA21-22-048.
2. MIL-N-25027 requirement for torque is 30 lbf-in. maximum ON and 3.5 lbf-in. minimum OFF breakaway.
3. Torque values were checked after bolt was installed with two thread pitches exposed.
4. CRES bolts were bare.

CONCLUSIONS

This test program has demonstrated the acceptability of a fully reuseable self-locking fastener system, employing Vespel (SP-1 polyimide) elements in lieu of crimped nuts, for SRB application. The torque tests performed on fasteners installed with three different configurations of Vespel self-locking elements confirm that Vespel has properties which can be used in threaded fasteners at temperatures to 450°F. Our testing investigation of up to 60 reuse cycles on three bolt sizes did not reveal any galling or seizure problems and this one feature of using Vespel achieved our goal of extended reuse without damage and solved the main problem in using A-286 fasteners.

Vespel self-locking elements in nuts/anchor nuts successfully met all requirements for SRB use. Locking torque was marginally high, but considered acceptable. The Navy's qualification approval of Vespel elements in steel anchor nuts (MS14179) for 500 reuses and our success in passing SRB vibration tests lends confidence that Vespel elements are acceptable for SRB.

TABLE 21. RESULTS OF TORQUE TESTING WITH VESPEL SELF-LOCKING ELEMENTS INSTALLED IN BOLTS

Bolt Size (in.)	Round Vespel Elements 50 Reuse Cycles Bare Bolts 10 Specimens		Round Vespel Elements 15 Reuse Cycles Bare Bolts 10 Specimens		Two Vespel Strips 15 Reuse Cycles Lubricated Bolts 10 Specimens		Vibration 5 Specimens	450°F Breakaway Torque 10 Specimens
	Room Temperature Torque	Heat-Cond. Torque	Room Temperature Torque	Heat-Cond. Torque	Room Temperature Torque	Heat-Cond. Torque		
1/4	Passed	Failed	Passed	Failed			Passed	Not Tested
1/2	Failed	Failed	Passed	Failed			Passed	Not Tested
3/4	Failed	Failed	Failed	Failed			Passed	Not Tested
							3/5 Specimens	10 Specimens
1/4					Passed	Passed	Passed*	Not Tested
1/2					Passed	Passed	Passed	Passed
3/4					Failed	Passed	Passed	Not Tested

Note: * Denotes Anchor Nut only.

1) CRES lubricated nuts/anchor nuts in sizes No. 10, 1/4 in. and 5/16 in. are acceptable for SRB use.

2) CRES lubricated and bare bolts plus other sizes of lubricated CRES nuts/anchor nuts with Vespel elements require further testing and evaluation for certification for SRB use.

Table 21 shows the results of all tests completed in our investigation of Vespel for use as self-locking elements installed in bolts. It shows the round element failed all but one of the reuse torque tests and the reason is most likely the size elements furnished with the bolts. The lubricated bolts with two Vespel strip elements passed all torque and vibration tests except for three 3/4 in. bolts which failed the minimum locking torque requirements at room temperature. The strip element configuration was not satisfactory because it broke in all bolts.

RECOMMENDATIONS

We recommend that nuts and anchor nuts in sizes No. 10-32 UNJF-3B 1/4-28UNJF-3B and 5/16-24UNJF-3B currently being used on the SRB be changed to include the use of Vespel self-locking elements in the nut when the maximum service temperature will not exceed 450°F. Specific part drawings will be required. Guidelines are:

A. BOLTS

1. Bolts shall be made from A-286 material and the surface finish shall be bare and passivated.

2. The bolt threads shall comply with MIL-S-8879 and shall be rolled after heat treatment.

3. Material and strength shall be specified on the part drawing.

4. Certificate of performance shall be furnished with all bolts made to these requirements.

B. NUTS/ANCHOR NUTS — Self-locking

1. The nut/anchor nut shall be coated with a dry film lubricant qualified in accordance with MIL-L-8937 or approved by M & P Laboratory.

2. The self-locking element shall be Vespel polyimide, Type SP-1.

3. The self-locking element shall provide a minimum of 25 cycles reuse and pass all torque tests in MIL-N-8937 except the maximum locking torque shall be increased 1/3 and minimum breakaway torque shall be tested at 450°F on new bolts.

4. Material and strength shall be specified on the drawing.

5. Certificate of performance shall be furnished with all nuts/anchor nuts made to these requirements.

C. Drawings shall include bolt and mating nut/anchor nut.

APPROVAL

TESTING AND EVALUATION OF VESPEL UP TO 450°F WHEN USED IN NUTS AND BOLTS AS A SELF-LOCKING ELEMENT

By Carl M. Wood

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

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