[redacted]

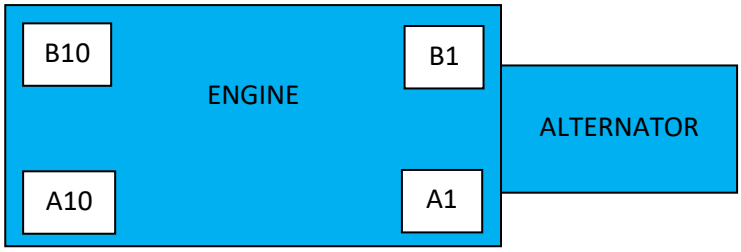
Borescope Inspection Report

Site: [redacted]
Engine ID: #1
Engine Model: MTU 20V4000 L64
Inspection date: 7 November 2023

[redacted]

Highlights

This is the first borescope inspection carried out on the #1 gas engine at [redacted] at 6,150 engine hours and 2,153 starts, and using [redacted]. The engine has been suffering with detonation, leading to ignition timing being retarded and the output power reduced to allow continued operation. At the time of writing the author is not aware of which cylinders are affected.



A photographic record of each liner was made at the 12 and 6 o'clock positions at the top, middle and bottom of each liner, as well as records taken from the flame deck, piston crown, and valves (when visible). A number of other specific comments have also been made where appropriate. All the photos taken during the inspection are available for a limited time via a [redacted] link.

The borescope inspection shows the engine to be as expected for the age and power response application. Honing marks are clear throughout the engine though there is slightly more lacquer at the top of some liners than ideal, but this is not a concern.

There is evidence across a number of cylinders of the engine being stored for a period of time, shown by witness marks on the liner surface, and some corrosion pitting in a couple of cylinders. These are unlikely to have any detriment to the engine or its longevity.

There is evidence of a pinkish tinge on some flame decks typically indicative of coolant contamination. However, there are no indicators of such contamination in the used oil analysis data.

Around half of the cylinders had significant amounts of oil on the liner, and the associated piston crowns were generally darkened from the edges, likely oil contamination. Generally, the flame decks were dry with no evidence of excessive oil contamination coming from the valve guides. This suggests that excessive amounts of oil are contaminating the combustion chamber through the piston rings, though it also has to be remembered, as highlighted in the report, that the heavier contamination was seen in the cylinders inspected after the engine had been barred over more.

This inspection and this report were completed as part of [redacted] program.

[redacted] Lubrisult would like to thank [redacted] and [redacted] for their assistance in completing this inspection. We appreciate the opportunity to be of service to [redacted]

Respectfully,

[redacted]

David Squirrell B.Eng (Hons), MBA, C.Eng, MIMechE, MIPowerE
Consultant Engineer
Lubrisult Limited

[redacted]

Specific Comments

During the inspection a number of specific observations were made. In A9 black deposits were noted, as shown below. Similar deposits were also seen in B7.

In a number of cylinders evidence of a historic water marks were seen, possibly from the engine being stored for an extended period of time and water collected on the piston crown and between the piston ring and liner. Typical photos are shown below. These are shown for completeness and are unlikely to be associated with the engine derating issues.

In most instances the mark is just that.

In A1 at the 06:00 bottom location the mark is more unusual.

In B10 there is evidence of corrosion pitting, as shown below.

Cylinders A1 and B8, both at the 06:00 mid position, had unusual marks not seen elsewhere, again unlikely to be related to the derating issue.

In B9, at the 12:00 bottom position there is a fresh looking mark, possibly some debris has been trapped in the piston ring and has created this score during the barring, hence the non-linear nature of the score as the piston ring has rotated slightly.

A slight pink discolouroration was noted in some cylinders, A2, A5, and B9. This is usually associated with coolant contamination but there are no indicators in the used oil analysis data (up to and including the sample from 4 October 2023, 5843 hours).

The ash was generally light and even with the exception of B2, B3 and B9 which had patchy ash coverage and exposed areas of piston material.

Time constraints limited the number of valves that were inspected and only exhaust valves were seen. Those were similar in condition with light even coating of ash and the seats in good condition.

Excess oil was noted on a number of liners, some examples of which are shown below. The liners affected in a similar manner were

Barring Cycle	Oily Cylinders
Virtually none	A9
1st	A1, A10
2nd	A3, A8
3rd	A5, B2, B4, B7
4th	A4, A7, B2, B9

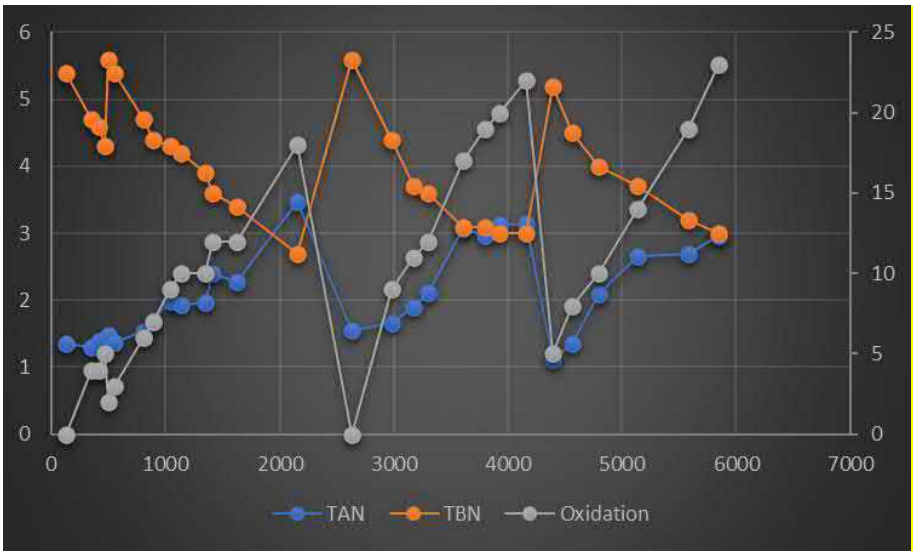
Excess oil was also noted on a number of piston crowns.

It is appreciated that some oil contamination of the liner and piston crown can occur when the engine is barred over to allow the full swept liner area to be inspected. The above photo had almost no engine movement prior to be taken. The order of inspection is shown on page 49.

Used Oil Analysis

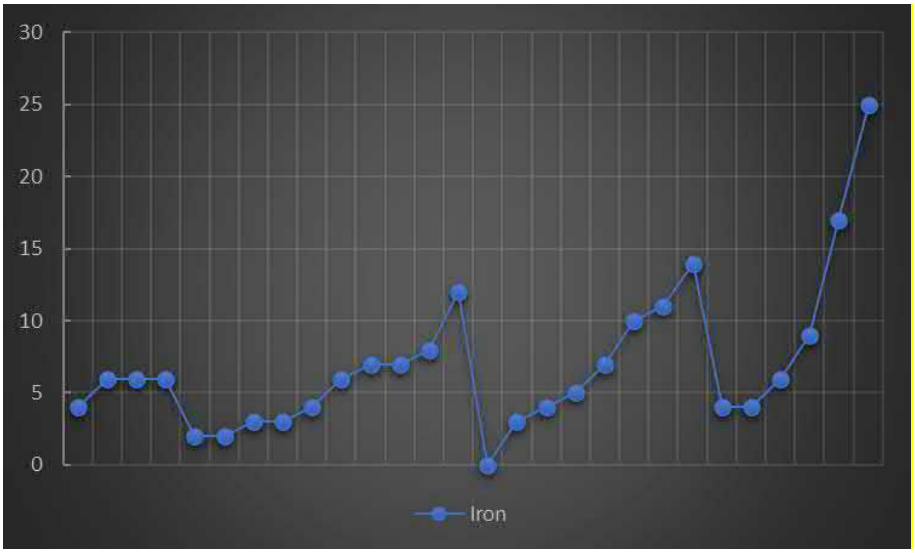
The used oil analysis (UOA) data has been reviewed from new to 4 October 2023 (5,843 hours). Three corrections were made to the unit life and oil life data.

The first oil drain was completed at 479 hours which removed the initial copper levels expected with a new oil cooler. The second oil charge achieved 2,141 hours with only TAN and TBN showing caution. The third change was initiated at 1,698 hours by an alert for oxidation at 22, though TAN and TBN had hardly changed from the previous result and were normal. The last available sample is caution for TAN and TBN as well as alert for oxidation. It should be noted that when this oil was changed, around late March 2023, the oxidation figure was 5 at 78 hours oil life, suggesting that a significant amount of oil from the previous charge remained. However, the TAN and TBN data do not reflect this, they are very good. Thus, it is suspected that the oxidation figures may be unrelaiable and should be clarified with the lab. An updated reference sample is likely to be needed.



[redacted]

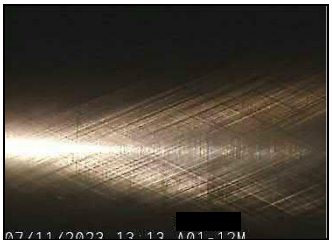
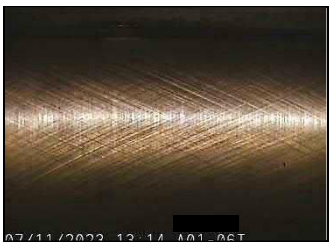
Wear metals are all consistently very low with the exception of iron which gradually increases over the life of the oil charge, as normal wear occurs to the liner. The last two samples show an increase in the rate of wear possibly associated with more frequent stop / starts on the engine, which is inferred from the UOA data in the sample dates and the recorded number of engine starts. Most recently the number appears to have increased from around 2.6 to 3.9 per day. There is no evidence of piston ring wear as chromium is consistently not seen.



There are no other notable comments to make about the other data.

[redacted]

Cylinder A1

	Inspection 1	Inspection 2	Inspection 3	Inspection 4
12:00 TOP				
12:00 MIDDLE				
12:00 BOTTOM				
06:00 TOP				
06:00 MIDDLE				
06:00 BOTTOM				

Cylinder A1

	Inspection 1	Inspection 2	Inspection 3	Inspection 4
PISTON BOWL				
PISTON BOWL				
FLAME DECK				
FLAME DECK				
INLET VALVE	X			
EXHAUST VALVE	X			

Cylinder A2

	Inspection 1	Inspection 2	Inspection 3	Inspection 4
12:00 TOP				
12:00 MIDDLE				
12:00 BOTTOM				
06:00 TOP				
06:00 MIDDLE				
06:00 BOTTOM				

[redacted]

Cylinder A2

	Inspection 1	Inspection 2	Inspection 3	Inspection 4
PISTON BOWL				
PISTON BOWL				
FLAME DECK				
FLAME DECK				
INLET VALVE	X			
EXHAUST VALVE	X			

Cylinder A3

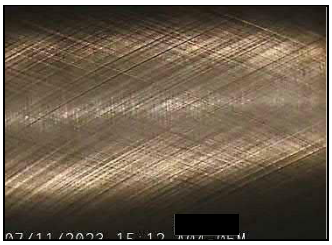
	Inspection 1	Inspection 2	Inspection 3	Inspection 4
12:00 TOP				
12:00 MIDDLE				
12:00 BOTTOM				
06:00 TOP				
06:00 MIDDLE				
06:00 BOTTOM				

[redacted]

Cylinder A3

	Inspection 1	Inspection 2	Inspection 3	Inspection 4
PISTON BOWL				
PISTON BOWL				
FLAME DECK				
FLAME DECK				
INLET VALVE	X			
EXHAUST VALVE	X			

Cylinder A4

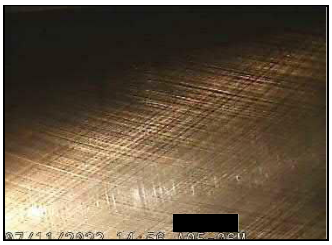
	Inspection 1	Inspection 2	Inspection 3	Inspection 4
12:00 TOP				
12:00 MIDDLE				
12:00 BOTTOM				
06:00 TOP				
06:00 MIDDLE				
06:00 BOTTOM				

[redacted]

Cylinder A4

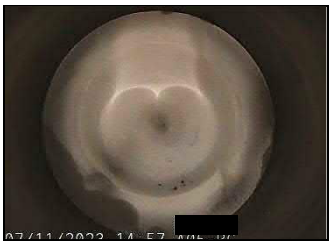
	Inspection 1	Inspection 2	Inspection 3	Inspection 4
PISTON BOWL				
PISTON BOWL				
FLAME DECK	X			
FLAME DECK	X			
INLET VALVE	X			
EXHAUST VALVE	X			

Cylinder A5

	Inspection 1	Inspection 2	Inspection 3	Inspection 4
12:00 TOP				
12:00 MIDDLE				
12:00 BOTTOM				
06:00 TOP				
06:00 MIDDLE				
06:00 BOTTOM				

[redacted]

Cylinder A5

	Inspection 1	Inspection 2	Inspection 3	Inspection 4
PISTON BOWL				
PISTON BOWL				
FLAME DECK				
FLAME DECK				
INLET VALVE	X			
EXHAUST VALVE	X			

Cylinder A6

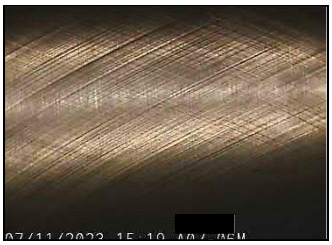
	Inspection 1	Inspection 2	Inspection 3	Inspection 4
12:00 TOP				
12:00 MIDDLE				
12:00 BOTTOM				
06:00 TOP				
06:00 MIDDLE				
06:00 BOTTOM				

[redacted]

Cylinder A6

	Inspection 1	Inspection 2	Inspection 3	Inspection 4
PISTON BOWL				
PISTON BOWL				
FLAME DECK	X			
FLAME DECK	X			
INLET VALVE	X			
EXHAUST VALVE	X			

Cylinder A7

	Inspection 1	Inspection 2	Inspection 3	Inspection 4
12:00 TOP				
12:00 MIDDLE				
12:00 BOTTOM				
06:00 TOP				
06:00 MIDDLE				
06:00 BOTTOM				

[redacted]

Cylinder A7

	Inspection 1	Inspection 2	Inspection 3	Inspection 4
PISTON BOWL				
PISTON BOWL				
FLAME DECK				
FLAME DECK				
INLET VALVE	X			
EXHAUST VALVE	X			

Cylinder A8

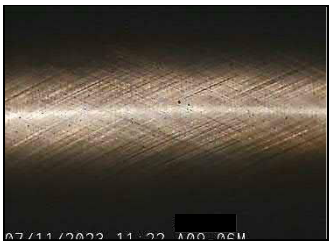
	Inspection 1	Inspection 2	Inspection 3	Inspection 4
12:00 TOP				
12:00 MIDDLE				
12:00 BOTTOM				
06:00 TOP				
06:00 MIDDLE				
06:00 BOTTOM				

[redacted]

Cylinder A8

	Inspection 1	Inspection 2	Inspection 3	Inspection 4
PISTON BOWL				
PISTON BOWL				
FLAME DECK				
FLAME DECK				
INLET VALVE	X			
EXHAUST VALVE	X			

Cylinder A9

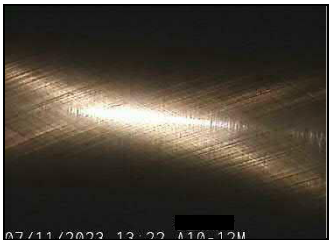
	Inspection 1	Inspection 2	Inspection 3	Inspection 4
12:00 TOP				
12:00 MIDDLE				
12:00 BOTTOM				
06:00 TOP				
06:00 MIDDLE				
06:00 BOTTOM				

[redacted]

Cylinder A9

	Inspection 1	Inspection 2	Inspection 3	Inspection 4
PISTON BOWL				
PISTON BOWL				
FLAME DECK				
FLAME DECK				
INLET VALVE	X			
EXHAUST VALVE	X			

Cylinder A10

	Inspection 1	Inspection 2	Inspection 3	Inspection 4
12:00 TOP				
12:00 MIDDLE				
12:00 BOTTOM				
06:00 TOP				
06:00 MIDDLE				
06:00 BOTTOM				

[redacted]

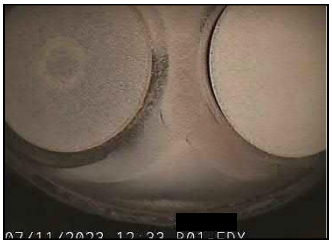
Cylinder A10

	Inspection 1	Inspection 2	Inspection 3	Inspection 4
PISTON BOWL				
PISTON BOWL				
FLAME DECK				
FLAME DECK				
INLET VALVE	X			
EXHAUST VALVE	X			

Cylinder B1

	Inspection 1	Inspection 2	Inspection 3	Inspection 4
12:00 TOP				
12:00 MIDDLE				
12:00 BOTTOM				
06:00 TOP				
06:00 MIDDLE				
06:00 BOTTOM				

Cylinder B1

	Inspection 1	Inspection 2	Inspection 3	Inspection 4
PISTON BOWL				
PISTON BOWL				
FLAME DECK				
FLAME DECK				
INLET VALVE	X			
EXHAUST VALVE	X			

Cylinder B2

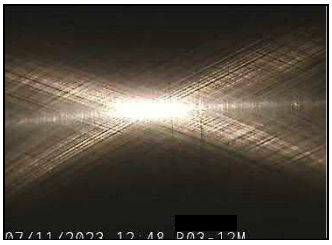
	Inspection 1	Inspection 2	Inspection 3	Inspection 4
12:00 TOP				
12:00 MIDDLE				
12:00 BOTTOM				
06:00 TOP				
06:00 MIDDLE				
06:00 BOTTOM				

[redacted]

Cylinder B2

	Inspection 1	Inspection 2	Inspection 3	Inspection 4
PISTON BOWL				
PISTON BOWL				
FLAME DECK				
FLAME DECK				
INLET VALVE	X			
EXHAUST VALVE	X			

Cylinder B3

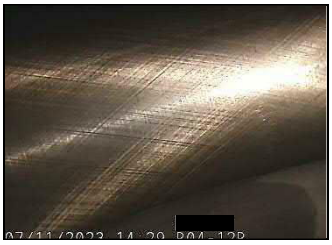
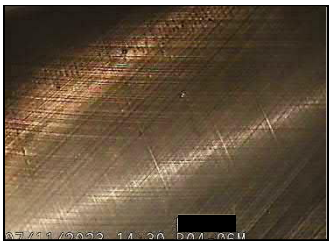
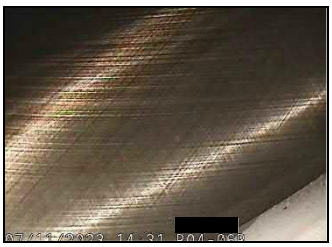
	Inspection 1	Inspection 2	Inspection 3	Inspection 4
12:00 TOP				
12:00 MIDDLE				
12:00 BOTTOM				
06:00 TOP				
06:00 MIDDLE				
06:00 BOTTOM				

Cylinder B3

	Inspection 1	Inspection 2	Inspection 3	Inspection 4
PISTON BOWL				
PISTON BOWL				
FLAME DECK				
FLAME DECK				
INLET VALVE	X			
EXHAUST VALVE	X			

[redacted]

Cylinder B4

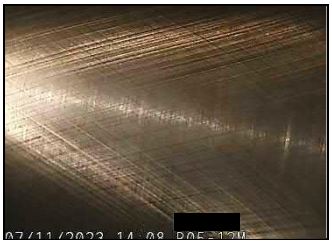
	Inspection 1	Inspection 2	Inspection 3	Inspection 4
12:00 TOP				
12:00 MIDDLE				
12:00 BOTTOM				
06:00 TOP				
06:00 MIDDLE				
06:00 BOTTOM				

[redacted]

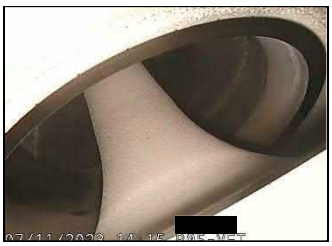
Cylinder B4

	Inspection 1	Inspection 2	Inspection 3	Inspection 4
PISTON BOWL				
PISTON BOWL				
FLAME DECK				
FLAME DECK				
INLET VALVE	X			
EXHAUST VALVE	X			

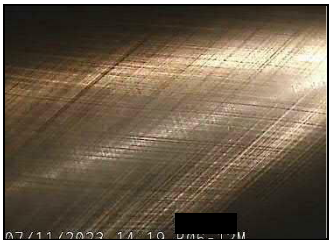
Cylinder B5

	Inspection 1	Inspection 2	Inspection 3	Inspection 4
12:00 TOP				
12:00 MIDDLE				
12:00 BOTTOM				
06:00 TOP				
06:00 MIDDLE				
06:00 BOTTOM				

Cylinder B5

	Inspection 1	Inspection 2	Inspection 3	Inspection 4
PISTON BOWL				
PISTON BOWL				
FLAME DECK				
FLAME DECK				
EXHAUST TOP				
EXHAUST BTM				

Cylinder B6

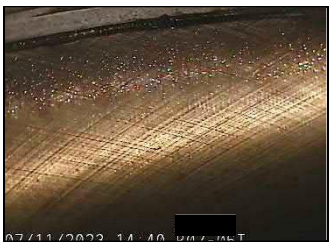
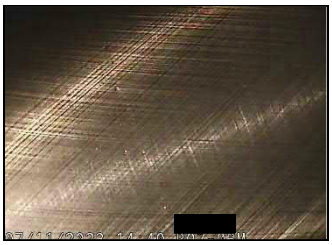
	Inspection 1	Inspection 2	Inspection 3	Inspection 4
12:00 TOP				
12:00 MIDDLE				
12:00 BOTTOM				
06:00 TOP				
06:00 MIDDLE				
06:00 BOTTOM				

[redacted]

Cylinder B6

	Inspection 1	Inspection 2	Inspection 3	Inspection 4
PISTON BOWL				
PISTON BOWL				
FLAME DECK				
FLAME DECK				
INLET VALVE	X			
EXHAUST VALVE	X			

Cylinder B7

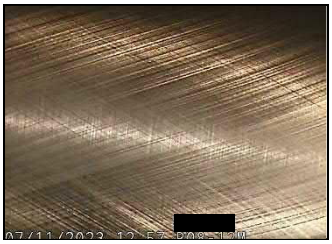
	Inspection 1	Inspection 2	Inspection 3	Inspection 4
12:00 TOP				
12:00 MIDDLE				
12:00 BOTTOM				
06:00 TOP				
06:00 MIDDLE				
06:00 BOTTOM				

[redacted]

Cylinder B7

	Inspection 1	Inspection 2	Inspection 3	Inspection 4
PISTON BOWL				
PISTON BOWL				
FLAME DECK				
FLAME DECK				
INLET VALVE	X			
EXHAUST VALVE	X			

Cylinder B8

	Inspection 1	Inspection 2	Inspection 3	Inspection 4
12:00 TOP				
12:00 MIDDLE				
12:00 BOTTOM				
06:00 TOP				
06:00 MIDDLE				
06:00 BOTTOM				

[redacted]

Cylinder B8

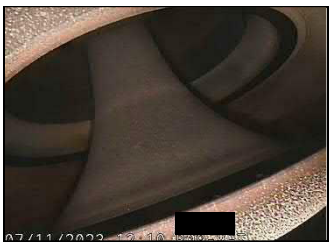
	Inspection 1	Inspection 2	Inspection 3	Inspection 4
PISTON BOWL				
PISTON BOWL				
FLAME DECK				
FLAME DECK				
INLET VALVE	X			
EXHAUST VALVE	X			

Cylinder B9

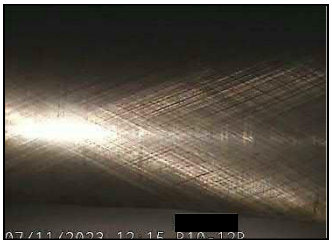
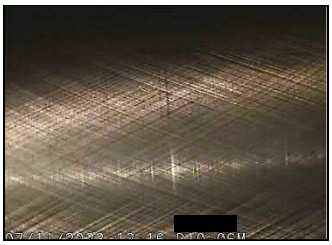
	Inspection 1	Inspection 2	Inspection 3	Inspection 4
12:00 TOP				
12:00 MIDDLE				
12:00 BOTTOM				
06:00 TOP				
06:00 MIDDLE				
06:00 BOTTOM				

[redacted]

Cylinder B9

	Inspection 1	Inspection 2	Inspection 3	Inspection 4
PISTON BOWL				
PISTON BOWL				
FLAME DECK				
FLAME DECK				
EXHAUST TOP				
EXHAUST BTM				

Cylinder B10

	Inspection 1	Inspection 2	Inspection 3	Inspection 4
12:00 TOP				
12:00 MIDDLE				
12:00 BOTTOM				
06:00 TOP				
06:00 MIDDLE				
06:00 BOTTOM				

[redacted]

Cylinder B10

	Inspection 1	Inspection 2	Inspection 3	Inspection 4
PISTON BOWL				
PISTON BOWL				
FLAME DECK				
FLAME DECK				
INLET VALVE	X			
EXHAUST VALVE	X			

Inspection Sequence

To minimize the barring of the engine cylinders were inspected in groups of four with the inspected cylinders at the bottom of their stroke. The inspection sequence was:

A9, A2, B1, B10

B3, B8, A1, A10

A8, A3, B5, B6

B4, B7, A5, A6

A4, A7, B2, B9

Thus, the first set of cylinders (A9 etc.) had virtually no movement when the photos were taken while the last set (A4 etc.) had the most engine movement.

Photograph Naming

The original photos, supplied separately to this report, are named as follows:

C03-XXX-NNN

The first three characters indicate the cylinder number, the next characters are the part of the engine:

06B	Bottom of the liner at the six o'clock position
06M	Middle of the liner at the six o'clock position
06T	Top of the liner at the six o'clock position
12B	Bottom of the liner at the twelve o'clock position
12M	Middle of the liner at the twelve o'clock position
12T	Top of the liner at the twelve o'clock position
FD	Flame deck
FDX	Flame deck close-up
PC	Piston crown
PCX	Piston crown close-up
VET	Exhaust valve top
VEB	Exhaust valve bottom
VIT	Inlet valve top
VIB	Inlet valve bottom

[redacted]

The last three digits are a unique number for each cylinder and represent the original order the photos were taken in that cylinder. A number may occasionally be missing if that photo was deleted, usually as it was taken erroneously, or if it was indistinguishable.

Naming Errors

Occasionally a picture may be labelled incorrectly, as shown below. The picture is annotated as 06T whereas it is obviously the bottom and the file name has been recorded correctly, A05-06B.

The file name should be correct and overrides the picture annotation.