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REVIEW OF ALLOYS AND FABRICATING METHODS USED FOR TACTICAL MISSILE MOTOR CASES

DEFENSE METALS INFORMATION CENTER
BATTELLE MEMORIAL INSTITUTE
COLUMBUS, OHIO 43201

The Defense Metals Information Center was established at Battelle Memorial Institute at the request of the Office of the Director of Defense Research and Engineering to provide Government contractors and their suppliers technical assistance and information on titanium, beryllium, magnesium, aluminum, high-strength steels, refractory metals, high-strength alloys for high-temperature service, and corrosion- and oxidation-resistant coatings. Its functions, under the direction of the Office of the Director of Defense Research and Engineering, are as follows:

1. To collect, store, and disseminate technical information on the current status of research and development of the above materials.

2. To supplement established Service activities in providing technical advisory services to producers, melters, and fabricators of the above materials, and to designers and fabricators of military equipment containing these materials.

3. To assist the Government agencies and their contractors in developing technical data required for preparation of specifications for the above materials.

4. On assignment, to conduct surveys, or laboratory research investigations, mainly of a short-range nature, as required, to ascertain causes of troubles encountered by fabricators, or to fill minor gaps in established research programs.

Contract No. AF 33(615)-3408

Roger J. Runck

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Director

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REVIEW OF ALLOYS AND FABRICATING METHODS USED FOR TACTICAL-MISSILE MOTOR CASES

J. E. Campbell*

SUMMARY

This memorandum discusses alloys used for motor cases for 21 solid-propellant and four liquid-propellant missiles of the tactical type. Early solid-propellant-missile motor cases were usually fabricated of AISI 4130 steel and were often not heat treated. Since then, there has been a trend toward use of higher strength alloy steels — primarily AISI 4340 and D6ac — and the cases have been heat treated to 200,000 to 250,000-psi tensile strength. In recent developments, maraging steels are being considered for the motor cases and other components of new missiles because of the ease of shear spinning, heat treating, etc. The trend toward higher strength motor-case materials is reasonable so long as the fabricators can demonstrate capabilities for "inspecting out" flaws that approach critical size and that are larger than critical size. Fabrication procedures also have advanced from the roll-and-weld technique to deep-drawing and shear-spinning techniques that provide definite advantages for production of missile cases.

Alloy steels and aluminum alloys have been used for liquid-propellant motor cases of "prepackaged propellant" design. Use of titanium alloys for production motor cases is limited to cases for the second stage of the Minuteman missile.

INTRODUCTION

A number of inquiries have been received by the Defense Metals Information Center for information on alloys and fabricating methods for motor cases for tactical missiles. This memorandum summarizes available information on missile motor cases that are in either development or production phases. Data on alloys used for motor cases of specific tactical missiles, obtained through a DMIC survey of the missile project offices, are given in the Appendix. For the reader's convenience, basic missile data from the March 6, 1967 issue of Aviation Week and Space Technology are included. Because improvements are frequently made in design, material selection, fabrication procedures, missile performance, etc., the status of any of these motor cases may change over a period of time. For example, the trend toward the use of higher strength alloys for solid-propellant rocket motor cases is evident in the changes which have already been made in the choice of materials.

The early missile motor cases were often made of AISI 4130 steel rolled and welded or flow turned from a forged ring. In some instances, the cases were not heat treated after fabrication. However, because of requirements for lower inert-weight and the resulting increased service stresses, heat treatments were established for AISI 4130 steel motor cases and motor cases of other low-alloy steels. Development of the early Polaris motor cases indicated a need for improved nondestructive testing procedures, improved welding procedures, and a better understanding of fracture toughness requirements in high-strength pressure vessels. Certain improvements have been made in these areas over the past 9 or 10 years.

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Minimum weight of the inert components of missiles is desired from the standpoint of transportation, the amount of ordnance that can be carried by a single aircraft, and the potential range of the missile. As a consequence, most motor cases designed for more recent missiles are being made of high-strength materials such as D6ac steel, maraging steels, solution-treated-and-aged Ti-6Al-4V alloy, and glass-fiber composites. (Glass-fiber cases are not considered in this memorandum.) The only production missile motor case for which the Ti-6Al-4V alloy is used is the second stage of the Minuteman.* Its use is limited because of cost factors. Aluminum alloys are used for several missile motor cases such as the Lance (2024-T6 alloy) and the Zuni (7075-T6 alloy). Motor cases in most of the other tactical missiles are fabricated from alloy steels.

USE OF MARAGING STEELS FOR MISSILE CASES

Maraging steels have been used for large boosters of 120- and 260-inch diameter in several programs involving successful test firings with solid propellants.[1,2]** Maraging steels were selected for the large boosters because of their ease of forming in the annealed condition, the relatively simple aging treatment for developing comparatively high strength levels in thick sections, good weldability under controlled conditions, feasibility of localized aging of weld areas, and good toughness.

These advantages also apply to the manufacture of smaller tactical-missile motor cases. The work-hardening coefficient of the alloy is lower than that of other alloy steels. Thus, deep drawing and shear spinning are feasible processes for forming cylindrical shapes of the maraging steels. Ring forgings or rolled-and-welded plate preforms may be used as blanks for shear spinning cylindrical sections. Cold working actually adds to the strength level that can be achieved on aging. However, the cold-working effect is eliminated in the heat-affected zones at welds. Aging at 900 F to develop maximum tensile properties causes little if any distortion from warping and almost negligible change in dimensions from the age-hardening reaction. Also, there is no decarburization. Fracture toughness of the aged alloy at a given strength level is higher than that of other alloy steels. A partial list of applications of maraging steels for missile motor cases is presented in Table 1.

Because of the advantages noted above, there is a tendency for designers to select the 300 grade (280,000 to 290,000-psi yield strength, or higher for the cold-worked alloy) of maraging steel. If the 300 grade is selected, the fabricator should demonstrate a capability for detecting flaws near critical size by production nondestructive-testing techniques. Accurate techniques for estimating critical flaw sizes in thin shells at certain

*Titanium alloys have been used in experimental fabrication of solid-propellant motor cases, such as Pershing and Alcor.

**References are given on page 3.

TABLE 1. SELECTED APPLICATIONS OF MARAGING STEELS FOR MISSILE MOTOR CASES[(a)]

Name of Missile	Contractor	Case Dimensions Diam, in.	Length, in.	Wall Thickness, in.	Quantity Produced	Alloy Grade	Forming Process	Yield Strength, ksi	Tensile Strength, ksi	Status
Condor	Bostrom	--	--	--	--	300	Shear spin	--	--	Development
Condor	Thiokol, RMD	17	--	--	--	250	Shear spin	--	--	Development
Lance	Coast Metal Craft	15.28	Bell-shaped thrust chamber		300+	250	Roll and weld (EBM), contoured to size	250	--	Production
Minuteman 1st Stage	Allison (subscale)	24	48	0.120	--	300	Shear spin	285	--	Development
Minuteman 1st Stage	Curtiss-Wright Corp.	65	--	--	1	250/300	Shear spin	225/270	--	Development
Pershing	Intercontinental	39.82	78.55	--	1	250	Shear spin	--	--	Development
Pershing 2nd Stage	Curtiss-Wright Corp.	40	--	--	4	--	--	--	--	--
Redeye	Marquardt	2.5	26	--	1	300	Roll and weld ring, shear spin	270	--	Development
Redeye	Missile Engrg	2.5	24	--	several	?	Roll extrusion	--	--	Development
Tow	General Electric	2.75	24	--	9	300	Shear spin	280	--	Development
Tow	Norris-Thermador	5.75	5	0.220	100+	250	Deep draw	--	310-320	Development
		2.5	17	0.070	100+	300	Deep draw	--		Development

(a) Coleman, A. A., "High-Strength Maraging Steels for Tactical Missile Rocket Motors", Report R-4384, Rocketdyne Division, North American Aviation, Inc., Solid Rocket Division, McGregor, Texas (July 13, 1966).

strength levels and proof pressures are not well established, since methods for plane-stress fracture-toughness testing have not been standardized. However, prototype cases containing small intentional flaws produced by electrical-discharge machining may be subjected to proof tests. If the nondestructive testing methods used are capable of detecting all flaws near critical size and larger,* the material selection would appear to be satisfactory. If not, a lower strength, tougher alloy should be evaluated in the same way.

Vacuum-remelted alloy steels tend to be tougher than corresponding air-melted alloy steels, which also may be true of the maraging steels. However, if air-melted maraging steels have adequate toughness for a given application, the higher cost of vacuum-remelted alloys of the same grades would not be warranted, even though they may be tougher. Information is being sought on this question for a future Defense Metals Information Center report. For a specific motor-case design, air-melted maraging steel certainly may be used for prototype cases. These cases then can be proof tested with and without intentional flaws, as suggested above, to arrive at an apparent critical flaw size. It is suggested that this technique be used to verify critical-crack-size estimates even after the state of the art has advanced to the point where reasonably accurate critical-crack-size estimates can be made. This practice will aid in developing confidence in the NDT methods and should lead to fewer failures on proof testing. If it is found that the air-melted alloys have adequate toughness, the extra expense of the vacuum-melted alloys could be avoided.

*A critical-size flaw is the smallest size that will initiate fracture of a given material at a given strength level at a specified proof stress for a definite wall thickness, orientation, and service temperature.

OTHER ALLOY STEELS FOR MISSILE MOTOR CASES

Following the trend for developing missile motor cases with higher strengths than could be obtained with AISI 4130 steel, steels having higher carbon contents and higher hardenabilities have been used in more recent missile designs. Modifications of AISI 4340 steel or D6ac steel are being used in many current motor cases for tactical missiles. Cases of these alloy steels are usually fabricated by the roll-and-weld technique or by shear spinning. Forged end closures are then welded onto the cylindrical sections.

To develop high strength levels in these steels, heat treating, which consists of austenitizing, quenching, and tempering, is required. In some instances, hot-salt-bath quenching has been used to minimize quenching distortion on heat treating. Special fixturing is usually necessary to minimize distortion of thin-wall cases during the high-temperature austenitizing treatment. Special furnace atmospheres also are required to prevent or minimize decarburization. These special processing procedures have been developed successfully to meet the requirements of high-strength missile motor cases produced from low-alloy steels. D6ac alloy steel has been fabricated for the cylindrical section of the Shillelagh missile by ausforming techniques, which result in high strength and good toughness. The end closures are welded to the cylindrical sections by electron-beam welding.

The low-alloy martensitic steels can be obtained for substantially lower cost than other more highly alloyed steels such as the maraging or the HP-9Ni-4Co steels. However, for certain applications, the maraging steels may have specific advantages.

Use of the HP-9Ni-4Co steels for motor-case applications has been limited to large cases, specifically those 120 inches in diameter (Technology Week, p. 28, June 13, 1966). Plate of the

HP-9Ni-4Co-25 grade may be heat treated to 190,000-psi yield strength before forming. After heat treating, it is rolled into a cylindrical shape, welded at the longitudinal joint, and then roll extruded to final dimensions for the cylindrical portion of the case. This procedure results in a motor case of high strength and good toughness, requiring no heat treatment after fabrication. DMIC is not aware of any production fabrication of smaller motor cases for tactical missiles using HP-9Ni-4Co-25 steel by this technique.

Experimental missile motor cases have been produced by cryoforming Type 301 stainless steel. In this process, a preform of the case is produced by welding together cylindrical and conical shapes of annealed Type 301 stainless steel. The preform is submerged in and pressurized with liquid nitrogen (-320 F). A simple cylindrical die controls the outside diameter limit. During pressurizing, the shell is stretched about 12 percent, resulting in considerable cold working and strengthening. The weld areas are strengthened about the same as the parent metal. The strength levels achieved are competitive with the strength levels achieved in maraging steels.

REFERENCES

(1) "260-In.-Dia. Motor Feasibility Demonstration Program", Aerojet-General Corporation, Sacramento, California, Final Program Summary Report, NASA CR 72127, Contract NAS 3-6284 (April 8, 1966).

(2) "Design, Fabrication, and Hydrotesting of a 120-Inch Diameter Pressure Vessel Using 18 Percent Ni Maraging Steel", Lockheed Propulsion Company, Redlands, California, Final Report RPL-TDR-64-82, Contract AF 04(611)-8525 (October 2, 1964).

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APPENDIX A

DATA ON MISSILES AND MISSILE MOTOR CASES

APPENDIX A

DATA ON MISSILES AND MISSILE MOTOR CASES

Solid-Propellant Missiles

ASROC

Designation	RUR-5A
Service	USN
Mission	Antisubmarine
Prime Contractor or Technical Director	Honeywell

Missile Data

Overall Length, ft	15
Maximum Body Diameter, in.	12 (span 2.5 ft)
Total Launch Weight, lb	940
Number of Stages (Motors)	1
Motor Designation	--
Motor Contractor	Naval Propellant Plant
Propellant Type	Solid extruded double base

Motor-Case Data

Case Material	Steel
Fabricating Methods	Rolled and welded
Case Length, in.	56.3
Case Diameter, in.	--
Wall Thickness, in.	0.200
Proof or Burst Pressure, psig	--

Mechanical Properties of Case Material

Yield Strength, psi	160,000 minimum
Tensile Strength, psi	--
Elongation, percent	8.9 minimum

References

Missile Propulsion Branch, Department of the Navy; Aviation Week (March 6, 1967).

FALCON

Designation	AIM 4G
Service	USAF
Mission	Air to air
Prime Contractor or Technical Director	Hughes

Missile Data

Overall Length, ft	6.77
Maximum Body Diameter, in.	6.64
Total Launch Weight, lb	145
Number of Stages (Motors)	1
Motor Designation	M-46
Motor Contractor	Thiokol
Propellant	Polysulfide, Al + NH_4ClO_4

Motor Case Data

Case Material	AISI 4130 (MIL-S-18729) steel, annealed
Fabricating Methods	Drawn and machined for attachments

Motor Case Data (continued)

Case Length, in.	19.355
Case Diameter, in.	6.259 + 0.002
Wall Thickness, in.	0.081 + 0.004
Motor Length with Nozzle, in.	28.43

Mechanical Properties of Case Material

Yield Strength, psi	75,000
Tensile Strength, psi	95,000
Elongation, percent	10 minimum

References

Technical Services Section, Missile Support Branch, Hill Air Force Base, Utah

HAWK

Designation	MIM-23A
Service	Army
Mission	Surface to air
Prime Contractor or Technical Director	Raytheon

Missile Data

Overall Length, ft	16
Maximum Body Diameter, in.	14
Total Launch Weight, lb	1300
Number of Stages (Motors)	1 (dual thrust)
Motor Designation	M-22E8
Motor Contractor	Aerojet
Propellant Type	Polyurethane + NH_4ClO_4
Maximum Range, nautical miles	22

Motor-Case Data

Case Material	AISI 4132 steel
Fabricating Methods	Roll and weld
Case Length, in.	85
Case Diameter, in.	--
Wall Thickness, in.	0.093 to 0.105

Mechanical Properties of Case Material

Yield Strength, psi	170,000 to 175,000
Tensile Strength, psi	180,000 to 200,000
Elongation, percent	10-12

References

Hawk Project Manager's Office, Redstone Arsenal; Aviation Week (March 6, 1967)

MINUTEMAN II

Designation	LGM-30F
Service	USAF
Mission	Surface to surface
Prime Contractor or Technical Director	AFSC/BSD, Boeing

Missile Data

Overall Length, ft	60		
Maximum Body Diameter, in.	65.5		
Total Launch Weight, lb	--		
Number of Stages (Motors)	3		
	Stage I	Stage II	Stage III
Motor Designation	TU-122	XSR-19-AJ1	M-57
Motor Contractor	Thiokol	Aerojet	Hercules
Propellant Type	Solid composite	Solid composite	Solid double base
Maximum Range, nautical miles			7000 +

Motor-Case Data

	Stage I	Stage II	Stage III
Case Material	D6ac steel	Ti-6Al-4V	Glass fiber composite
Fabricating Methods	Shear form	Shear form, STA,(a) weld, re-age	Fiber wrapping
Case Length, in.(b)	222.6/257.9	108.7/122.5	61.8/69.5
Case Diameter, in.	--	--	--
Wall Thickness, in.	--	--	--

Mechanical Properties of Case Material

	Stage I	Stage II	Stage III
Yield Strength, psi	--	--	--
Tensile Strength, psi	--	--	--
Elongation, percent	10	8	--

References

Headquarters Ballistic Systems Division (AFSC), Norton Air Force Base, California; Aviation Week (March 6, 1967)

(a) Solution treat and partial age. Complete aging follows the welding.
(b) Skirt to skirt/forward dome to nozzle flange.

PERSHING

Designation	MGM-31A
Service	Army
Mission	Battlefield support
Prime Contractor or Technical Director	Martin/Orlando

Missile Data

Overall Length, ft	30.61
Maximum Body Diameter, in.	40.15
Total Launch Weight, lb	10,252
Number of Stages (Motors)	2
Motor Designation	TX-174 (XM-105), TX-175 (XM-106)
Motor Contractor	Thiokol
Propellant Type	PBAA composite (hydrocrabon, aluminum, and NH_4ClO_4)
Maximum Range, nautical miles	400

Motor-Case Data

Case Material	D6ac steel	
Fabricating Methods	Hydro-spun cylindrical sections with welded end closure	
	First Stage	Second Stage
Case Length, in.	102.6	96.0
Case Diameter, in.	40	40
Wall Thickness, in.	0.090	0.068

Mechanical Properties of Case Material

Yield Strength, psi	--
Tensile Strength, psi	195,000 to 220,000
Elongation, percent	6

References

Pershing Project Manager's Office, Redstone Arsenal; Aviation Week (March 6, 1967)

PHOENIX

Designation	AIM-54A
Service	USN
Mission	Air to air
Prime Contractor or Technical Director	Hughes

Missile Data

Overall Length, ft	14
Maximum Body Diameter, in.	15
Total Launch Weight, lb	1000
Number of Stages (Motors)	1
Motor Designation	MK 47 Mod 0
Motor Contractor	NAA/Rocketdyne
Propellant Type	Solid composite

Motor-Case Data

Case Material	Ladish D6ac steel
Fabricating Methods	Machined forgings formed by shear spinning
Case Length, in.	41.4
Case Diameter, in.	14.7
Wall Thickness, in.	0.043
Case Weight, lb	32.89

Mechanical Properties of Case Material

Yield Strength, psi	--
Tensile Strength, psi	200,000 to 225,000
Elongation, percent	--
Reduction in Area, percent	--

References

Missile Propulsion Branch, Department of the Navy; Rocketdyne, Solid Rocket Division, McGregor, Texas; Aviation Week (March 6, 1967)

REDEYE

Designation	FIM-43A

General Data (continued)

Service	Army
Mission	Surface to air
Prime Contractor or Technical Director	General Dynamics/ Pomona

Missile Data

Overall Length, ft	4
Maximum Body Diameter, in.	2.77
Total Launch Weight, lb	18
Number of Stages (Motors)	2
Motor Designation	XM-99
Motor Contractor	Atlantic Research
Propellant Type	Arcite

Motor-Case Data

Case Material	H-11 steel
Fabricating Methods	Deep draw(a) (Fabricator is Norris Industries)
Case Length, in.	24
Case Diameter, in.	--
Wall Thickness, in.	0.020

Mechanical Properties of Case Material

Yield Strength, psi	190,000
Tensile Strength, psi	--
Elongation, pecent	4.5

References

Redeye Project Office, Redstone Arsenal; Aviation Week (March 6, 1967)

(a) The motor case has been fabricated in small quantities by the roll-extrusion process of NTW Missile Engineering Company. Motor cases of both H-11 steel and maraging steel have been fabricated by this method.

SERGEANT

Designation	MGM-29A
Service	Army
Mission	Battlefield support
Prime Contractor or Technical Director	Sperry Utah Company

Missile Data

Overall Length, ft	33.5
Maximum Body Diameter, in.	31
Total Launch Weight, lb	10,000
Number of Stages (Motors)	1
Motor Designation	XM-100
Motor Contractor	--
Propellant Type	Polysulfide ammonium perchlorate
Maximum Range, nautical miles	75

Motor-Case Data

Case Material	AISI 4130 steel
Fabricating Methods	Roll and weld fabrication

Motor-Case Data (continued)

Case Length, in.	170 (motor length 195 in.)
Case Diameter, in.	31
Wall Thickness, in.	0.109

Fins are AZ91-T6 magnesium alloy castings. Jet vanes are glass fiber-phenolic resin composite with molybdenum (AMS 7805) leading edges.

Mechanical Properties of Case Material

Yield Strength, psi	135,000
Tensile Strength, psi	165,000 to 195,000
Elongation, percent	6 to 7 (MIL-H-6875)

References

U. S. Army Missile Command, Redstone Arsenal, Alabama; Aviation Week (March 6, 1967)

SHILLELAGH

Designation	XMGM-51B
Service	Army
Mission	Battlefield support
Prime Contractor or Technical Director	Philco Aeronutronic

Missile Data

Overall Length, ft	3.8
Maximum Body Diameter, in.	5.95
Total Launch Weight, lb	61.54
Number of Stages (Motors)	1 + control reaction jets
Motor Designation	--
Motor Contractor	Picatinny Arsenal, Amoco Chemicals Solid (N5 and LFT3A)
Maximum Range, nautical miles	10

Motor-Case Data

Case Material	Type D6ac alloy steel
Fabricating Methods	Tubing, cut to length, EB welded, and finish machined
Case Length, in.	16.29
Case Diameter, in.	5.95
Wall Thickness, in.	0.040 (short chamber) 0.047 (long chamber)
Proof Pressure, psig	2200 (30 seconds minimum) for short chamber and 2000 (5 seconds minimum) for long chamber

Mechanical Properties of Case Material

Yield Strength, psi	185,000 minimum
Tensile Strength, psi	210,000 minimum (210,000 to 230,000)
Elongation, percent in 2 in.	5 minimum (transverse)
Hardness	RC 42 to RC 48

Mechanical Properties of Case Material (continued)

Heat Treatment	Preheat to 1150 F, austenitize at 1650 F for 30 minutes, salt quench to 400 F for 5 minutes, temper at 1025 F twice for 2 + 2 hours

References

Project Manager, Shillelagh, Redstone Arsenal; "Electron Beam Spurs Shillelagh-Making", Steel, p. 58 (March 21, 1966).

SHRIKE

Designation	AGM-45A
Service	USN, USAF
Mission	Air to surface
Prime Contractor or Technical Director	Naval Ordnance Test Station, Texas Instruments, Sperry-Farragut

Missile Data

Overall Length, ft	12
Maximum Body Diameter, in.	8
Total Launch Weight, lb	400
Number of Stages (Motors)	1
Motor Designation	Mk39 Mod 3
Motor Contractor	NAA/Rocketdyne, Aerojet
Propellant Type	Solid composite

Motor Case Data

Case Material	AISI 4130 steel
Fabricating Methods	Rolled and welded or deep drawn
Case Length, in.	48.2
Case Diameter, in.	8.0
Wall Thickness, in.	0.052 to 0.060
Case Weight, lb	22.6

Mechanical Properties of Case Material

Yield Strength, psi	170,000
Tensile Strength, psi	185,000 to 205,000
Elongation, percent	8 minimum

References

Missile Propulsion Branch, Department of the Navy; Rocketdyne, Solid Rocket Division, McGregor, Texas; Aviation Week (March 6, 1967)

SIDEWINDER

Designation	AIM-9C and 9D
Service	USN
Mission	Air to air
Prime Contractor or Technical Director	Naval Ordnance Test Station, Philco, Raytheon

Missile Data

Overall Length, ft	9.5
Maximum Body Diameter, in.	5
Total Launch Weight, lb	195
Number of Stages (Motors)	1
Motor Designation	Mk 36 Mod 2 and 5
Motor Contractor	NAA/Rocketdyne
Propellant Type	Solid-composite polybutadiene carboxyl termination
Maximum Range, nautical miles	10

Motor-Case Data

Case Material	AISI 4130 steel
Fabricating Methods	Deep drawn and welded
Case Length, in.	70.9
Case Diameter, in.	5.01
Wall Thickness, in.	0.060 ± 0.003
Case Weight, lb	24
Burst Pressure, psig	3500

Mechanical Properties of Case Material

Yield Strength, psi	--
Tensile Strength, psi	160,000 minimum
Elongation, percent	6 minimum

References

Missile Propulsion Branch, Department of the Navy; Rocketdyne, Solid Rocket Division, McGregor, Texas; Aviation Week (March 6, 1967)

SPARROW III-6B

Designation	AIM-7E
Service	USN, USAF
Mission	Air to air
Prime Contractor or Technical Director	Raytheon

Missile Data

Overall Length, ft	12
Maximum Body Diameter, in.	8
Total Launch Weight, lb	400
Number of Stages (Motors)	1
Motor Designation	Mk 38 Mod 2
Motor Contractor	NAA/Rocketdyne, Aerojet
Propellant Type	Solid composite
Maximum Range, nautical miles	12

Motor-Case Data

Case Material	AISI 4130 steel
Fabricating Methods	Rolled and welded or deep drawn
Case Length, in.	48.2
Case Diameter, in.	8.0
Wall Thickness, in.	0.052 to 0.060
Case Weight, lb	22.6

Mechanical Properties of Case Material

Yield Strength, psi	170,000
Tensile Strength, psi	185,000 to 205,000
Elongation, percent	8 minimum

References

Missile Propulsion Branch, Department of the Navy; Rocketdyne, Solid Rocket Division, McGregor, Texas; Aviation Week (March 6, 1967)

STANDARD MISSILE, TYPE I-MR
(MR for medium range)

Designation	YRIM-66A
Service	USN
Mission	Surface to air
Prime Contractor or Technical Director	General Dynamics/ Pomona

Missile Data

Overall Length, ft	15
Maximum Body Diameter, in.	13.5
Total Launch Weight, lb	1406
Number of Stages (Motors)	1 (dual thrust)
Motor Designation	Mk 27 Mod 2
Motor Contractor	Aerojet-General
Propellant Type	Solid composite dual burning
Maximum Range, nautical miles	10 + (tartar replacement)

Motor-Case Data

Case Material	AMS 6429 steel (4340)
Fabricating Methods	Rolled and welded or shear formed, forged ends
Case Length, in.	90
Case Diameter, in.	13.5
Wall Thickness, in.	0.110 to 0.115

Mechanical Properties of Case Material

Yield Strength, psi	190,000
Tensile Strength, psi	210,000
Elongation, percent	12

References

Missile Propulsion Branch, Department of the Navy; Surface Missile Systems Project Office, Department of the Navy; Aviation Week (March 6, 1967)

STANDARD MISSILE, TYPE I-ER
(ER for extended range)

Designation	YRIM-67A
Service	USN
Mission	Surface to air
Prime Contractor or Technical Director	General Dynamics/ Pomona

Missile Data

Overall Length, ft	27
Maximum Body Diameter, in.	18
Total Launch Weight, lb	3000
Number of Stages (Motors)	2

Missile Data (continued)

Motor Designation	Mk 30 Mod 1, Mk 30 Mod 2
Motor Contractor	Atlantic Research
Propellant Type	Solid (both stages)
Maximum Range, nautical miles	30+ (terrier replacement)

Motor-Case Data

Case Material	AISI 4130 and 4140 steel
Fabricating Methods	Slip-rolled cylinders, forged ends, welded

	Booster	Sustainer
Case Length, in.	131.26	55.84
Case Diameter, in.	--	13.5
Wall Thickness, in.	0.087 to 0.099	0.063 to 0.068

Mechanical Properties of Case Material

Yield Strength, psi	75,000	75,000
Tensile Strength, psi	95,000	95,000
Elongation, percent	12	12

References

Missile Propulsion Branch, Department of the Navy; Surface Missile Systems Project Office, Department of the Navy; Aviation Week (March 6, 1967).

SUBROC

Designation	UUM-44A
Service	USN
Mission	Antisubmarine
Prime Contractor or Technical Director	Goodyear Aerospace

Missile Data

Overall Length, ft	21
Maximum Body Diameter, in.	21
Total Launch Weight, lb	4000
Number of Stages (Motors)	1
Motor Designation	TE-260G (Mk 45 Mod o)
Motor Contractor	Thiokol
Propellant Type	Solid composite polyurethane

Motor-Case Data

Case Material	AISI 4132 steel
Fabricating Methods	--
Case Length, in.	137
Case Diameter, in.	--
Wall Thickness, in.	0.219

Mechanical Properties of Case Material

Yield Strength, psi	--
Tensile Strength, psi	--
Elongation, percent	--

References

Missile Propulsion Branch, Department of the Navy; Aviation Week (March 6, 1967)

TALOS

Designation	RIM-8E	
Service	USN	
Mission	Surface to air	
Prime Contractor or Technical Director	Bendix	

Missile Data

Overall Length, ft	32	
Maximum Body Diameter, in.	36	
Total Launch Weight, lb	7700	
Number of Stages (Motor)	2	
	Booster	Sustainer
Motor Designation	Mk 11 Mod 5	(Ramjet)
Motor Contractor	Naval Propellant Plant	Bendix, McDonnell
Propellant Type	Solid double base	Ramjet JP-5
Maximum Range, nautical miles		65+

Motor-Case Data

Case Material	AISI 4130, 4140 steel	--
Fabricating Methods	Stamped and drawn or welded	--
Case Length, in.	101.5	101
Case Diameter, in.	--	--
Wall Thickness, in.	0.150 to 0.165	--

Mechanical Properties of Case Material

Yield Strength, psi	160,000 minimum	--
Tensile Strength, psi	185,000 minimum	--
Elongation, percent	7 minimum	--

References

Missile Propulsion Branch, Department of the Navy; Aviation Week (March 6, 1967)

TARTAR

Designation	RIM-24B
Service	USN
Mission	Surface to air
Prime Contractor or Technical Director	General Dynamics/ Pomona

Missile Data

Overall Length, ft	15
Maximum Body Diameter, in.	13.5
Total Launch Weight, lb	1425
Number of Stages (Motors)	1 (dual thrust)
Motor Designation	Mk 27 Mod 2
Motor Contractor	Aerojet
Propellant Type	Dual-burning solid composite
Maximum Range, nautical miles	10+

Motor-Case Data

Case Material	AISI 4135 steel
Fabricating Methods	Shear-formed cylinder, forged end closures
Case Length, in.	81.8
Case Diameter, in.	13.5
Wall Thickness, in.	0.105 to 0.115
Proof or Burst Pressure, psig	2560 (burst)

Mechanical Properties of Case Material

Yield Strength, psi	75,000
Tensile Strength, psi	95,000
Elongation, percent	12

References

Missile Propulsion Branch, Department of the Navy; Aviation Week (March 6, 1967)

TERRIER (HT)

Designation	RIM-2E	
Service	USN	
Mission	Surface to air	
Prime Contractor or Technical Director	General Dynamics/ Pomona	

Missile Data

Overall Length, ft	27	
Maximum Body Diameter, in.	18	
Total Launch Weight, lb	3000	
Number of Stages (Motors)	2	
	Booster	Sustainer
Motor Designation	MK 12 Mod 1	Mk 30 Mod 2
Motor Contractor	Naval Propellant Plant	Atlantic Research
Propellant Type	Solid	Solid (polyrinal chloride + NH_4ClO_4)
Maximum Range, nautical miles	--	20+

Motor-Case Data

Case Material	AISI 4130, 4140 steel	AISI 4130, 4135 steel
Fabricating Methods	Slip-rolled cylinders, welded, forged end closures	Slip-rolled cylinders, welded, forged end closures
Case Length, in.	131.26	55.84
Case Diameter, in.	--	13.5
Wall Thickness, in.	0.087 to 0.099	0.063 to 0.068

Mechanical Properties of Case Material

Yield Strength, psi	75,000	75,000
Tensile Strength, psi	95,000	95,000
Elongation, percent	12	12

References

Missile Propulsion Branch, Department of the Navy; Aviation Week (March 6, 1967)

TOW

Designation	XMGM-71A
Service	Army
Mission	Battlefield support
Prime Contractor or Technical Director	Hughes

Missile Data

Overall Length, ft	--
Maximum Body Diameter, in.	--
Total Launch Weight, lb	--
Number of Stages (Motors)	2 chambers
Motor Designation	K-41
Motor Contractor	Hercules (cases fabricated at Norris Thermador)
Propellant Type	Solid

Motor-Case Data

Case Material	18Ni (259)	18Ni (300)
Fabricating Methods	Deep drawn	Deep drawn
Case Length, in.	5.0	17
Case Diameter, in.	5.75	2.5
Wall Thickness, in.	0.220	0.070

Mechanical Properties of Case Material

Yield Strength, psi	--	--
Tensile Strength, psi	250,000	310,000
Elongation, percent	---	--

References

"High Strength Maraging Steels for Tactical Missile Rocket Motors", Rocketdyne Report R-4384; Aviation Week (March 6, 1967)

ZEUS (DM 15X-2)

Designation	XLIM-49A
Service	Army
Mission	Surface to air
Prime Contractor or Technical Director	Bell Telephone Laboratories, Western Electric

Missile Data

Overall Length, ft	50
Maximum Body Diameter, in.	--
Total Launch Weight, lb	--
Number of Stages (Motors)	3

	Booster	Sustainer	Vectoring Motor
Motor Designation	TX-135	TX-235-6	TX-239
Motor Contractor	Thiokol	Thiokol	Thiokol
Propellant Type	Hydro-carbon, Al + NH_4ClO_4	Hydro-carbon, Al + NH_4ClO_4	Hydro-carbon, Al + NH_4ClO_4
Maximum Range, nautical miles	--	--	100

Motor-Case Data

	Booster	Sustainer	Vectoring Motor
Case Material	AISI 4340 steel	---	--
Fabricating Methods	Rolled, seam welded	--	--
Motor Length, in.	203.1	--	48.2
Motor Diameter, in.	43.1	--	29.4
Wall Thickness, in.	--	--	--

Motor-Case Data (continued)

Mechanical Properties of Case Material

Yield Strength, psi	200,000
Tensile Strength, psi	250,000
Elongation, percent	6

References

Information Office, Department of the Army, Redstone Arsenal; Aviation Week (March 6, 1967)

ZUNI

Designation	Mk 41
Service	USN
Mission	Air to surface
Prime Contractor or Technical Director	Naval Ordnance Test Station, Naval Ammunition Depot

Missile Data

Overall Length, ft	9.2
Maximum Body Diameter, in.	5.125
Total Launch Weight, lb	107
Number of Stages (Motors)	1
Motor Designation	--
Motor Contractor	--
Propellant Type	Solid standard X-8 (extruded)

Motor-Case Data

Case Material	7075-T6 aluminum alloy
Fabricating Methods	Deep drawn
Case Length, in.	61.698
Case Diameter, in.	5
Wall Thickness, in.	0.138

Mechanical Properties of Case Material

Yield Strength, psi	66,000
Tensile Strength, psi	77,000
Elongation, percent	7 minimum

References

Missile Propulsion Branch, Department of the Navy; Aviation Week (March 6, 1967)

Liquid-Propellant Missiles

BULLPUP A and B

Designation	AGM-12B, AGM-12C
Service	USN
Mission	Air to surface
Prime Contractor or Technical Director	Maxson Electronics, Martin Company

Missile Data

	12B	12C
Overall Length, ft	11	13.5
Maximum Body Diameter, in.	12	18
Total Launch Weight, lb	575	1800
Number of Stages (Motors)	1	1
Motor Designation	LR58-RM-4	LR62-RM-2
Motor Contractor	Thiokol/ RMD	Thiokol/ RMD
Propellant Type	Prepackaged liquid[a]	Prepackaged liquid[a]
Maximum Range, nautical miles	6	9

Motor-Case Data

Case Material	AISI 4130 steel	2014-T6 Al
Fabricating Methods	Stamped, drawn, welded	--
Case Length, in.	32.09	61
Case Diameter, in.	12	17.3
Wall Thickness, in.	0.069	--

Mechanical Properties of Case Material

Yield Strength, psi	75,000	--
Tensile Strength, psi	95,000	--
Elongation, percent	12	--
Reduction in Area, percent	--	--

References

Missile Propulsion Branch, Department of the Navy; Aviation Week (March 6, 1967)

(a) MAF-1 (mixed amine fuel) and inhibited red fuming nitric acid.

CONDOR

Designation	AGM-53A
Service	USN
Mission	Air to surface
Prime Contractor or Technical Director	North American Aviation, Inc. (Columbus Division)

Missile Data

Overall Length, ft	--
Maximum Body Diameter, in.	--
Total Launch Weight, lb	--
Motor Designation	--
Motor Contractor	Thiokol, Reaction Motors Division
Propellant Type	Prepackaged liquid

Motor-Case Data

Case Material	Maraging steel
Fabricating Methods	Shear spinning
Case Length, in.	--
Case Diameter, in.	17
Wall Thickness, in.	--

Mechanical Properties of Case Material

Yield Strength, psi	--
Tensile Strength, psi	--
Elongation, percent	--

References

Thiokol, Reaction Motors Division; Aviation Week (March 6, 1967)

LANCE

Designation	XMGM-52A
Service	Army
Mission	Battlefield support
Prime Contractor or Technical Director	Ling-Temco-Vought

Missile Data

Overall Length, ft	20
Maximum Body Diameter, in.	22
Total Launch Weight, lb	3262
Number of Stages (Motors)	Boost and sustain from one system
Motor Designation	--
Motor Contractor	Rocketdyne
Propellant Type	Liquid (IRFNA & UDMH)

Motor-Case Data

Case Material	2014-T6
Fabricating Methods	Shear formed cylindrical shells, forged end closures, joined by electron-beam welding
Case Length, in.	111.5
Case Diameter, in.	22
Wall Thickness, in. 0.336 + 0.005	

Mechanical Properties of Case Material

Yield Strength, psi	59,000 transverse 60,000 longitudinal
Tensile Strength, psi	67,000 transverse, 68,000 longitudinal
Elongation, percent	6

References

Lance Project Office, Redstone Arsenal; Aviation Week (March 6, 1967); "Lance Material Selection", Report MBE-63-2, Redstone Arsenal (October 1, 1963).

Other Tactical Missiles

No information beyond that already published in Aviation Week & Space Technology, March 6, 1967, was available because of security restrictions or because final decisions had not been reached on case material for the following missiles which presumably have metal cases:

Advanced Surface Missile System
Chaparral (Surface to air version of Sidewinder)
Entac
Genie
Honest John
Lacrosse
Little John
Mauler (AMS 6434 cylinder, AISI 4130 end closures)
MAU
Nike-Hercules
Sam-D
SRAM
SS-10
SS-11
Teton

Ramjet and turbojet missiles are outside the scope of this report.

LIST OF DMIC MEMORANDA ISSUED
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DMIC Number	Title
203	Recent Information on Long-Time Creep Data for Columbium Alloys, April 26, 1965 (AD 464715)
204	Summary of the Tenth Meeting of the Refractory Composites Working Group, May 5, 1965 (AD 465260)
205	Corrosion Protection of Magnesium and Magnesium Alloys, June 1, 1965 (AD 469906)
206	Beryllium Ingot Sheet, August 10, 1965 (AD 470551)
207	Mechanical and Physical Properties of Invar and Invar-Type Alloys, August 31, 1965 (AD 474255)
208	New Developments in Welding Steels With Yield Strengths Greater Than 150,000 psi, September 28, 1965 (AD 473484)
209	Materials for Space-Power Liquid Metals Service, October 5, 1965 (AD 473754)
210	Metallurgy and Properties of Thoria-Strengthened Nickel, October 1, 1965 (AD 474854)
211	Recent Developments in Welding Thick Titanium Plate, November 24, 1965 (AD 477403)
212	Summary of the Eleventh Meeting of the Refractory Composites Working Group, April 1, 1966
213	Review of Dimensional Instability in Metals, June 23, 1966 (AD 481620)
214	Surface Welding in the Space Environment, June 9, 1966
215	Titanium - 1966 (Lectures Given at a Norair Symposium, March 28-29, 1966), September 1, 1966
216	Weldability of High-Strength Aluminum Alloys, August 22, 1966
217	A Survey of the Feasibility of an Analytical Approach to Die Design in Closed-Die Forging, June 1, 1966
218	Corrosion of Titanium, September 1, 1966
219	Vacuum-Degassed Steels From the Consumer's Viewpoint, September 15, 1966
220	The 9Ni-4Co Steels, October 1, 1966 (AD 801977)
221	First National Symposium of The Center for High-Energy-Rate Forming, November 1, 1966
222	Summary of the Twelfth Meeting of the Refractory Composites Working Group, April 1, 1967
223	Designations of Alloys for the Aerospace Industry, April 12, 1967

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Review of Alloys and Fabricating Methods Used for Tactical-Missile Motor Cases

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5. AUTHOR(S) (Last name, first name, initial)
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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY United States Air Force, Research and Technology Division, Wright-Patterson Air Force Base, Ohio

13. ABSTRACT

This memorandum discusses alloys used for motor cases for 21 solid-propellant and four liquid-propellant missiles of the tactical type. The factors involved in the choice of higher strength steels for solid-propellant motor cases are discussed, with particular emphasis on the problem of fracture toughness. Trends in the selection of alloys for missile motor cases are pointed out. An appendix provides detailed information on materials and fabrication methods used for selected missiles.

Unclassified
Security Classification

14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Tactical Missiles Motor Case Materials Maraging Steels Fracture Toughness Non-Destructive Testing						

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