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Datasheet for the decision of 22 October 2021

Case Number: T 2246/18 - 3.2.04

Application Number: 09250625.2

Publication Number: 2098704

IPC: F02C9/16, F02K1/16, F02K3/06, F04D29/66

Language of the proceedings: EN

Title of invention:
Fan flutter management system in a turbofan engine with variable area fan nozzle

Patent Proprietor:
Raytheon Technologies Corporation

Opponent:
Safran Aircraft Engines

Headword:

Relevant legal provisions:
EPC Art. 56
RPBA 2020 Art. 13(2)

Keyword:
Inventive step - main request (no) - auxiliary request (no)
Amendment after summons - exceptional circumstances (no)

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Catchword:

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Beschwerdekammern

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Case Number: T 2246/18 - 3.2.04

D E C I S I O N
of Technical Board of Appeal 3.2.04
of 22 October 2021

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Decision under appeal: **Decision of the Opposition Division of the European Patent Office posted on 6 July 2018 rejecting the opposition filed against European patent No. 2098704 pursuant to Article 101(2) EPC.**

Composition of the Board:

Chairwoman S. Hillebrand
Members: G. Martin Gonzalez
T. Bokor

Summary of Facts and Submissions

I. The appeal was filed by the Opponent against the decision of the Opposition Division to reject the opposition filed against the patent in suit.

In its decision, the Opposition Division held i.a. that the subject-matter of granted claims 1 and 7 (a gas turbine engine and method for controlling it) involved an inventive step.

II. In a communication according to Article 15(1) RPBA, the Board did not share these findings in a preliminary opinion. It considered also the auxiliary request not to involve an inventive step.

III. Oral proceedings were held before the Board in the presence of all parties.

IV. The Appellant-Opponent requests that the decision under appeal be set aside and that the patent be revoked.

The Respondent-Proprietor requests that the appeal be dismissed, i.e. that the patent be maintained as granted, or that the patent be maintained in an amended form on the basis of an auxiliary request, titled First Auxiliary Request, filed with the reply to the grounds of appeal on 18 March 2019, or a second auxiliary request, titled likewise First Auxiliary Request, filed during oral proceedings before the Board.

V. Claims 1 and 7 of the main request read as follows:
"*1. A gas turbine engine (10) comprising:*
a core engine defined about an axis (A);
a fan (20) driven by said core engine about said axis

(A);
a core nacelle (12) defined at least partially about said core engine;
a fan nacelle (34) defined around said fan and at least partially around said core nacelle, and
a variable area fan nozzle (VAFN) (42) to define a fan exit area (44) downstream of said fan (20) between said fan nacelle (34) and said core nacelle (12); and characterized by
a controller (66) trimmed in response to a neural network to control a fan blade flutter characteristic through control of said VAFN (42)."

"7. *A method of controlling a gas turbine engine (10) characterized by comprising the step of:*
adjusting a variable area fan nozzle (42) in response to a neural network (68) to control a fan blade flutter characteristic."

Independent claims 1 and 6 of the first auxiliary request comprise the following additional feature or step, respectively:
"*wherein the neural network is trained through fan blade companion testing*";
"*training a neural network (68) through fan blade companion testing*".

Independent claims 1 and 6 of the second auxiliary request comprise the following additional feature specifying the training and testing:
"*to determine a baseline fan blade deterioration profile*".

VI. In the present decision, reference is made to the following documents:

D1: US 2003/0077163 A1
D2: US 5 857 321
D3: EP 1 420 153 A2
D4: "A Neural Adaptive Controller", Ph. Meyne et al.

VII. The Appellant's (Opponent's) arguments can be summarised as follows:
The subject-matter of the independent claims according to all requests lacks inventive step in the light of the disclosure of D1 and general knowledge of the person skilled in the art or in combination with D4.

The Respondent's (Proprietor's) arguments can be summarised as follows:
Neither trimming a VAFN controller during the life time of a turbofan engine, nor employing a neural network for this purpose according to the independent claims of all requests is suggested or rendered obvious by any of the cited prior art or common general knowledge.

Reasons for the Decision

1. The appeal is admissible.

2. **The patent and its technical background**

The patent deals with the control of aircraft turbofan engines and in particular of variable area fan nozzles ("VAFN").

The fan of a turbofan engine creates a pressurized bypass air flow surrounding the core engine. It works most efficiently in terms of fuel consumption with a low pressure ratio of air outlet pressure to air inlet pressure. The minimum outlet area of the fan nozzle is

designed for optimal operation at TOC (top of climb) and during cruise. During take-off and landing, with relatively low air speed, thus under conditions of low mass flow and inlet pressure, the VAFN increases the bypass outlet area, thereby fostering mass flow, lowering the outlet pressure and keeping the pressure ratio low. This is not only necessary for maintaining best possible operational conditions, but also for preventing fan blades from deflecting and "fluttering", which is detrimental to fan stability and integrity.
The opening degree of the VAFN has thus to be controlled during take-off to provide optimal fan operation whilst always keeping a safety margin with regard to the so-called "fan blade flutter boundary", see VAFN SCHEDULED % OPEN in Fig. 5 of the patent and Fig. 1 of D1.
The fan flutter boundary is slightly different for each individual fan and furthermore subject to change due to differing environmental conditions and ageing of fan components. Therefore, the VAFN controller is "trimmed" accordingly, i.e. adjusted, taking into account individual and variable factors.
According to the patent, this trimming is effected by a neural network, which allows in particular to compensate for component deterioration, as explained in the embodiment of Fig. 5 and paragraph [0027].

3. **Main request - interpretation of the independent claims**

3.1 Since the "fan blade flutter *characteristic*" is controlled *through* control of (claim 1) or *by* adjusting (claim 7) the VAFN, it can neither be understood as a fan blade characteristic *stricto sensu*, such as a "fan blade flutter signature" mentioned in paragraph [0004] of the patent, nor as "flutter boundary management characteristics", *on the basis of* which the VAFN can be controlled or adjusted. What is actually controlled by means of VAFN control or adjustment, is the fan blade flutter itself or the fan blade flutter *behaviour*.

The Board is not convinced that the claimed "control of fan blade flutter characteristic" implied preventing fan blade flutter from even occurring. Even if this might be the case in the patent's embodiment, as put forward by the Respondent, the broad wording of claims 1 and 7 is by no means limited to such control result.

3.2 According to claim 1, a controller is "trimmed in response to a neural network", in claim 7 a VAFN is "adjusted in response to a neural network".

"Trim" does not have a recognized technical meaning in controlling. The only applicable definition in Merriam Webster (https://www.merriam-webster.com/dictionary/trim#:~:text=1%20%3A%20to%20put%20decorations%20on,need%20to%20trim%20our%20expenses.) is "to adjust".

In the embodiment of the patent, the FADEC 66 represents a controller, which is "trimmed", i.e. adjusted by a neural network (NN) 68 "to compensate for component deterioration and other operations", paragraphs [0020], [0026]. The Board notes that claim 1 leaves it open, how often such kind of controller setting might occur. Trimming the controller once and only is therefore encompassed, too.
The unspecified controller of claim 1 can, however, also be considered as being a VAFN actuator controller, which in turn is adjusted in the sense of controlled by a neural network flutter controller located at a higher control level.

4. **Document D1**

4.1 It is common ground that D1 discloses as closest prior art a gas turbine engine comprising a core engine ("motor"), a fan 110 and a variable area fan nozzle 132 defining a fan outlet area downstream of the fan between a fan nacelle and a core nacelle, see abstract ("fan"), paragraph [0046], Fig. 3. A controller 124 generates a control signal to control operation of actuators 135, which vary the cross sectional area of exhaust nozzle 132 accordingly, paragraphs [0051], [0057]. Additional, separate control units, which might execute the control signals generated by the controller 124 by controlling VAFN actuator motors, are not mentioned in D1.

4.2 As the patent, D1 aims at operating the fan "at an optimal operating mode, while avoiding the flutter instability characteristics", paragraph [0010]. D1's controller 124 is explicitly a "flutter control circuit", which controls fan blade flutter (characteristics) through control of or by adjusting VAFN 132, see above, even if an "acceptable level of blade instability" or an "existing sensed flutter" (paragraphs [0038], [0041]) is tolerated.

4.3 D1 discloses in Figs. 5 and 2 two alternative flutter control methods as second and third aspects of the invention (paragraphs [0017] - [0029]) and corresponding to independent method claims 11 and 15, respectively.

Both methods are carried out by means of the structural features cited above, see paragraph [0051], and involve the generation of a flutter or amplitude signal indicative of an existing flutter level (step 530 in

Fig. 2B , steps 420, 424, 426 in Fig. 5A). The flutter or amplitude signal is compared to a threshold called "differential quantity" or "noise signal" in order to determine whether generating a control signal for the VAFN actuators is necessary for reducing fan blade flutter (steps 538, 542, 550 in Fig. 2B, steps 434, 438, 450 in Fig. 5B).

4.4 For the method of Figs. 5, paragraphs [0051] to [0053] and [0063] to [0065] describe a so-called "first way" of generating a flutter control signal.
It starts with storing noise signals, which are normally expected to be present, in a memory, paragraphs [0051] and [0063].
As long as the sensed and computed amplitude signal, which represents existing fan flutter, is below the normal noise level, the fan flutter control does not intervene in normal fan operation including VAFN control (steps 434, 438, line 442 in Fig. 5B). If the amplitude signal becomes greater than the expected noise signal, a control signal is derived from the difference between the two signals, which is multiplied by a pre-programmed, fan-specific scaling factor, paragraphs [0052], [0064]. For the first method D1 proposes thus a PD (proportional-differential) algorithm for determining the magnitude of the control signal.

4.5 In the (second) method of Figs. 2, which is described in paragraphs [0040] to [0045] and [0054], a fan specific map as shown in Fig. 1 is generated first (steps 504, 508, 512, 516 of Fig. 2A). From the map maximally tolerable flutter characteristics - the differential quantity - along a critical region of operation (between points 264 and 268) are derived and stored (steps 520, 524 of Fig. 2A). The differential

quantity is defined such that a safety margin between the magnitude of existing flutter and detrimental flutter occurring in a flutter boundary region 255 (Fig. 1) is always respected, paragraph [0041].
During take-off, fan speed and VAFN outlet area are normally adjusted such that pressure ratio increases linearly with mass flow (step 542 in Fig. 2B, paragraph [0042]). Should existing fan flutter become greater than the differential quantity, a flutter control signal for modifying the mass flow is generated, which "overrules" the normal linear mode of fan operation (steps 550, 554, 556 in Fig. 2B, paragraph [0043]). Fan flutter control results thus in a temporary non-linear mode of fan operation.
D1's description is silent on how exactly the magnitude of the flutter control signal is determined in this method. As the Respondent sets out in their letter of 1 July 2021, "the control signal ... does not depend on the actual amount of flutter measured" (page 6, end of penultimate paragraph). Since Fig. 2B shows an iterative feed-back algorithm (line 562), it can, however, be assumed that mass flow / VAFN outlet area is increased by incremental steps until existing flutter drops below the differential quantity, see paragraph [0044]. The Board notes that such type of iterative control algorithm is prone to overshooting.

4.6 According to paragraph [0054], the parameters of the flutter region in Fig. 1 and operating conditions can later be "reprogrammed and *updated* as conditions require", i.e. adapted to changing conditions in order to reflect (correctly) the flutter boundary and optimum operating parameters of a particular fan as well as of a different environment, in which the fan might operate. In the terminology of the patent D1 thus envisages to update "flutter boundary management characteristics" (paragraph [0004]).

5. Document D4

5.1 In D4, a neural network is used for controlling the opening degree of a VAFN.

This is contested by the Respondent, since D4 employs expressions, such as "turbofan exhaust nozzle", "turbojet nozzle" (pages 80, 81, 83), which were indicative of exhaust or combustion gas produced by the core engine, not outlet air from the fan.
The Board is, however, convinced that all these expressions designate a VAFN. In D1, the VAFN is called "Exhaust Nozzle 132" as well, see Fig. 3, although the exhausted air has clearly not been combusted. It can thus not be concluded from the term "exhaust" in D4 that the variable area nozzle must exhaust combustion gas from a core engine. The term "turbofan" in D4, e.g. in "turbofan nozzle" on page 84, directs a person skilled in the art, an engineer specialised in turbofan engine control, rather to the meaning of "VAFN", since VAFNs are essential and indispensable components of a turbofan system.

Also the graphs in Figs. 6 and 7 of D4, which represent comparative tests of the reaction of a variable area nozzle to a control commanding a certain opening degree, do not lead to a different understanding. In contrast to the time t, which is given in seconds on the abscissa, the value "U" on the ordinate does not reflect an opening angle in degrees or an area in square units, but a controller output or command law without dimension (see Figs. 1, 3, 5, pages 82, 83). An opening degree or quick opening typical for a core engine or afterburner nozzle can thus not be derived from this test situation, contrary to the Respondent's suggestion.

5.2 The Board supports the Respondent's reading of D4 according to which in the practical example of section IV (pages 83, 84), the "classic" PID controller executes a given control command and assures that a VAFN assumes a certain opening degree or area without having previously determined this opening degree/area. In contrast, for example D1's controller explicitly generates such control commands or signals, in particular as a reaction to and in order to reduce fan flutter, see above.

6. **Main request - inventive step**

6.1 The gas turbine engine and method of claims 1 and 7 differ from those of D1 in that the controller is trimmed and the VAFN is adjusted "in response to a neural network".

In line with paragraph [0004] of the patent, the problem to be solved can thus be considered as providing an alternative or even improved control of fan stability/flutter at low power and low flight speeds, which is capable of adapting to changing conditions.

The last aspect of the problem is emphasized by the Respondent, in particular in the context of fan conditions changing over the lifetime of the fan because of deterioration of components. In the absence of claim features actually requiring self-learning or training of the neural network over the lifetime of the engine, the mere capability of neural networks to be trained or to be designed to learn during this time cannot result in a mandatory aspect of the problem, as proposed by the Respondent. Also the map and the scaling factor in D1 are basically capable of being reprogrammed during the lifetime of the engine, because they are part of software programs.

6.2 The person skilled in the art has been aware of neural networks used for trimming gas turbine engine controller at the priority date of the patent, see e.g. D2, abstract & Fig., D3, paragraph [0016].
Known characteristics and advantages of neural networks are that they are able to learn and to handle non-linear complex systems, as already mentioned by the Opposition Division in points 8.2.5, 9.2 of the impugned decision.

Although D4 does not deal with flutter control, the person skilled in the art would consider its content to be relevant for solving the problem, since it proposes efficient adaptive control of the opening of a turbofan exhaust nozzle, see abstract.
The known advantages of neural network controller are confirmed in the general introductory part of D4, page 80: "*Neural network are candidates for ... control of non-linear systems. Their use is particularly attractive if a mathematical model of the process is not available, but only empirical law and experimental data exist*".
Furthermore, D4 teaches on page 84 that a neural network might achieve a quicker and more exact response "with very low overshoot" compared to a "classic" PID control.

6.3 These characteristics and advantages of neural networks match the characteristics and requirements of the fan flutter control in the second method of D1 (Figs. 1, 2), i.e. adaptive control in a non-linear region of fan operation with possible risk of overshooting. In the Board's view, a neural network therefore lends itself for controlling fan flutter through control of the VAFN in the region of non-linear fan operation, where it is able to determine a magnitude of the flutter control signal based on empirical and experimental data. Furthermore, a neural network adapts to changing conditions by training and learning and is thus an obvious choice for taking over reprogramming and updating the map of Fig. 1 according to paragraph [0054] of D1, including adjustment of the differential quantity.

When implemented in the above obvious way in the gas turbine engine of D1, a neural network trims the controller 124 in the sense of claim 1 by varying the magnitude of the control signal and reconfiguring the map of Fig. 1. Thereby, the control method of Figs. 2 is improved and thus the problem solved.

6.4 Furthermore, as already set out in point 2.3 of the Board's communication under Article 15(1) RPBA, D4 proposes in section IV, page 83, Fig. 5 a way for improving a PID control by means of neural networks, which can be directly applied to the first method of fan flutter control of D1, Figs. 5.
A neural network model could learn the process behaviour and a neural controller the PI controller's behaviour. Once the neural network "model" is trained, it is used for trimming the neural network "controller" in order to elaborate a better command law than D1's PI. When trimmed and trained in this way, the neural controller takes over control of the fan flutter in the first method of D1.

6.5 The Respondent denies any obvious link between D1 and D4 or common general knowledge which would motivate a person skilled in the art to choose a neural network for solving the problem.
D4 did not deal with fan flutter control and the nature of the controller in D1 and D4 were different, so that D4's teaching neither appeared to be suitable for solving the problem, nor for combination with D4. Even when replacing D1's controller 124 with a neural controller, this was different from trimming D1's controller in response to a neural network as claimed.

The Board has taken into account most of these arguments in its above reasoning.
An obvious link between D1's first method and D4 is the "classic" character of the controller PI and PID. Even if the D1's PI controller was *replaced* by a neural network as suggested by D4, the latter is still trimmed by a further neural network, namely the neural model.
For the second method of D1, the general teaching of D4 with regard to neural networks is more relevant. Here, D1 already discloses updating the map of Fig. 1, which amounts to trimming the controller 123. Whilst it is true that the cited prior art does not provide a direct instruction to use a neural network specifically for this task or for determining the control signals in the non-linear mode of D1, the Board considers this to be obvious in the light of the salient correspondence between the second method of D1, the problem to be solved and the general teaching of D4 with regard to the aspects "improved and adaptive control of a complex non-linear process" and "determining the magnitude of a control signal".

6.6 For the above reasons, the subject-matter of claims 1 and 7 according to the main request do not involve an inventive step in the sense of Article 56 EPC.

7. **First auxiliary request - interpretation of the added features**

7.1 Companion specimens of the claimed gas turbine engine are other gas turbine engines of exactly the same type. Companion specimens may also include fans, fan blades or other engine components identical in design and construction with those employed in the claimed gas turbine engine.
Companion testing means subjecting the companion specimen to various conditions such as temperatures, loads etc. and observing the reaction in order to determine an expected behaviour of other, non-tested specimen in "real" operation. In this sense, the tests are equivalent to experiments in contrast to e.g. quality control tests, in which a pre-determined expected outcome is only verified. In the context of fan blade flutter, in particular the fan blade flutter signature and boundary can be determined by fan blade companion specimen testing.

7.2 According to the Respondent, the term "companion specimen test" always implies long term tests over the lifetime of an engine or component in order to determine the course and consequences of ageing and deterioration. Companion specimen testing was also argued to have been defined in paragraph [0023] of the patent in this sense.

The Board agrees that this can be one purpose of companion specimen testing. But there are many others. Accordingly, the cited paragraph [0023] states : "Companion specimen tests *may include* testing of fan blades and/or other engine components to determine the baseline expected deterioration profile". The corresponding granted method claim 10 is also silent about any duration and purpose of testing.

8. **First auxiliary request- inventive step**

8.1 According to paragraph [0041] of D1, the second method includes in step 512 (Fig. 2A) the generation of data representing flutter conditions of the fan, which are indicative of flutter instability and define the flutter boundary region, from known information, experimental data or projections based on experimental data. This originally generated data can later be updated and reflects then the flutter boundary region of a particular fan blade or specimen (paragraph [0054]). Consequently, a person skilled in the art understands that the data is originally generated from experimental data or tests carried out with companion specimens. This is the usual, common approach for determining a flutter boundary region, as convincingly set out by the Appellant, since fan flutter experiments and tests on particular fan blades of engines in actual service would inevitably degrade the performance of the fan and may lead to fatigue failure and other permanent damage (paragraph [0006] of D1), and as such would pose a danger to the aircraft being tested.

8.2 Like any neural network, also a neural network replacing and updating part of the software programs employed in the second method of D1 (as detailed above in point 6.3) needs to be trained. Here, data suitable for training the neural network are already available in the form of experimental data, which are stored in the the memory for determining the differential quantity in step 520 of Fig. 2A of D1, see paragraph [0041].

In the Board's view it is a straightforward option to to use these existing experimental data obtained by companion specimen testing to train a neural network, which needs to learn initially the map of Fig. 1. It is indeed the only option already suggested by D1 for the second method.

8.3 The Respondent objects that information about lifetime testing and data about expected deterioration of the fan blades over time is missing in the prior art, so that nothing could lead a person skilled in the art to consider training through fan blade companion testing.

The Board acknowledges that the experimental data collected according to paragraph [0041] of D1 are not described as containing deterioration data. Also the later update of the fan flutter boundary according to paragraph [0054] seems to be based on fan specific experience during flight events, aircraft mission and fleet data rather than companion specimen tests.
This is, however, not relevant, because neither claim 1, nor claim 6 are limited to testing deterioration through lifetime.

8.4 Since also the additional features of claims 1 and 6 are thus obvious in the light of D1 and common general knowledge, the subject-matter of claim 1 and method of claim 6 according to the first auxiliary request do not involve an inventive step in the sense of Article 56 EPC.

9. **Second auxiliary request - admission**

9.1 During oral proceedings, after refusal of the first auxiliary request, the Respondent announced for the first time their intention to file a second auxiliary

request.
An auxiliary request filed at such a late stage of the proceeding is, in principle, not taken into account unless there are exceptional circumstances, which have been justified by cogent reasons, Article 13(2) RPBA.

9.2 The Respondent claims hat they have been surprised by the new lines of argumentation on inventive step produced by both the Appellant and the Board during oral proceedings, in particular with regard to general knowledge and companion specimen testing.

9.3 The Board is unable to see any surprising development during oral proceedings.

D1 was considered to be the closest prior art document since the opposition proceedings. In their grounds of appeal, the Appellant has argued lack of inventive step in the light of general knowledge of the skilled person, as apparent from D4. This was even their main line of arguments and explained over more than 4 pages. The Board indicated in its preliminary opinion under Article 15(1) RPBA that the subject-matter of granted claim 1 did not appear inventive over a combination of D1 (first method) and D4. With regard to the added feature of the first auxiliary request, it held that D1 already seemed to disclose in paragraph [0041] experimental testing of turbofan engines in order to establish fan flutter boundary, the results of which would obviously be used for training the neural network. The Appellant has argued the same in their reply to the filing of the first auxiliary request. Neither the Opposition Division, nor the Board, nor the Appellant did take into account any deterioration or life time aspect for defining the problem to be solved, since this was not reflected in an independent claim of

the main and first auxiliary request.
The Respondent has thus been aware of all lines of arguments leading to the above conclusion of lack of inventive step since October 2020. Yet they did not react to the Board's negative preliminary opinion by filing a further auxiliary request until the very last moment in oral proceedings.

Even an actual change in the Board's opinion or reasoning during oral proceedings would not have represented an exceptional circumstance justifying the filing of further auxiliary request, as long as the arguments, on which the decision is based, were known to the Respondent before and/or discussed during oral proceedings. This is presently the case.

9.4 Furthermore, the Appellant objects that the amendments in the independent claims of the second auxiliary request did not comply with the requirements of clarity and unambiguous original disclosure, Articles 84 and 123(2) EPC.
The purpose of companion testing "to determine the baseline expected deterioration profile" was taken from the context of paragraph [0022] of the description of the published application (corresponding to paragraph [0023] of the patent cited by the Respondent). The intended limitation conferred by such motivation to execute tests and the impact on structural features of the claimed gas turbine engine were obscure. Already the term "deterioration profile" did not have a clearly defined meaning.

The Board recognizes some merit in these arguments. In any case, admission of the second auxiliary request would have opened the floor for discussion of new questions and problems introduced for the first time by

the amendments in the independent claims.
In view of the late stage of the proceedings and the opportunity for the Respondent to file a further request much earlier, the Board considers this not the justified with regard to procedural fairness and economy, let alone by exceptional circumstances.

9.5 For the above reasons the Board decides not to admit the Respondent's second auxiliary request to the proceedings according to Article 13(2) RPBA.

10. **Conclusion**

With their appeal, the Opponent successfully challenges the findings of the Opposition Division that the subject-matter of claim 1 and the method of claim 7 as granted (main request) involve an inventive step. Consequently, the decision under appeal has to be set aside.
Taking into account the amendments made in the first auxiliary request, the subject-matter of claim 1 and the method of claim 6 do still not meet the requirement of Article 56 EPC. Since the second auxiliary request was not admitted to the proceedings, there is no allowable request and the patent must be revoked pursuant to Articles 101(3)b) and 111(1) EPC.

Order

For these reasons it is decided that:

1. The decision under appeal is set aside.

2. The patent is revoked.

The Registrar: The Chairwoman:

G. Magouliotis S. Hillebrand

Decision electronically authenticated