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(71) Applicant *(for all designated States except US)*: THE SECRETARY OF STATE FOR DEFENCE IN HER BRITANNIC MAJESTY'S GOVERNMENT OF THE UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND [GB/GB]; Whitehall, London SW1A 2HB (GB).

(72) Inventor; and
(75) Inventor/Applicant *(for US only)* : BRYCE, William, Dean [GB/GB]; 40 Shortheath Crescent, Farnham, Surrey GU9 8SB (GB).

(74) Agent: BECKHAM, Robert, William; IPD/DRA, Room 2016, Empress State Building, Lillie Road, London SW6 1TR (GB).

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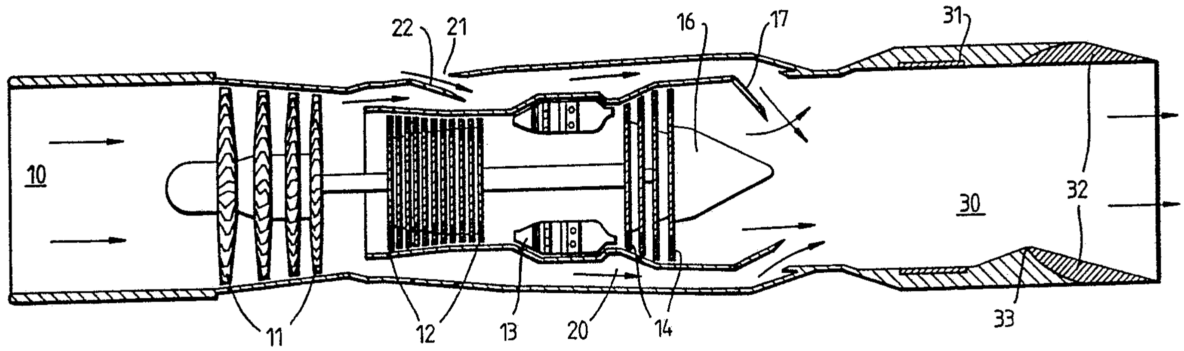

(57) Abstract

A gas turbine engine suitable for supersonic aircraft uses a variable configuration to reduce jet noise at take-off without compromising engine efficiency at high cruise speeds. In the take-off configuration, supplementary air intakes (21) are opened to admit ambient air into bypass duct (20). The combined flow of bypass air and entrained ambient air is mixed with the engine core flow at the upstream end of jet pipe (30) to exhaust through a large common nozzle (32). Opening and closure of the intakes (21) is linked to the control of variable area nozzles (17, 22 and 32) such that nozzles (17 and 22) are reduced in area when intakes (21) are open whilst nozzle (32) is opened. This promotes efficient mixing as far upstream as possible, thereby attenuating the exhaust jet velocity and thus reducing its noise-generating capacity. In cruise operation the engine adopts the configuration of a conventional low bypass ratio engine: intakes (21) are closed, nozzles (17 and 22) are opened and nozzle (32) is reduced in area.

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VARIABLE CYCLE GAS TURBINE ENGINE FOR SUPERSONIC AIRCRAFT

This invention relates to aircraft engines and in particular to a variable cycle gas turbine engine of the type comprising: a core section, an outer casing defining a by-pass duct around the core section and a common jet pipe through which the engine core stream and the engine by-pass stream are discharged, the jet pipe including a sound-absorbing lining at an intermediate portion thereof, a variable area primary nozzle at its downstream end and a variable area core nozzle at its upstream end in the region where core and by-pass streams meet.

Variable cycle engines have been widely proposed as the best means of satisfying the conflicting requirements of future generation supersonic transport aircraft for Mach 2-plus capability combined with the noise characteristics of present-day turbofan engines during take-off, climb and overland flight.

In order to achieve a cruise speed of around Mach 2 to 2.5 in an aircraft carrying between 200 and 300 passengers over a range of 11000 kilometres, technical considerations and economic factors such as fuel consumption dictate the use of low by-pass ratio engines. It is generally thought that this will mean operating with by-pass ratios of the order of unity or less, more specifically with by-pass ratios of 1.2 or lower. However, the disadvantages of such engines are that their efficiency is compromised at low speeds and also that they are very noisy. The dominant cause of noise in these engines is the turbulence created externally of the engine casing when fast-moving gases in the exhaust jet mix with ambient air. This noise problem is exacerbated at low aircraft speeds because of the large difference between the velocity of the jet efflux and that of the surrounding air.

Under take-off conditions, a typical low by-pass ratio engine produces a very high jet velocity of around 800 metres per second. However, at a typical take-off speed of Mach 0.3, international airport regulations currently stipulate that engine noise should be limited to a value which equates to a jet velocity of around 450 metres per second. Thus it is clear that measures are required to reduce in some way the noise which the engine would otherwise produce.

The variable cycle engines which have been proposed previously to address this problem combine two engine cycles within the same body. For example, by using variable area front end air inlets, the same engine can be operated to provide thrust subsonically using a high by-pass ratio, or supersonically using a low by-pass configuration. To date, however, the proposed engine designs have all suffered from the drawback of increased complexity, usually accompanied by extra weight which it is preferable to avoid.

Conventional techniques for aircraft noise reduction impose penalties on the performance of the aircraft which must be borne throughout the entire flight envelope of the aircraft, even though the benefit of reduced noise is required for only a small portion of its flight. This occurs, for example, when shrouds equipped with sound deadening material are used to extend the engine casing. Although such shrouds are effective in reducing noise, they incur ever-present weight and drag penalties.

It has previously been proposed to reduce exhaust jet noise using methods which increase the contact area between the atmosphere and the emerging gas stream. For example, by using a corrugated nozzle, atmospheric air can be caused to flow along the external corrugations and into the exhaust jet to promote rapid mixing. Alternatively, using a lobe-type nozzle, the exhaust gases can be divided into a number of separate exhaust jets which issue through a series of lobes and a small central nozzle. The resulting increase in the surface area of the exhaust jet facilitates rapid mixing with the ambient air entrained by the lobes. Unfortunately, nozzle design alone is not sufficient to give the degree of noise reduction required for the type of engine contemplated in future supersonic transport aircraft.

In our earlier U.K. Patent No. 1 409 887 a modified jet pipe is described which acts as a noise shield in selected operating modes of the engine. The jet pipe is formed with the usual primary nozzle at its downstream end but is additionally provided with a plurality of movable members located immediately aft of the turbine assembly at a position well upstream from the primary nozzle. These members are operable between a first position, where they sit retracted from the gas flow through the pipe, and a second position where they extend into the gas flow to create a secondary nozzle. The secondary nozzle is of smaller diameter than the primary nozzle and its configuration is such that exhaust gases passing through it are divided into a number of gas streams. The jet pipe downstream of this secondary nozzle then acts as a noise shield. This method, too, is inadequate to achieve the degree of noise reduction required in the proposed engines.

It is therefore an aim of the present invention to provide a variable cycle gas turbine engine suitable for supersonic aircraft, which engine is capable of operating with reduced noise emission during take-off, climb and overland flight without incurring the undesirable weight and drag penalties of prior art engines.

The invention is a variable cycle gas turbine engine suitable for supersonic aircraft comprising: a core section, an outer casing defining a by-pass duct around the core section, a common jet pipe through which the engine core stream and the engine by-pass stream are discharged, the jet pipe including a sound-absorbing lining at an intermediate portion thereof, a variable area primary nozzle at its downstream end and a variable area core nozzle at its upstream end in the region where core and by-pass streams meet, characterised in that the engine has one or more occludable supplementary air intakes which serve, when open, to deliver ambient air through the outer casing *via* a variable area supplementary nozzle into the by-pass duct to boost the mass flow of air emerging from the downstream end of the by-pass duct and in that it has control means operative to increase the area of the primary nozzle and reduce the respective areas of the core nozzle and the supplementary nozzle in response to opening of the supplementary air intakes such that mixing is promoted within the by-pass duct between the by-pass stream and the entrained ambient air and within the jet pipe between the core stream and the boosted by-pass stream to dilute the exhaust jet with ambient air and thereby attenuate the velocity of the emergent composite stream.

Unlike those engines which muffle noise using an ancillary shroud attached to the jet pipe, the present invention works by shifting the mixing zone as far upstream as possible, both for take-off and during subsequent flight when quiet operation is required. This is achieved by operating the primary nozzle at the downstream end of the jet pipe in its retracted mode, so that the core nozzle and the supplementary nozzle effectively behave as the throat for the emergent gas stream.

A suitable operating configuration can be selected for the engine to match flight circumstances. In the take-off or "quiet" configuration the engine is operated with its supplementary air intakes open to draw extra, ambient air into the engine by-pass stream, where mixing is promoted between the stream of by-pass air and the entrained stream of ambient air prior to its emergence from the by-pass duct. This boosted by-pass flow is caused to mix with the air from the engine core stream, thereby diluting it so that the exit velocity of the composite exhaust jet is reduced in comparison to that of the undiluted stream. This lower velocity creates less intense turbulence externally of the engine and thus less noise is generated. In practice it is preferable to increase the engine by-pass flow with an approximately equal mass flow of entrained ambient air.

In its cruise configuration the engine is operated with the supplementary air intakes closed so that it performs as an unsuppressed low by-pass ratio turbo-jet engine. Engine core flow and engine by-pass flow are still exhausted through the common jet pipe but no special provision need be made to promote their mixing, nor to reduce the noise which the engine generates under these operating conditions.

Preferably, the core nozzle is a mixing nozzle and as such may have a corrugated perimeter or may include holes or tubes for assisting in the formation of the core flow into a jet of increased periphery so as to promote efficient mixing of gases in the jet pipe. The movable elements of the core nozzle are retracted for operation of the engine in its cruise configuration, when efficient mixing of core and by-pass streams is less important. Minor adjustment of these core nozzle elements may also serve as a means of controlling the engine mix-plane conditions.

The supplementary air intakes may take the form of plain openings in the engine outer casing. Advantageously, these are sited to introduce ambient air into the by-pass duct at a position well forward of the turbine section to maximise the opportunity for mixing between the by-pass air stream and the entrained ambient air stream before their emergence from the by-pass duct into the jet pipe. When the supplementary air intakes are open, ambient air is entrained into the by-pass duct by the by-pass stream, even when the aircraft is stationary or moving at low speeds. In normal flight, i.e. cruise configuration, the intakes are kept closed. Alternatively, scoops can be used which protrude from the engine outer casing in order to assist the intake of ambient air for boosting the by-pass flow.

An additional benefit of siting the openings as far forward as possible is that it avoids the need to increase the cross-sectional area of the by-pass duct in the region where it surrounds the turbine section. The turbine section is the widest part of the engine and any increase in casing diameter to accommodate a wider by-pass duct would be undesirable because it would contribute to increased drag.

A variable area supplementary nozzle having extensible/retractable elements operates in the region where the supplementary air intakes discharge into the by-pass duct. When the supplementary air intakes are open, the supplementary nozzle elements are extended in order to decrease the nozzle area and thereby reduce the static pressure of the by-pass flow to a value near to that of the ambient air. Preferably, this supplementary nozzle is a mixing nozzle having a geometry which promotes thorough mixing between the by-pass airflow and the entrained ambient air. When the supplementary air intakes are closed, the supplementary nozzle elements are retracted.

In order for the engine to operate efficiently at high aircraft speeds it is necessary to use a variable-geometry inlet duct. This serves to control the air velocity between the mouth of the inlet duct and the forward compressor section, since air entering the compressor must usually be slowed to subsonic velocity. As the aircraft approaches the speed of sound, shock waves develop which can give rise to high duct losses in both pressure and air flow if they are not controlled. Poor air pressure and velocity distribution can lead in turn to compressor stall. Various techniques are known for varying the inlet duct geometry, but since they do not form part of the present invention they will not be described in detail here.

The invention will now be described by way of example only with reference to the drawing. The upper half of the drawing is a section through an engine constructed according to the invention shown in its take-off configuration, whilst the lower half shows a section through the same engine in its cruise configuration.

At its left hand end as shown, the engine is provided with a variable-geometry inlet duct 10, details of which have been omitted from the drawing for the reasons given above. Air from the inlet duct is delivered at uniform pressure and velocity to the low pressure compressor or fan assembly 11 and is then divided into separate core and by-pass streams. The air in the by-pass stream passes downstream along annular by-pass duct 20 and is reunited with the core stream at the upstream end of jet pipe 30 in a manner to be described in more detail below. The air in the core stream passes through high pressure compressor 12, combustor array 13 and turbine assembly 14. At the downstream end of turbine assembly 14 is a bullet 16 which aids smooth diffusion of gas flow into the jet pipe 30. An intermediate portion of the jet pipe 30 is provided with sound-absorbing linings 31 which assist in absorbing some of the noise generated inside the engine casing. At its downstream end the jet pipe 30 is equipped with a variable-area convergent-divergent primary nozzle 32.

Referring now to the upper half of the drawing, this depicts the engine in its take-off configuration. At take-off, supplementary air intakes 21 are opened to admit ambient air into the by-pass duct 20. These supplementary air intakes discharge into the by-pass duct 20 downstream of the fan assembly 11 and their operation is linked to that of a variable area supplementary nozzle 22. When the supplementary air intakes are open, the movable elements of the supplementary nozzle 22 are extended into the by-pass duct to decrease the cross-sectional area of the nozzle and thereby reduce the static pressure of the by-pass flow to a value near to that of the ambient air. This combined or boosted flow passes downstream to the end of the by-pass duct 20 and issues into the jet pipe immediately aft of the turbine assembly 14.

Still referring to the upper half of the drawing, a variable area core nozzle 17 is provided at the point of entry of the by-pass duct 20 into the jet pipe 30. Operation of the core nozzle is also linked to that of the supplementary air intakes 21 so that, in the take-off configuration, the nozzle 17 is deployed with its movable elements extended to decrease the nozzle area and thereby reduce the static pressure of the core flow to encourage mixing thereof with the combined or boosted flow. The core nozzle is preferably a mixing nozzle of convoluted shape and may have surface features such as holes, tubes or lobes to promote division of the core flow into a number of smaller streams or to create a stream of greatly increased periphery. The core nozzle thus aids mixing of the gas streams within the jet pipe 30 so that the noise which arises from any resulting turbulence is attenuated by the sound-absorbing linings 31. Moreover, because the exhaust jet which emerges from the primary nozzle 32 is diluted with low velocity air, its aggregate velocity is sufficiently low that turbulence occurring externally of the engine casing is reduced to a level such that the generated jet noise is within acceptable limits.

The upper half of the drawing also shows that operation of the primary nozzle 32 is linked to that of the supplementary air intakes 21, so that in take-off configuration the nozzle is opened up to a relatively large area in order to minimise the difference between the static pressure in the jet pipe and the ambient pressure external to the engine.

Thus, for quiet operation, the exemplified engine requires the following conditions to be satisfied:

i Supplementary air intakes open;

ii Supplementary nozzle elements extended (nozzle area small);

iii Core nozzle elements extended (nozzle area small), and

iv Primary nozzle elements retracted (nozzle area large).

In the bottom half of the drawing the engine is shown in its contrasting configuration for cruise operation, in which the features listed above assume their opposite modes. Accordingly, the movable elements of the primary nozzle 32 are extended to define a convergent-divergent passage in which the cross-sectional area of throat 33 is relatively small compared to the throat area of the nozzle 32 at take-off. The reduction in throat area increases the static pressure difference across the primary nozzle. The movable elements of the core nozzle 17 are retracted so that the airflows pass from the fan 11 and from the turbine 14 to the throat 33 with minimal losses. The precise position of the core nozzle 17 may be varied in order to balance the conditions under which the core and by-pass flows meet. At cruise, the movable elements of the supplementary nozzle 22 are also retracted because the supplementary air intakes are closed and there is no need to balance the by-pass flow against boost air.

Unlike some prior art engines which attempt to control noise by employing an ancillary shroud attached to the jet pipe, the engine described here uses the existing jet pipe 30 as a large integral shroud by shifting the mixing zone as far upstream as possible, both for take-off and during subsequent flight whenever quiet operation is required. Effectively, this is achieved by coordinating the variation in area of the nozzles 17, 22 and 32 with the opening and closure of the supplementary air intakes 21, such that the core nozzle 17 and supplementary nozzle 22 together assume the role of throat 33 when primary nozzle 32 is opened in response to opening of the supplementary air intakes 21. In the cruise configuration, drag penalties in the present invention are minimal and the principal penalty incurred relative to an engine having no noise suppression is due to the weight of the extra length of jet pipe and the variable area nozzles 17 and 22.

Although nozzles 17, 22 and 32 have been described as variable area devices, the variability is not necessarily achieved using flaps/petals as shown in the drawing. Other conventional means such as retractable nozzle plugs may be used instead, and a given engine design may even use a variety of variable area devices to suit particular requirements.

In order to maximise the benefit from this type of engine design it may be desired to use some variable features in the turbomachinery, such as variable stator blades or a variable by-pass ratio effected by movable flaps at the forward end of the high pressure compressor section.

These engines are primarily intended to be constructed without after-burners. However, for certain aircraft designs, after-burning may be desirable to assist in overcoming the effects of transonic drag. Where possible it is preferable to omit after-burners because they add to the weight and complexity of what is otherwise a simple engine design, especially since they would be used for only a brief period as the aircraft accelerates through the sound barrier. Nevertheless, the perceived engine has a relatively long jet pipe which does make it suitable for the installation of an after-burning system if desired.

CLAIMS

1. A variable cycle gas turbine engine suitable for supersonic aircraft comprising: a core section, an outer casing defining a by-pass duct around the core section, a common jet pipe through which the engine core stream and the engine by-pass stream are discharged, the jet pipe including a sound-absorbing lining at an intermediate portion thereof, a variable area primary nozzle at its downstream end and a variable area core nozzle at its upstream end in the region where core and by-pass streams meet, characterised in that the engine has one or more occludable supplementary air intakes which serve, when open, to deliver ambient air through the outer casing *via* a variable area supplementary nozzle into the by-pass duct to boost the mass flow of air emerging from the downstream end of the by-pass duct and in that it has control means operative to increase the area of the primary nozzle and reduce the respective areas of the core nozzle and the supplementary nozzle in response to opening of the supplementary air intakes such that mixing is promoted within the by-pass duct between the by-pass stream and the entrained ambient air and within the jet pipe between the core stream and the boosted by-pass stream to dilute the exhaust jet with ambient air and thereby attenuate the velocity of the emergent composite stream.

2. A variable cycle gas turbine engine as claimed in claim 1, further characterised in that the core nozzle is a mixing nozzle which assists in the formation of the core stream into a jet of increased periphery in order to enhance mixing of gases in the jet pipe.

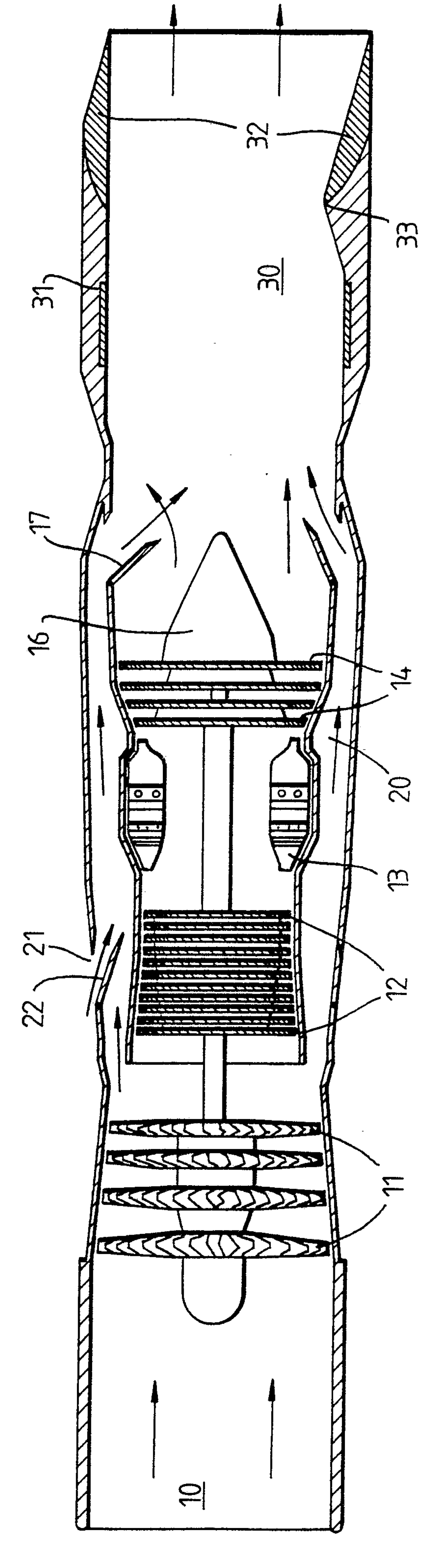
3. A variable cycle gas turbine engine as claimed in claim 1 or claim 2, further characterised in that the supplementary nozzle is a mixing nozzle which assists in the formation of the by-pass stream into a jet of increased periphery in order to enhance mixing within the by-pass duct between the by-pass stream and the entrained ambient air.

4. A variable cycle gas turbine engine as claimed in any preceding claim, further characterised in that the supplementary air intakes include scoops which are operable to protrude from the engine outer casing to assist the intake of ambient air for boosting the by-pass stream.

5. A variable cycle gas turbine engine as claimed in any preceding claim, further characterised in that the supplementary air intakes are sited to introduce ambient air into the by-pass duct at a position well forward from the turbine section in order to maximise the opportunity for mixing between the by-pass air stream and the entrained stream of ambient air before their emergence from the by-pass duct.

6. A variable cycle gas turbine engine as claimed in any preceding claim, further characterised in that the the engine by-pass flow is increased with an approximately equal mass flow of entrained ambient air when the supplementary air intakes are open.

Fig. 1.



INTERNATIONAL SEARCH REPORT

International Application No PCT/GB 91/00754

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all)[6]

According to International Patent Classification (IPC) or to both National Classification and IPC

Int.Cl. 5 F02K3/075 ; F02K1/38 ; F02K1/36

II. FIELDS SEARCHED

Minimum Documentation Searched[7]

Classification System	Classification Symbols
Int.Cl. 5	F02K

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched[8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT[9]

Category °	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No.[13]
P,X	EP,A,405796 (NORDAM) 02 January 1991 see column 1, line 28 - column 2, line 48	1-4
A	see column 5, line 35 - column 6, line 34; figures 1-5	5
P,X	FR,A,2642793 (MTU + DFLR) 10 August 1990 see the whole document	1-3
A	GB,A,1208520 (SNECMA) 14 October 1970 see the whole document	1-6
A	US,A,3534831 (NAGAMATSU) 20 October 1970	

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IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
25 JULY 1991	08. 08. 91
International Searching Authority	**Signature of Authorized Officer**
EUROPEAN PATENT OFFICE	IVERUS D. D. Iverus

Form PCT/ISA/210 (second sheet) (January 1985)

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO. GB 9100754

SA 47370

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The members are as contained in the European Patent Office EDP file on 25/07/91
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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP-A-405796	02-01-91	US-A- 4909346 JP-A- 3037363	20-03-90 18-02-91
FR-A-2642793	10-08-90	DE-A- 3903713 GB-A- 2231092	09-08-90 07-11-90
GB-A-1208520	14-10-70	FR-A- 1547756 US-A- 3524588	 18-08-70
US-A-3534831	20-10-70	None	

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82