AUTHOR: JOHN BRISTOW

Development of an advanced environmentally friendly turbine oil

Deluxe Materials founders

John Bristow, owner of Deluxe Materials, has had a career that embraces both adhesives and also lubricants. An interest in chemistry of materials led John to gain degrees in Chemistry at Exeter University and then in engineering at Cranfield Institute of Technology, where he specialised in Tribology, the science of lubrication including the study of synthetic lubricants for gas turbines.
Shortly after leaving Cranfield in 1973, John's first job moved him into the application of epoxy resin composites for military use in submarines and deep water submersibles. At the same time, he and his wife, Vivienne, set up Deluxe Materials.
In 1975 John joined a major international oil company designing synthetic lubricants for all types of small engines and worked closely with many worldwide engine manufacturers. His work addressed not only growing environmental concerns, but set new technical standards in the industry which are still valid today.
John and Vivienne have today created over 100, often unique, model hobby products designed with safety in mind, to solve modelling tasks and to enhance modellers' enjoyment of their hobby. **www.deluxematerials.com**

Introduction

The story starts when I was in the offices of Ripmax a few years back and Colin Straus walked into the office. We just launched Power Model 2-TS, our synthetic two stroke oil which offers unique heat protection, and Colin asked "Do you think you could make us a model gas turbine lubricant; our customers need one, and we need to offer something that does not include Organophosphates, which are known to be dangerous to human health".
Well, I was aware Colin knew his stuff, so I started to think in depth about this problem. As soon as I had a time slot in our development agenda I thought I should do some investigation and see what we could do for the industry. The concept of an environmentally friendly oil turbine oil matched the philosophy of our company perfectly, so I was very keen to tackle what seemed a very worthwhile project. A look at the market situation told me the use of model turbines was becoming more and more popular and it seemed to be a growing market worldwide. Personally I know of more than 15 manufacturers of these lovely engines around the world.
Model turbines are of course lubricated with fuel oil mix, which is quite different to full size gas turbine engines, these having a pumped oil circuity, often with gearbox reduction drives.

1 - Oils commonly used until now

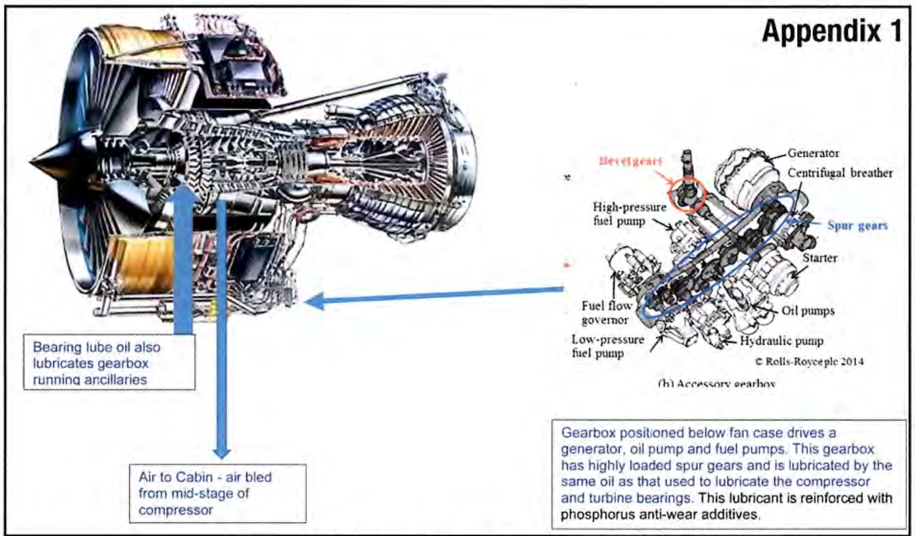
Jet modellers had been using one of 3 choices of oil **(Fig 1)**.
1. Full size gas turbine lubricants made by the larger oil companies BP, Shell and Mobil etc. These had good thermostability and were also widely available worldwide, but of course were not designed to be burnt.
2. Two stroke oils as in theory they were meant to be burnt, but they are not designed for extreme high temperatures.
3. Oil marketed by model turbine makers.

2 - The case for a new, safer oil

When we consulted modellers and turbine manufacturers about their usage of these existing oil options, there were concerns about gaseous emissions and the smell from the oil (and kerosene) that they were burning; there was also awareness of the toxic gases caused by the burning of these additives, and the possible harmful effect to human health of the emissions from these model engines. The EU in fact had investigated the matter following health complaints by aircraft crew related to the

Fig. 1

Appendix 1



How contaminated air might reach the cabin

Fig 2 Phosphorus content of model aviation oils/ ppm

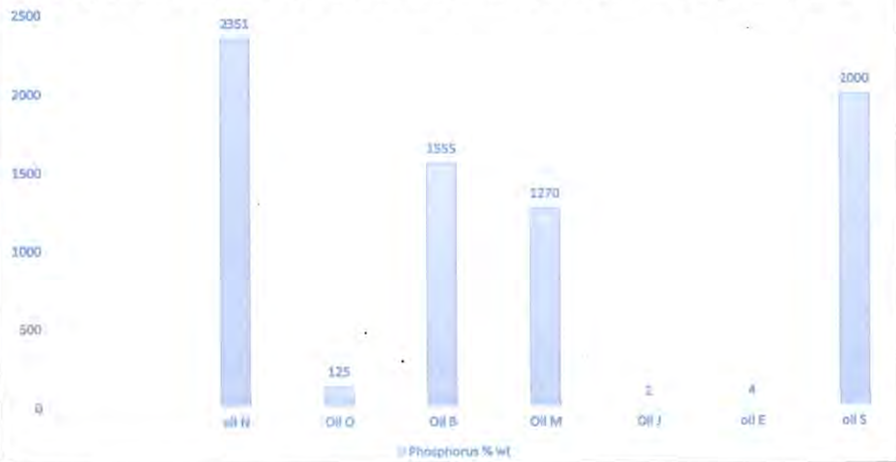


Fig 3 - Simple comparison of common lubricants

	Mil spec Turbine oil	2 stroke oil	Ideal lubricant concept
Base oil			
Base oil Viscosity	Low	High	Low
Base oil volatility	Low	low	Low
Additive			
Anti oxidant	Yes important	No	Yes important
Antiwear	Yes (gear lubrication)	No	No
Detergent cleaning	No	Yes important	
Defoaming , Metal stabilisers	Yes	Non	

Fig 4 Ash generating tendency
% weight of oil that creates ash

inhalation of cabin air vapours from the turbine oil (hydraulic oils) used in jet engines. Gas turbine oils are in fact hydraulic oils that are required to lubricate a gearbox as well as shaft bearings; a schematic is shown in **appendix 1**.

Organophosphorus was linked to this issue, and it was noted in a survey of the military specs (MIL-L-23699E) that the amount of phosphorus additive used in these oils is restricted.

We analysed many of the turbine oils on the market, which included many full-size gas turbine oils. The phosphorus content is shown in **Fig 2** - as you can see there are levels of phosphorus in many oils currently in use.

In **Fig 3** we compare the types of additives and base oils used in a modern military spec gas turbine with a 2 stroke oil and the concept of the oil we planned to develop. Today's military spec Turbine Oil will be fully synthetic, have low viscosity and relatively low volatility to cope with the heat inside the turbine. It will also have a wide range of other additives which stabilise the oil during heat soak, stop foaming and reduce internal corrosion, but most importantly phosphorus based anti-wear additives to lubricate reduction gear boxes. A short history of gas turbine oils is appended at the end of this article **(Appendix 2)**.

In contrast two stroke oils will have a higher viscosity SAE 40 to cushion pistons and seal piston rings, but no antioxidants, as these additives pass straight through the combustion chamber into the exhaust. The two-stroke engine run runs relatively cooler than a gas or model turbine. What it does have though are metallic based detergents to keep the piston and piston ring groove clean and free thus maintaining compression for easy starting. These additives are normally metal based additives which when burnt form ash (metal oxides with melting point above >2000C) in the combustion chamber **(Fig 4)**; if used for prolonged periods the ash would block the air passages in the turbine combustion chamber, or worse still bond to the turbine blades. Anti-wear additives are not used since there are no gears in the 2-stroke engine compartment. As an aside the ash content of passenger car and diesel oils shown in **Fig 4** are also much higher than 2 stroke oils and are thus even less suitable.

As neither of these types of oils are ideal for model turbines, some turbine makers market their own oils, but nobody is making one that is environmentally friendly.

3 - Key consumer needs

From discussions with model turbine makers and Jet modellers we identified the fol-

lowing key consumer needs:
- A 1 litre pack so would mix readily with 20 litres of kerosene (5% mix)
- High temperature ceramic bearing lubrication
- Clean combustion from the oil
- A distinctive dyed colour so that modellers would be able to see if oil had been added to their kerosene
- A stable oil mixture even at low temperature and measured over time
- To be suitable for all types of turbine running on kerosene or diesel

We added:
- Cleaner and safer air quality/emissions

Fig 5 Viscosity and high temperature volatility of oils-Mineral & Synthetic oils compared

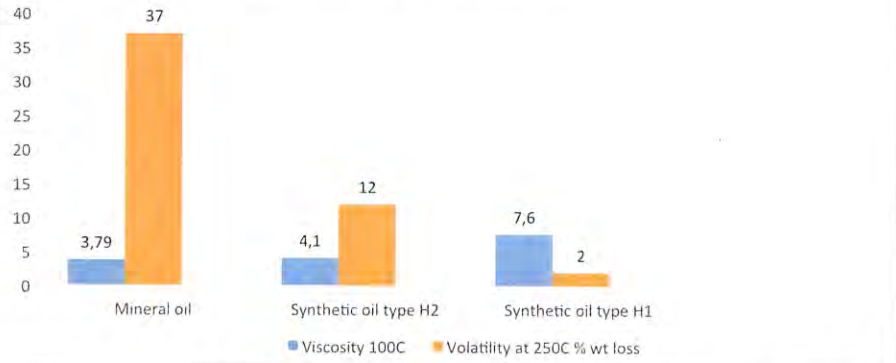


Fig 6 Viscometry of Jet engine oils Formulation P0 compared to others

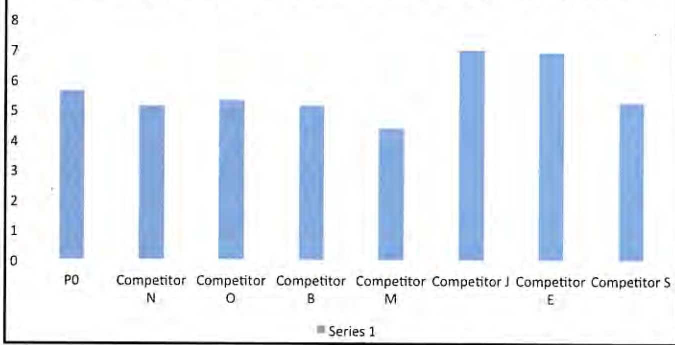
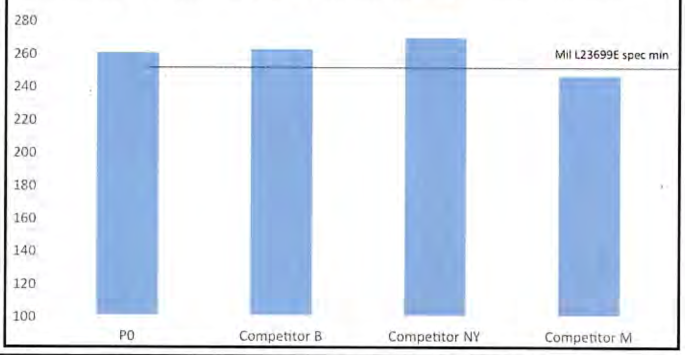


Fig 7 Flash point of Turbine oils
Candidate P0 compared to conventional synthetic turbine oils



- Affordability and good availability through hobby dealers
- Safety and ease of handling
- A non-hazardous and non-flammable formula for easy shipping around the world.

There have also been reports of electrostatic interference to radio control equipment but discussion of that will come later.

4 - Technical targets

The model turbine oil which we wanted to design needed
- A clean burning aromatic free base oil for low emissions
- Low volatility - important to stop evaporation and ensure lubrication
- Good resistance to oil thickening caused by high temperature (~300C)
- Enables easy cold starting.
- An ashless formulation to reduce combustion chamber deposits.

It certainly doesn't need phosphorus antiwear additive technology, metallic detergent or metal stabilisers.

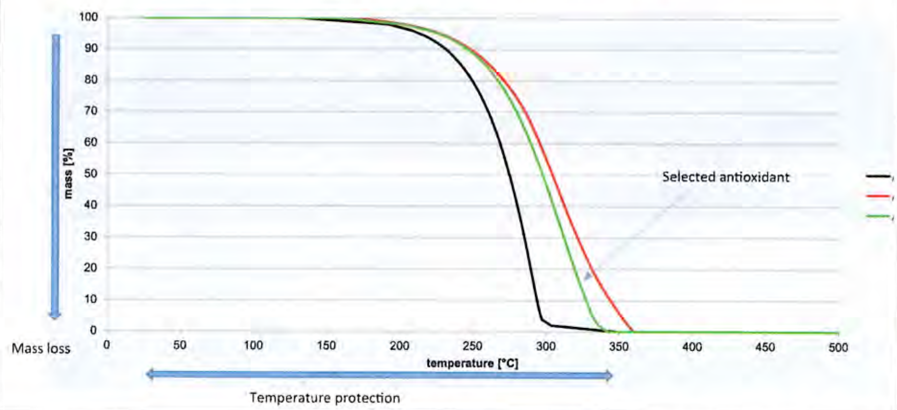
5 - Formulation concept and physical properties

We wanted a purpose designed lubricant for model turbines. The oil is formulated from a carefully selected base oil fortified with the right additive technology, both addressing the need for safer environmental performance.

The formulation approach was separated into 3 stages:

1. Design of the base oil and additive system
2. Screening formulations for thermal performance (volatility/ deposits)
3. Turbine testing

Fig 8 Antioxidant performance 20-600C
3 types compared: 715, 732, 735



5.1 - Design of base oil and additives - why synthetic?

Base oils **Fig 5** shows the viscosity and high temperature volatility of both mineral and synthetic oils, H1 and H2, making it clear that only a synthetic base oil would provide the needed combination of viscometry and volatility control.

We selected synthetic Type H1 because
- It had the best volatility control
- It would meet the environmental benefits we were targeting being free of aromatics, sulphur and nitrogen, as well as being biodegradable
- It was cost effective (synthetics costing 5-10 times more than mineral oil) **(Fig 6 - 7).** show the viscosity and flash points of an initial 5-centistoke formulation (P0) which compares favourably with the turbine oils modellers were using, whilst exceeding the 246C min in US military spec limit Mil - L-023699E.

Additive selection and making them work

The next stage in the oil design process was critical, in particular the design of the additive antioxidant system that would perform up to 300C in the synthetic fluid.
Antioxidant **(Fig 8)** is a thermal test we used to select type 732 antioxidant system because it gave a wide range of antioxidant performance up to the required 300 centigrade temperature. There were other antioxidants, but these didn't give the range of temperature protection we wanted.
As you can see from **(Fig 9)** certain additives will simply not dissolve in some modern synthetic lubricants such as H1/H2. The introduction of a second more polar type of synthetic S2, (an ester with identical viscosity and volatility properties) solved the problem, resulting in a modified formula, P1. At this point, and before we went further we decided to confirm the solubility of P1 in kerosene. **(Fig 10)** shows P1 was soluble over a period of five days down to minus 18 centigrade, 0 Fahrenheit.
(Fig 11) Certain chemical structures exhibit good biodegradability - those with high level S2 and H1 eventually becoming part of the final formulation. We knew that using our base oil choice of S2 technology gave relatively high conductivity, so would also reduce any electrostatic problems, without resorting to additives. Industry experience from refuelling full size aircraft suggested that there would be little risk of a static discharge when the fluid itself has a conductivity greater than 400 pico Siemens per square metre. **(Fig 12)**

Fig 9. Additive Design

Synthetic H2
H1 S2 H1+S2
Synthetic base oil - Additive compatibility studies

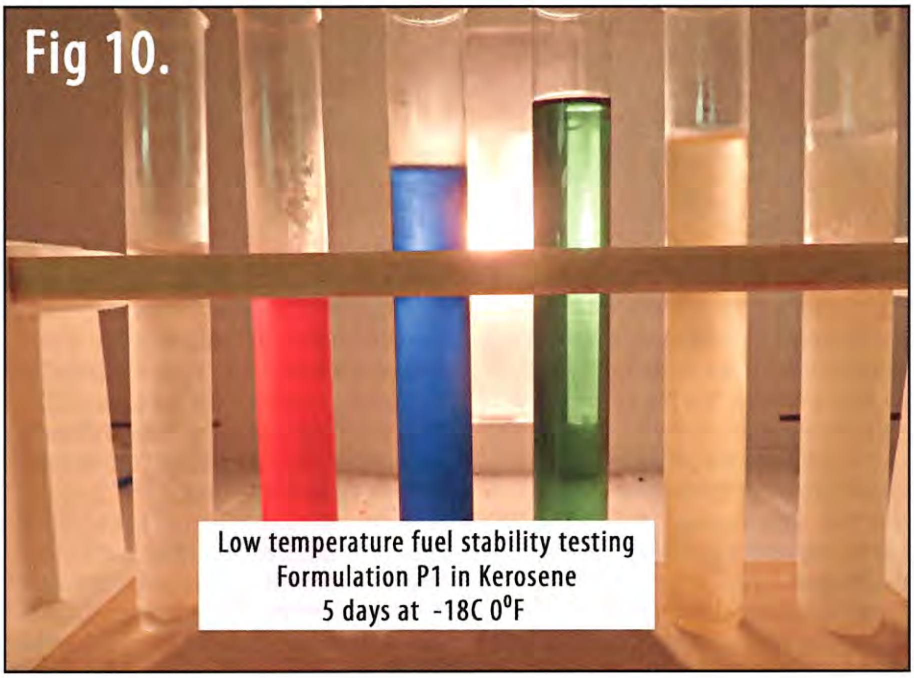


Fig 10.
Low temperature fuel stability testing
Formulation P1 in Kerosene
5 days at -18C 0°F

Fig 11 Biodegradability of base oils

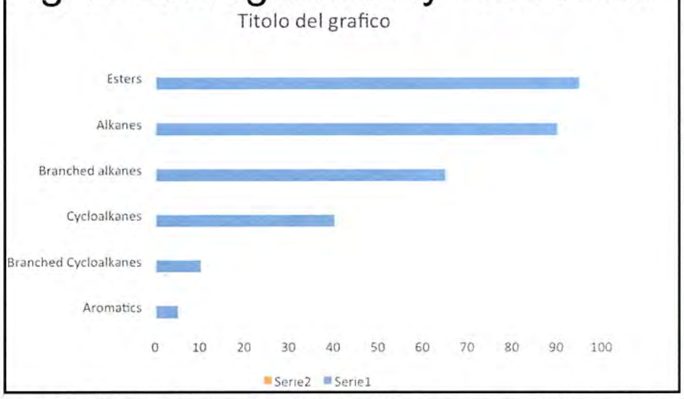
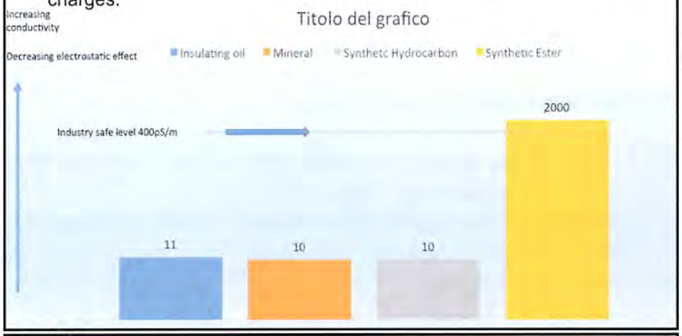


Table 2 Electrostatic properties of types of base oils-Conductivity
If the conductivity is more than 400 pS/m at 68 degrees F (20 degrees C), there is little risk of damage to the oil or the system from electrostatic charges.



5.2 - Screening formulations for volatility and thermal stability

The initial development test method using a fixed amount of oil dropped onto a hot plate was abandoned, due to the difficulty in capturing emission vapour and measuring volatility.

5.2.1 - Volatility:

We had gained sufficient confidence in formulation P1 so checked the volatility against an important reference oil, B, in a 96-hour oven test at 210C. As you can see oil P1 showed superior volatility loss (60% less) when compared to this advanced oil B. which is a ref Mil spec turbine oil **(Fig 13)**.

Fig 13.

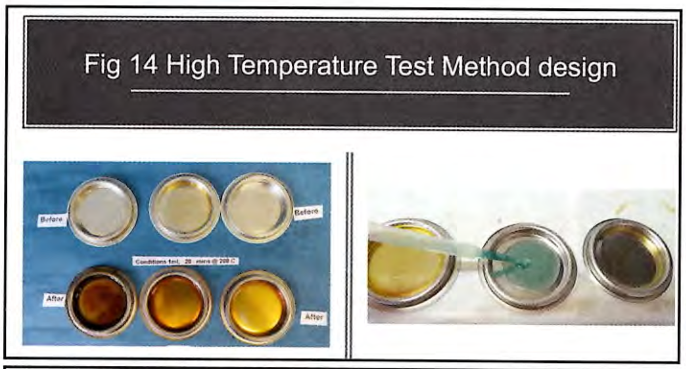


Fig. 15

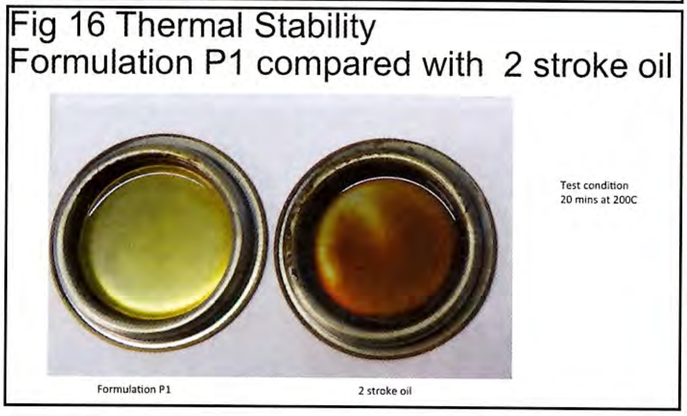


Fig 17 - Engine screening test results:

Model Turbine: Wren 44 Gold kerosene, ceramic element.

Test oil Mix 20:1	Ambient Temperature /C	Switch to Full kerosene Rpm		Idle	Half speed	Full speed	Comments
[illegible]	20	12,000	Temperature /C	476	456	656	
	Rpm: 000	12,000	RPM	55,000	143000	192000	
[illegible]	20	12,000	Temperature /C	464	458	636	Nice smell present right down to cool down. Quiet spin on cooldown.
	RPM: 000	12,000	RPM	55000	136000	193000	Noticeably quiet on hand spin on cooled engine (no bearing noise).

5.2.1 - Thermal stability: An oven test was developed to assess the tendency to thicken and carbonise. The test consisted of:

- 1 gram of test oil
- 200 centigrade temperature
- Test duration of 20 minutes

(Fig 14) shows three types of oil both before and after test.

Bench marking : The candidate oil P1 for Power Model synthetic oil should be equal or superior to a Mil spec turbine oil, Oil B.

(Fig 15) shows formulation P1 compares favourably with the best oils on the market. Furthermore, in **(Fig 16)**, P1 compared favourably with a 2 stroke oil, which darkened and thickened due to its lack of oxidation stability.

5.3 - Turbine testing in real Turbines

5.3.1 - (Fig 17) We felt confident enough to go to some real turbine tests with oil P1. I am indebted to Geoff Leigh and Bob Petrie who kindly offered to test the new oil in their own model turbines.

Geoff ran a Wren 44 Gold -as you can see the oil performed well achieving high top end speed and comparable running temperatures. A reduction of bearing noise on hand spinning the turbine once it had cooled down was noticed, possibly due to increased residual oil left in the bearing.

Bob Petrie ran a smaller model **(Fig 18)** with a Wren 44 and achieved 10 minutes of flying time without issue.

5.3.2 - Turbine makers tests

We now felt confident to seek approval of this product from turbine manufacturers. I am indebted to Paul Hardman at Turbine Solutions who completed a total of 35 hours of testing on Jan 15th, 2020.The turbine parts including the bearings can be seen to be in good condition **(Fig 19)** with carbonization being virtually non-existent in the combustion chamber **(Fig 20)**, with no signs of overheating.

6.0 - P1 to P2 The final touch

Finally, an attractive odourant and green dye **(Fig 21)** was designed and added to enable rapid recognition in kerosene fuel, resulting in oil P2.

Samples also went off to a number of turbine manufacturers who expressed an interest in our new concept for a model tur-

Fig. 19

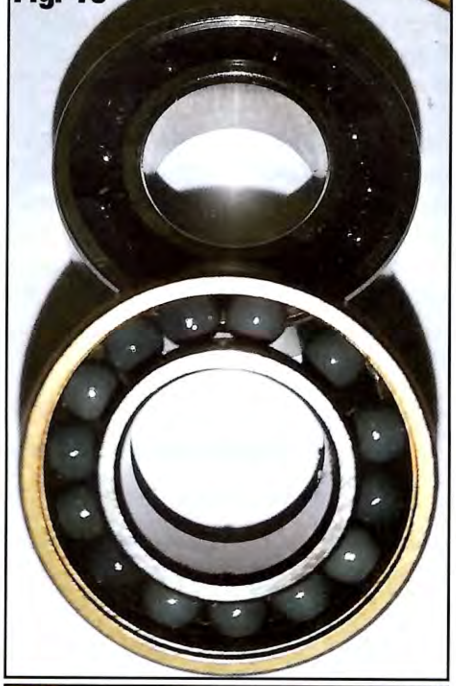


Fig. 18

Fig. 20

Fig. 21

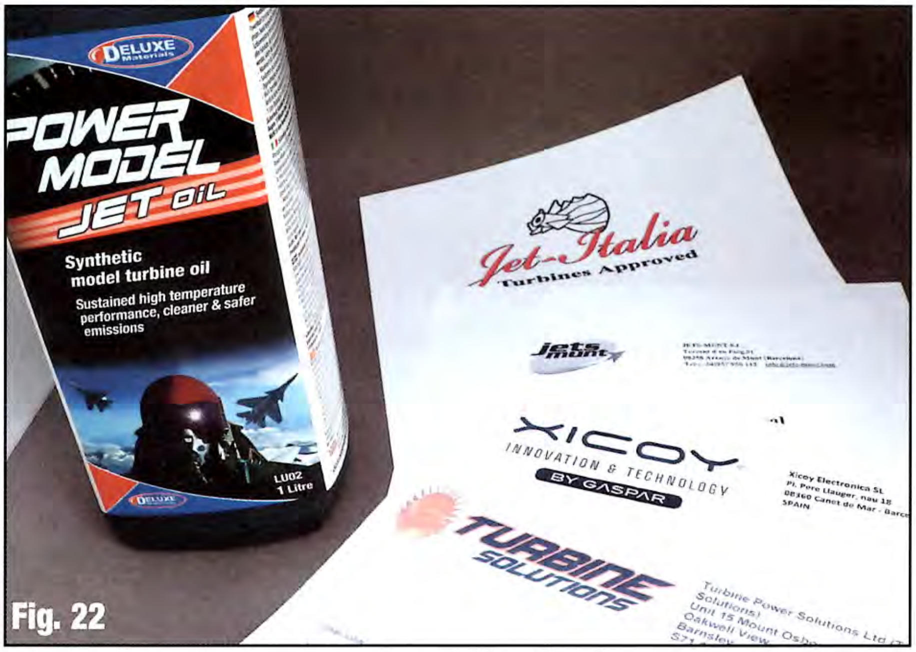


Fig. 22

bine oil. At the time of printing this issue of the magazine, six manufacturers of turbines have already approved this product: AMT Netherlands, JetCat, Jet Italia, JetsMunt, Turbine Solutions and Xicoy **(Fig 22)**. We would like to thank them for their belief in our product and their commitment and time to testing the product.

6 - In conclusion

So, let's summarise the environmental credentials for our new oil
- It's free of organic phosphorus additives
- It uses clean game changing synthetics
- Thermally stable fluid that has none of the toxic aromatics normally found in crude oil or refined oil
- Free of sulphur and nitrogen (no SOx, no NOx)
- The formula is also non-harmful and non-flammable, so therefore easy to ship around the world
- It does contain some readily biodegradable material
- The health and safety analysis shows it also to be non-harmful and therefore easy the ship with minimal costs to shops or the consumer around the world.
- It has a surprisingly attractive odour to add to consumer appeal.

Well in total this was over 18 months' work and took me on a journey in which I felt lonely at times, but along which I learnt a great deal and met some nice people in the hobby. I also sincerely hope our new oil will be a contribution to the jet modelling hobby for many years to come.
PowerModel Jet is available and distributed to good model shops through our network of international distributors.
www.deluxematerials.com

7 - Acknowledgements

My thanks to:
1. Ripmax Ltd - in particular Colin Straus for the encouragement to create this product.
2. To the following manufacturers who have believed in our product and given their resources to test and approve it:
I. Paul Hardman of Turbine Solutions.
II. Francesco Pieroni, Managing Director of Jet-Italia Turbines
III. Gaspar Espiell of Xicoy Electronica and JETS-MUNT turbines
3. The fellow modeller friends that helped me test this oil in the early days
1. Geoff Leigh - Wren 44 Gold
2. Kristien Milne - Jet Cat - flight testing
3. Bob Petrie - Wren
4. Colin Straus for bench testing.
5. Dave Wilshere consultant.
6. Eddie Pink consultant, friend and colleague MPhil, PhD, Eddie Pink Design Consultancy Ltd
Without your support none of this would have been possible.
Thank you again!

John Bristow

Appendix 2 - History of gas turbine oils

The earliest gas turbine lubricants were developed using straight mineral oils in order to meet the operational requirements at low temperature e.g. starting on the ground or at high altitude. This led to the development of a range of SAE 20 mineral oils shown in the chart as oils A 3cst and C 9cst for heavier loadings. Gas turbine oils had a lower viscosity than those for conventional aircraft using piston engines - piston engine oils were typically around SAE 50 i.e. around 20 centistokes at 100C. This higher viscosity is required to cushion pistons and seal piston rings. Higher thrust and loads plus the introduction of reduction gears led to the need for ashless additives that would improve the load carrying capacity of these lubricants.

Synthetic lubricants made from castor oil or similar organic material had been researched in Germany as early as the 1930's. It could be said that the battle of Stalingrad was lost due to the seizure of guns and tanks which were immobilised due to the intense cold during that period that turned mineral lubricants into thick Jelly. These low viscosity synthetic lubricants such as dioctyl sebacate had better volatility control and eventually found application in turbine oils (oil D). Eventually even these diester synthetic oils needed to be fortified with Phosphorus containing additives in order to lubricate reduction gears. The advent of supersonic flight led to what is called Type 11 5cst (centistoke oils) being developed based on hindered Ester technology oil F.

In more recent years the intense need for increased fuel economy led to designs that further increase thermal loading and the need for greater stability and the need to lubricate external gear boxes including helicopter transmissions.