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Investigation of Rocket Motors 3" No. 1 MK 4

L.M. Barrington

DEPARTMENT OF DEFENCE
DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

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DSTO Technical Report
DSTO-TR-0017

Abstract

In 1992, Aircraft Research and Development Unit (ARDU), RAAF, experienced two misfires with Rocket Motors, 3", No. 1, Mk 4, during a series of firings at Woomera. These motors were sampled from a batch manufactured in 1957, and subsequent to the misfires this batch was withdrawn from use.

An alternate batch of motors manufactured in 1966 was available to ARDU. Tests were conducted on a number of these motors to advise on their suitability for use, and as a result, a further five years life was assigned with a recommendation to retest after that period.

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1. *Introduction*

Task AIR 93/057 "Investigation of Rocket Motors 3" No. 1 Mk 4" was raised in Explosives Ordnance Division (EOD), Aeronautical and Maritime Research Laboratory, at the request of Aircraft Research and Development Unit (ARDU), RAAF, after ARDU personnel reported that in two attempts during 1992 to fire 3" Rocket Motors at Woomera, misfires had occurred. Subsequent to ARDU's request, Directorate of Explosive Engineering, RAAF, agreed to sponsor Task AIR 93/057 in February 1993.

Task objectives were agreed as follows:

"To conduct surveillance testing on Rocket Motors 3" No. 1 Mk 4 currently used by ARDU, to advise on their suitability for continued use. This testing to include:

a. propellant testing (NG migration and propellant stability)

b. static firings, and

c. igniter firings."

This report describes the tests which were conducted and discusses their results.

2. *Background*

The earliest records available to EOD relating to the Rocket Motor 3" No. 1 Mk 4 consist of a set of blueprints for the motor, originating in the UK in 1941. In the ensuing years, it is estimated that in excess of 80,000 3" Motors were manufactured under license in Australia at Maribyrnong. The steel motor case is

55.2" long and 3.25" diameter, with a filled weight of 28.8 lb. A number of variants of the motor were designed, for land, naval and air service: each consisted of the same basic motor tube and charge, with for example alternate fin attachments or lengths of igniter lead to suit the different applications.

Two 'batches' of these 3" Motors are stored at Woomera, one manufactured in 1957 and the other in 1966. Motors that misfired were from the 1957 batch: ARDU has subsequently marked this batch for destruction. Twenty four motors manufactured in 1966 were sampled from Woomera and allocated to this task, to assess the suitability of this batch for use.

An internal publication, PDS 215 - Operating Instruction C15, "Disassembly, propellant sampling and static firing of 3" Rocket Motors, No. 1, Mk 4", was prepared by EOD to describe the procedures used during this task.

3. *Propellant Testing*

The propellant charge in the 3" Rocket Motor No. 1 Mk 4 consists of a single stick of cordite of cruciform cross-section, weighing approximately 11 lb. The characters SU/K/X/11 are stencilled on the exterior of the motor tube. These denote that the charge is of solventless cordite (SU), with an additive of potassium cryolite (K) to minimise the flash of burning. The 'X' indicates the cruciform cross section and the '11' denotes that the nominal weight of the charge is 11 lb.

Two rocket motors were selected at random for propellant and inhibitor sampling. Charges were marked Nos 2462E and 4422E. Both charges appeared to be in excellent condition, as shown in Figures 1 and 2, however there was some loose igniter composition around the head end of both charges. There was no odour of nitroglycerine when the nozzle seal was first ruptured, nor was there evidence of any nitroglycerine on the interior of the case as would be indicated by a yellowish deposit.

Samples of propellant from these two motors were analysed for nitroglycerine, potassium and ethyl centralite (stabiliser) content. The laboratory report from these tests is contained at Annex A. This examination found that the level of nitroglycerine in the propellant was within specification, and that the potassium and ethyl centralite levels were only slightly above and below specification respectively. The amount of ethyl centralite present indicates that the propellant still has high stability, and retesting is recommended in five years.

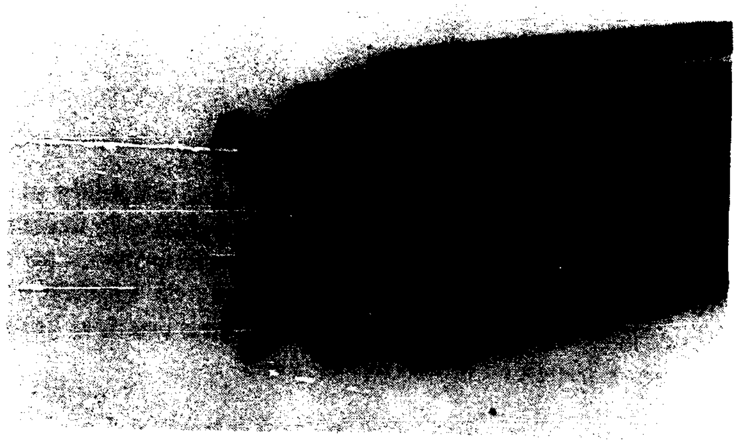

Figure 1: *Nozzle End of Charge 2462E*

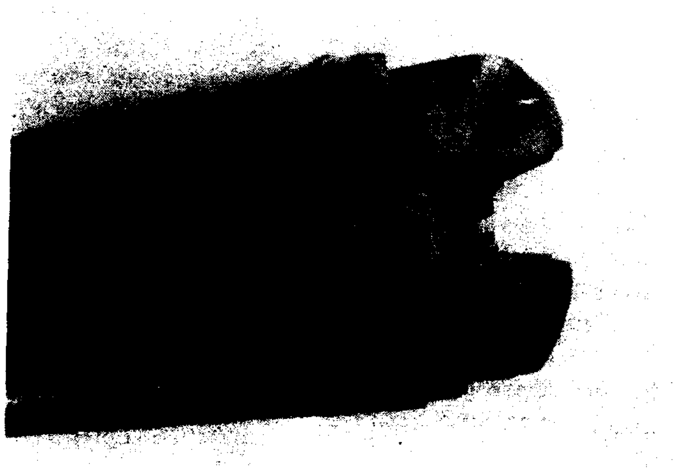

Figure 2: *Head End of Charge 2462E*

Samples of inhibitor strips (Plastic 'Q') from Charge No 2462E were analysed for migration of nitroglycerine from the propellant. The results showed 56.1% nitroglycerine and 3.5% ethyl centralite in the Plastic 'Q' strips tested. While the percentage of nitroglycerine in the inhibitor is extremely high, it is only of concern if it leads to gross changes in the ballistic performance of the charge, namely increased pressure and thrust from the increased effective burning surface area (since the inhibitor contains so much nitroglycerine, it essentially behaves as a low performance propellant). Results from rocket motor static firings are discussed in the next section.

4. *Static Firings*

Ten motors were selected for static firing to assess the reliability of ignition as well as the ballistic performance of the motors. It was desirable to establish some confidence that the motor pressures were not approaching the motor case failure pressure, which would lead to catastrophic failures on ignition and launch. Firings were conducted at -20°C, +20°C and +60°C, the nominal limits of motor firing temperature as stencilled on the motor tubes.

In order to measure chamber pressure, the motor head end configuration was modified: this involved removing the Head Obturator, providing 'O'-ring seals between the motors' Shell Ring and the Blanking Plug or Adaptor supplied, and drilling a pressure tap in the Adaptor.

A summary of the ballistic parameters from these ten static firings is given in Table 1.

No specifications for ballistic parameters could be located for these rocket motors. However, also included in Table 1 are some results for 3" Rocket Motors, No. 1, Mk 5, from static firings reported in Reference 1. This reference compares the ballistic parameters of motors from 'current' (that is, 1964) production from Albion Explosives Factory and Explosives Factory Maribrynong. The difference between Mk 4 and Mk 5 motors is unknown however both contain an SU/K/X/11 charge, and from details of No. 1 Mk 3's and Mk 4's, and No. 3 Mk 1's, it is believed that the 3" Rocket Motor internal design is unchanged from series to series as stated previously. Hence, an approximate comparison of static firing data from these firings can be made. An exact comparison is not possible since the definitions of the ballistic parameters quoted in Reference 1 are not given, so there may be some minor differences in how, for example, total burning time or total impulse are defined.

Notwithstanding the above considerations, data in Table 1 shows that the ignition delay times were all an order of magnitude larger than those expected from Reference 1.

Table 1: Ballistic Parameters from First Series of Static Firings

Motor/Firing Temperature (°C)	Ignition Delay (s)	Total Burning Time (s)	Maximum Pressure (psi)	Maximum Thrust (lbf)	Total Impulse (lb.s)
1 / 20	0.63	1.74	1245	2596	2158
2 / 20	0.47	1.79	1296	2714	2140
3 / 20	0.51	1.75	1281	2830	[illegible]
4 / 20	0.84	1.74	1308	2779	2153
5 / -20	0.80	2.31	1108	2343	2042
6 / -20	0.72	2.34	1115	2350	2029
7 / -20	0.94	2.31	1103	2323	2023
8 / 60	0.45	1.19	1725	3601	2276
9 / 60	0.11	1.21	1379	3055	2209
10 / 60	0.69	1.18	1598	3382	2216
A / -20	0.035 - 0.050	2.10 - 2.16	810 - 900	1720 - 1950	2040 - 2130
A / 60	0.030 - 0.035	0.94 - 1.05	1610 - 1680	3490 - 3880	1985 - 2140
B / 60	N/A	1.07	1550	N/A	N/A
C / -20	0.024 - 0.053	2.10 - 2.26	710 - 990	1380 - 2060	1950 - 2180
C / 60	0.024 - 0.040	0.95 - 1.28	1410 - 1870	2980 - 4040	1930 - 2290

Notes:

A. From Table 3 of Reference 1, PWC results - range over five firings.
B. From Table 5 (a) of Reference 1.
C. From Table 5 (b) of Reference 1 - range over unknown number of firings.

The remaining ballistic parameters (total burning time, maximum pressure and thrust values, and total impulse) were all generally in agreement with the results cited in Reference 1:

a. Total burning times at the low temperature limit were higher than the cited firings, indicating a lower burning rate for the current motors. Maximum values of thrust and pressure however were significantly higher at this temperature, suggesting an increased initial burning surface area. Even with the increased burning time and maximum thrust observed, total impulse values agreed very well with the Reference 1 firings, suggesting that the thrust (and pressure) versus time plots must decay faster with the current motors. These trends are consistent with the reported presence of nitroglycerine in the inhibitor 'Q' strips. The relatively large surface area of the propellant as compared to that of the inhibitor 'Q' strips implies that even if the inhibitor burns as a low performance propellant, it contributes little to the measured pressure (and thrust).

b. At the high temperature limit, total burning times were at the top end of the range quoted in Reference 1, while maximum pressures and thrusts, and total impulse all agreed well between firings. The fact that the ballistic parameters were in closer agreement with Reference 1 values at the higher temperatures may be a result of the propellant burn rate temperature sensitivity.

c. Taken together, results over the total temperature range suggest only a small amount of ballistic drift. Maximum operating pressures are presumably well within the limit for motor case failure, as they are all less than the maximum value recorded in Reference 1 (1870 psi at +60°C).

An incident occurred during the third rocket motor firing (firing temperature +20°C): the propellant ignited and the pressure increased as normal, however initially the motor was not venting and no thrust was recorded. It is believed that the Closing Disc did not release on ignition, blocking the nozzle. When the chamber pressure reached approximately 1200 psi, the Closing Disc released and the subsequent motor thrust stepped to more than 10,000 lb, causing a permanent set in the 5000 lb load cell used to measure thrust. Within 18 msec, the thrust had settled back to normal levels. The maximum thrust value given in Table 1 for this firing was taken after this initial 18 msec. The pressure results were normal throughout, and the remainder of the firing was uneventful.

Video records showed no other anomalies during the static firings. Post test inspection revealed that the 'O'-ring seals at the motor head end had performed satisfactorily during each firing, with no evidence of gas flow beyond the seals. After each of the three 'hot' firings, a small quantity of propellant in strips and flakes was recovered more than 20 m behind the motors. The total mass of the recovered propellant was 0.48 kg. This phenomenon is evidently to be expected, as discussed in Reference 1:

"At +140°F, and except for one round (ACB) which judged from the firing record did not break up at all, all rounds showed similar amounts of break up of the propellant charge towards the end of burning. The amounts observed were normal, as judged by reference to previous observations (Ref. 8)."[1]

Figure 3 shows a 'typical' thrust versus time curve for the firings at -20°C and +20°C, while Figure 4 is indicative of the results of all of the firings at +60°C. Pressure curves for all firings followed the thrust curves closely, reflected in the nearly constant thrust/pressure ratio. Note that in Figure 4, close to the end of firing, there is a short duration rise in thrust (and pressure). It is suggested that this is due to the strips and flakes of propellant which are expelled in the hot firings: these momentarily restrict the nozzle throat as they are being ejected and lead to the increase in pressure and thrust.

5. *Igniter Firings*

A total of fourteen motors were disassembled for propellant sampling and static firing as described above. In each case, the igniter was examined in situ and found to be split, either longitudinally, circumferentially around the end of the igniter away from the firing leads, or a combination of both.

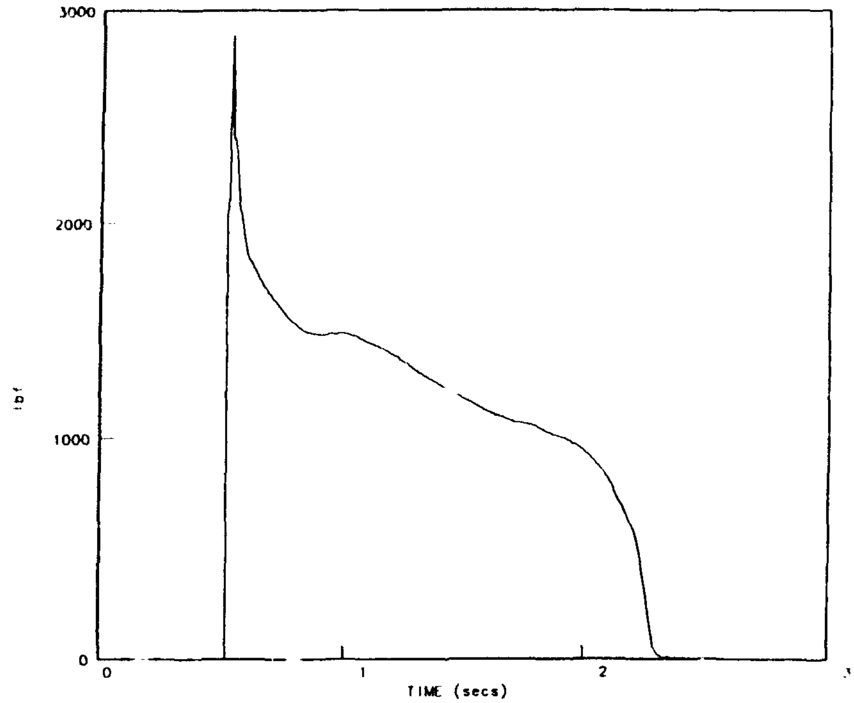

Figure 3: *Thrust versus time plot: Motor Number 3 fired at +20°C*

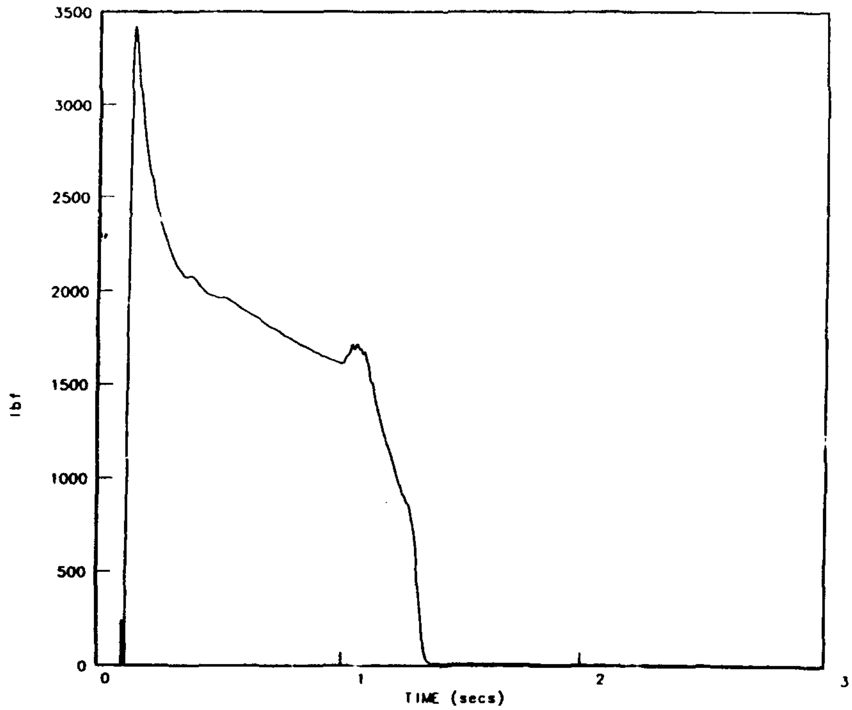

Figure 4: *Thrust versus time plot: Motor Number 9 fired at +60°C*

The igniter comprises a shellacked paper tube containing an F53 electric fuze (matchhead) and 16 grams of igniter composition SR371C. SR371C comprises 42% magnesium, 8% acaroid resin and 50% potassium nitrate, and if exposed to moisture (through, for example, inadequate protective coating being applied to the paper tube, or it cracking with age) the magnesium will oxidise.

The four motors which were not allocated for static firing were further disassembled and the igniters removed from each. Figure 5 shows a typical igniter, again split longitudinally. On each of these motors, there was evidence of varying quantities of igniter composition deposited around the head end of the charge, as shown in Figure 6. Two of these four igniters were substantially damaged, to the extent that the paper tube had lost any strength, and approximately 75% of the igniter composition was deposited around the head end of the charge.

The poor physical and chemical state of the igniters may account for the excessive ignition delays reported during rocket motor static firings. The fact that the igniters were not intact, together with the oxidation of some of the igniter composition, may have contributed towards the reduced igniter performance noted. Given the results of the motor static firings, independent igniter firings were not conducted.

6. *Discussion*

Based on the examinations conducted, it was considered that the 3" Rocket Motors were generally in very good condition, with only the long ignition delays potentially causing concern. The poor physical state of the igniters on disassembly did not provide confidence that the igniters would perform satisfactorily for the next five years. Consequently, after discussions with ARDU personnel in November 1993, EOD agreed to provide and fit replacement igniters into 50 off 3" Rocket Motors required in the first instance by ARDU.

For simplicity, ease of manufacture and refit, the replacement igniter selected was a silk bag containing an F53 matchhead and 12 g of igniter composition SR44 (25 % Boron: 75 % Potassium Nitrate). Three igniters were assembled into motors from the original allocation of twenty four, and these motors were statically fired at +20°C in March 1994. The ballistic parameters from these firings are given in Table 2.

Table 2: Ballistic Parameters from Second Series of Static Firings

Ignition Delay (s)	Total Burning Time (s)	Maximum Pressure (psi)	Maximum Thrust (lbf)	Total Impulse (lb.s)
0.010	1.69	1286	2634	2220
0.014	1.61	1200	2480	2161
0.014	1.70	1044	2265	2173

Comparing these results with Table 1 it is seen that the ignition delay times have been dramatically reduced with the new silk bag igniters, to better than reported in Reference 1. All other ballistic parameters are comparable to those given in Table 1 for firings at +20°C, and as expected the thrust and pressure versus time curves follow the same profile as the original set of static firings, an example of which is given in Figure 3.

Figure 5: *Igniter showing longitudinal split*

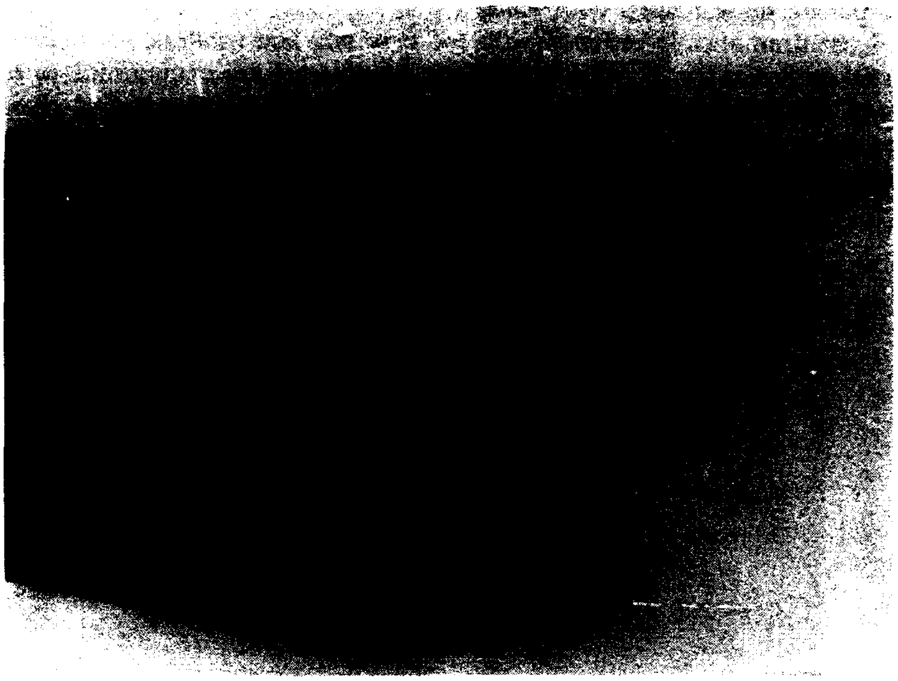

Figure 6: Head End of Charge showing deposits of Igniter Composition

7. Conclusions

The objectives of this task have been completed, and the condition of the subject Rocket Motors 3" No. 1 Mk 4 has been established by examining the propellant charge, as well as through the conduct of two series of static firings.

The charge has been examined and the propellant stabiliser levels are more than adequate. Although there is evidence of substantial migration of nitroglycerine from the propellant into the inhibitor, the motors performed very well during rocket motor static firings, with the exception of the original ignition delay times which were an order of magnitude larger than expected. Replacement igniters were fitted to three motors and statically fired, and the resulting ignition delay times were satisfactory.

Replacement igniters have been produced and fitted to 50 off 3" Rocket Motors No.1 Mk 4, as requested by ARDU. These motors should remain acceptable for use for at least five years: it is recommended that they be retested for further life extension if required in 1999.

8. Reference

1. J. T. McHenry and W. H. Clarke, "The Preparation of SUK Rocket Propellant using Nitrocellulose from Mechanically Nitrated Alpha Cellulose Board - Climatic Storage Trials of Propellant", Commonwealth of Australia Department of Supply Report No. EC 1475, 1964.

DSTO SAL BURY	MATERIALS RESEARCH LABORATORY EXPLOSIVES ORDNANCE DIVISION	LABORATORY REPORT NO. EOD93/57
SAMPLE Propellant Type SUK ex RAAF 3 in. rocket motor		LAB REGISTER NO. S059
SUBMITTED BY L. Barrington	WA M20415 Task AIR93/057	

Analysis of the main propellant ingredients

	Found (%)	Specified (%) *
Nitroglycerine	42.4	40.4 - 42.5
Ethyl Centralite	8.3	8.7 - 9.3
Potassium (expressed as potassium cryolite)	2.7	2.0 - 2.5

* As specified at manufacture - from UK information (origin unknown) and Army Supply Manual Vol 4 Pam 4 Chap 2 (Table 2).

Comments: Nitroglycerine in spec. range,
Potassium cryolite slightly above spec. range,
Ethyl Centralite slightly below spec. range, as would be expected for a propellant of this age, but amount present indicates propellant still has high stability - recommend retesting in 5 years.

There was no evidence of free nitroglycerine on the surface of the propellant or surrounding areas when the propellant was sampled from the rocket motor.

Methods: Nitroglycerine and ethyl centralite according to DEF(AUST)5623 Method 210/92 (employs HPLC). Potassium determined according to DEF(AUST)5623 Method 305/83 (employs Atomic Absorption Spectroscopy).

ANALYST: A. TURNER

Signature RMKempson
Propellant Materials

Date 20 Aug 93.

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Announcement of this report is unlimited

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Static firing tests	Thrust	

ABSTRACT

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