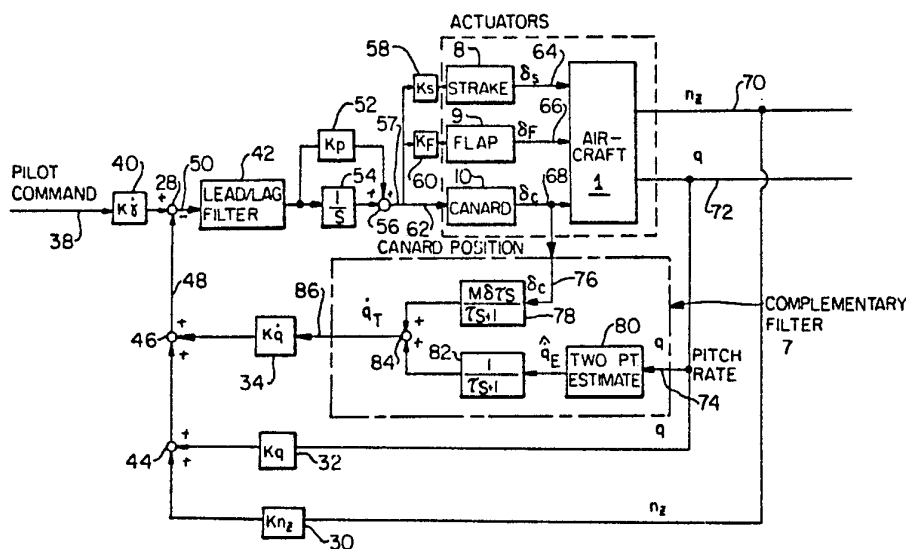




## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

<p>(51) International Patent Classification<sup>4</sup> : <b>B64C 13/16</b></p>	<p><b>A1</b></p>	<p>(11) International Publication Number: <b>WO 87/ 02964</b> (43) International Publication Date: 21 May 1987 (21.05.87)</p>
<p>(21) International Application Number: PCT/US86/02281 (22) International Filing Date: 30 October 1986 (30.10.86) (31) Priority Application Number: 797,089 (32) Priority Date: 12 November 1985 (12.11.85) (33) Priority Country: US  (71) Applicant: GRUMMAN AEROSPACE CORPORATION [US/US]; South Oyster Bay Road, Bethpage, NY 11714 (US). (72) Inventor: KLEIN, Robert, W. ; 121 Spindrift Lane, Rancho Palos Verdes, CA 90274 (US). (74) Agents: LISS, Morris et al.; Pollock, VandeSande &amp; Priddy, P.O. Box 19088, Washington, DC 20036 (US).</p>		<p>(81) Designated States: AT (European patent), AU, BE (European patent), CH (European patent), DE (European patent), FR (European patent), GB (European patent), IT (European patent), JP, LU (European patent), NL (European patent), SE (European patent).  <b>Published</b> <i>With international search report.</i></p>

## (54) Title: FLIGHT CONTROL SYSTEM EMPLOYING COMPLEMENTARY FILTER



## (57) Abstract

Flight control systems, more particularly such a system employed in an inherently unstable aircraft equipped with a movable canard. The present system provides the necessary stability margin for such an aircraft, and aircraft vibration is damped to a great extent due to lower control actuator noise. Strake (8), flap (9) and canard (10) control surfaces of an aircraft are driven by an error signal (57) which is comprised of a pilot stick command signal (38) and feedback components including measured vertical acceleration (30) and pitch rate (32) of the aircraft and third feedback component derived from a complementary filter (7). The filter has a high-pass filter section (78) which operates upon canard position data and a low-pass filter section (82) which operates upon pitch rate. A summation of the signals passing both filtering sections is summed with the vertical acceleration and pitch rate feedback signals to form a combined feedback signal (50).

**FOR THE PURPOSES OF INFORMATION ONLY**

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

<b>AT</b> Austria	<b>FR</b> France	<b>ML</b> Mali
<b>AU</b> Australia	<b>GA</b> Gabon	<b>MR</b> Mauritania
<b>BB</b> Barbados	<b>GB</b> United Kingdom	<b>MW</b> Malawi
<b>BE</b> Belgium	<b>HU</b> Hungary	<b>NL</b> Netherlands
<b>BG</b> Bulgaria	<b>IT</b> Italy	<b>NO</b> Norway
<b>BJ</b> Benin	<b>JP</b> Japan	<b>RO</b> Romania
<b>BR</b> Brazil	<b>KP</b> Democratic People's Republic of Korea	<b>SD</b> Sudan
<b>CF</b> Central African Republic	<b>KR</b> Republic of Korea	<b>SE</b> Sweden
<b>CG</b> Congo	<b>LI</b> Liechtenstein	<b>SN</b> Senegal
<b>CH</b> Switzerland	<b>LK</b> Sri Lanka	<b>SU</b> Soviet Union
<b>CM</b> Cameroon	<b>LU</b> Luxembourg	<b>TD</b> Chad
<b>DE</b> Germany, Federal Republic of	<b>MC</b> Monaco	<b>TG</b> Togo
<b>DK</b> Denmark	<b>MG</b> Madagascar	<b>US</b> United States of America
<b>FI</b> Finland		

## FLIGHT CONTROL SYSTEM EMPLOYING COMPLEMENTARY FILTER

## FIELD OF THE INVENTION

The present invention relates to flight control systems, and more particularly to such a system employed in an aircraft equipped with a movable canard.

5

## BACKGROUND OF THE INVENTION

Modern aircraft designs have included multi-control surface aircraft, such as the X-29 aircraft which employs a movable canard. Due to the location of the center of gravity of such an aircraft, there is inherent instability which must be carefully attended to by a computer-aided pilot flight control system. In conventional systems, feedback in the flight control system is provided with normal acceleration and pitch rate parameters, derived from gyros and accelerometers. This feedback data is supplied to a servo system which is intended to stabilize the aircraft.

10

15

In multi-control surface high performance aircraft such as the canard-equipped X-29, the craft is inherently unstable, and dependence upon conventional flight control system technology has raised the problems of stability margin and high control actuator noise. At high operational speeds, these factors detract from the effectiveness of such an aircraft.

20

25

## BRIEF DESCRIPTION OF THE PRESENT INVENTION

The present invention is an improvement of the flight control systems of the prior art. Strake, flap and canard control surfaces of an aircraft are driven by an error signal which is comprised of a pilot stick command signal and feedback components including measured vertical acceleration and pitch rate of the aircraft and a third feedback component derived from a complementary filter. The filter has a high-pass filter section which operates upon canard position data and a low-pass filter section which operates upon pitch rate. A summation of the signals passing both filtering sections is summed with the vertical acceleration and pitch rate feedback signals to form a combined feedback signal. As a result, the stability margin of an inherently unstable aircraft, incorporating a canard, is increased; and aircraft vibration is damped to a greater extent due to lower control actuator noise.

## BRIEF DESCRIPTION OF THE FIGURES

The above-mentioned objects and advantages of the present invention will be more clearly understood when considered in conjunction with the accompanying drawings, in which:

FIG. 1 is a schematic illustration of a canard-equipped aircraft incorporating a basic flight control system, shown in block diagram form;

FIG. 2 is a schematic illustration of a complementary filter, incorporated in a flight control digital computer;

FIG. 3 is a block diagram of a flight control system incorporating the present invention.

## DETAILED DESCRIPTION OF THE INVENTION

FIG. 1 schematically illustrates an aircraft 1 having a control surface 2, which may be a canard, such as employed in the X-29 jet aircraft. An actuator 3 variably positions the control surface 2 by conventional means. A flight control digital computer 4 of known design includes a number of inputs including a pilot command input and data inputs from accelerometers and gyros, collectively referred to by reference numeral 5. Thus far, the system described employs conventional components and subsystems to achieve flight control of a control surface. However, the present invention incorporates position data from the control surface itself, which serves as an additional input 6 to digital computer 4 which, in accordance with the present invention, must perform a complementary filtering function, as will be explained hereinafter.

FIG. 2 is a basic schematic illustration of digital computer 4 which is seen to include the necessary memory and control for achieving the function of a complementary filter 7. By being provided with canard position data as well as pitch rate data, the complementary filter 7 estimates pitch acceleration; further, the filter simultaneously reduces flight control system noise and improves aircraft stability margins.

An implementation of the present invention is illustrated in FIG. 3. The flight control circuit illustrated drives a strake actuator 8, flap 9, and canard 10 of the aircraft 1, which was schematically illustrated in FIG. 1 and indicated as a block in FIG. 3, with a corresponding numeral 1. A pilot command signal

on input line 38 is a pilot stick signal ( $K\dot{Y}$ ) which is multiplied in amplifier 40 by a gain. The resulting amplified signal is fed to difference point 28 where a number of feedback signals are subtracted from the amplified stick signal. These feedback signals include vertical acceleration  $n_z$ , which is detected along output line 70 of a conventional aircraft accelerometer (not shown) followed by amplification in amplifier 30 by a gain factor  $K_{nz}$ . This amplified vertical acceleration feedback signal is summed with a pitch rate signal which is measured by a conventional aircraft gyroscope (not shown) and amplified at amplifier 32 by a gain  $K_q$ . Normally, these two feedback signals are cumulatively subtracted from the amplified stick signal at point 28. However, in the present invention, a third feedback signal is provided from complementary filter 7 to summation point 46 where it is summed with the previously discussed feedback signals that were summed at point 44. This third feedback signal which is input to summing point 46 undergoes amplification in amplifier 34 by a gain  $K_q^*$ . The error signal appearing at the output 50 of difference point 28 is fed to a lead/lag filter of conventional design which differentiates the signal from point 28 thereby reforming the signal to a spike which has the capability of triggering faster response time by the circuitry of FIG. 3.

The output from the lead/lag filter 42 undergoes integration through integrator 54, the output of which is summed at 56 with the filtered signal having undergone amplification by amplifier 52 having a gain  $K_p$ .

The resulting error signal is fed along line 57 in parallel to amplifiers 58 and 60 which respectively

amplify the inputs thereto by gains  $K_s$  and  $K_f$ . These amplifiers respectively drive strake and flap actuators 8 and 9, which are of conventional design. The signal from summing point 56 is directly connected via line 62 to canard 10. Thus, for a particular error signal present at summing point 56, individual gains are provided to the control surface actuators in order to maintain stability for aircraft 1. The actual gains may be empirically derived for a particular aircraft in accordance with well-known techniques.

The outputs from the strake, flap and canard actuators are respectively indicated by the angular quantities  $\delta_s$ ,  $\delta_f$  and  $\delta_c$  on individual parallel actuator control lines 64, 66 and 68. The respective control surfaces, namely, the strake, flap and canard undergo the indicated angular displacement thereby varying the flight control characteristics for aircraft 1. As an aircraft changes its flight path, new vertical acceleration  $n_z$  and pitch rate ( $q$ ) occur to be fed back. The pitch rate  $q$  is not only fed back to the amplifier 32, but also forms the input to the complementary filter 7. Thus, the pitch rate signal from line 72 is connected to an input terminal 74 of a two-point estimator 80 which performs a well-known flight control calculation on pitch rate to form a translated quantity  $\hat{q}_E$ . This quantity is then fed to the input of a low-pass filter 82 which basically integrates the output from the two-point estimator circuit 80 and forms a first input at summing point 84.

Canard position data  $\delta_c$  present on control line 68 is connected in parallel to the complementary filter 7 so as to form a second input thereto. This input is connected to a high-pass filter 78, via connection line 76. The

high-pass filter has a gain  $M_\delta$  which relates to a well-known flight control moment parameter. The complementary filter 7 is so named due to the fact that the low-pass 82 filter operates upon pitch rate, and the high-pass filter 78 operates upon the canard position. Otherwise stated, high and low frequency components from pitch rate and canard position, respectively, complement one another. The time constants  $\tau$  for filters 78 and 82 are chosen to achieve maximum stability margin.

The outputs from filters 78 and 82 are added at summing point 84 to form a filter output signal  $\dot{q}_T$ , along line 86, which is then input to the amplifier 34 resulting in an amplified feedback signal from the complementary filter which is added at summing point 46 to the other two feedback signals from summing point 44. The resultant feedback signal is connected via line 48 to point 28, where a total error signal is formed.

It should be understood that the invention is not limited to the exact details of construction shown and described herein for obvious modifications will occur to persons skilled in the art.

## CLAIMS

I claim:

1. In a flight control system for increasing the stability of a multi-control surface aircraft wherein an error signal is formed from signal components including a pilot stick signal and a composite feedback signal, the system including:
- 5 means for sensing vertical acceleration of an aircraft and generating a signal corresponding thereto;
- means for sensing pitch rate of an aircraft and generating a signal corresponding thereto;
- 10 a complementary filter having
- (a) means for high-pass filtering a signal generated from a position sensor connected to one of the control surfaces;
- (b) means for low-pass filtering a translated
- 15 value of the pitch rate;
- (c) means for summing the low and high pass filtered signals;
- means for combining the stick signal, vertical acceleration, pitch rate, and summed filtered signals
- 20 to form the error signal; and
- means for connecting the error signal to actuators for each of the multi-control surfaces.
2. The structure set forth in claim 1 wherein said control surface having a position sensor connected thereto is a canard.

3. The structure set forth in claim 2 and further wherein the remaining control surfaces include a strake and a flap.
4. The structure set forth in claim 3 wherein the high-pass filtering means comprises means for differentiating the sensor signal from the canard with a time constant selected to maximize stability margin for  
5 the aircraft.
5. The structure set forth in claim 3 wherein the low-pass filtering means comprises:  
means for estimating a value of pitch rate from a two-point estimate; and  
5 means connected to the two-point estimating means for integrating the estimated value of pitch rate with a time constant selected to maximize the stability margin for the aircraft.
6. The structure set forth in claim 5 wherein the high-pass filtering means comprises means for differentiating the sensor signal from the canard with a time constant selected to maximize the stability margin  
5 for the aircraft.
7. A flight control method for use with a multi-control aircraft comprising the steps:  
sensing vertical acceleration of an aircraft and generating a signal corresponding thereto;  
5 sensing pitch rate of an aircraft and generating a signal corresponding thereto;

- high-pass filtering a signal generated from a position sensor connected to one of the aircraft control surfaces;
- low-pass filtering a translated value of the pitch rate;
- 10 summing the filtered signals;
- combining the stick signal, vertical acceleration, pitch rate and summed filtered signals to form the error signal; and
- 15 connecting the error signal to actuators for each of the multi-control surfaces.

8. The method set forth in claim 7 wherein the high-pass filtering further comprises the step of differentiating the sensor signal from a control surface with a time constant selected to maximize stability margin for the aircraft.

5

9. The method set forth in claim 7 wherein the low-pass filtering further comprises the steps:

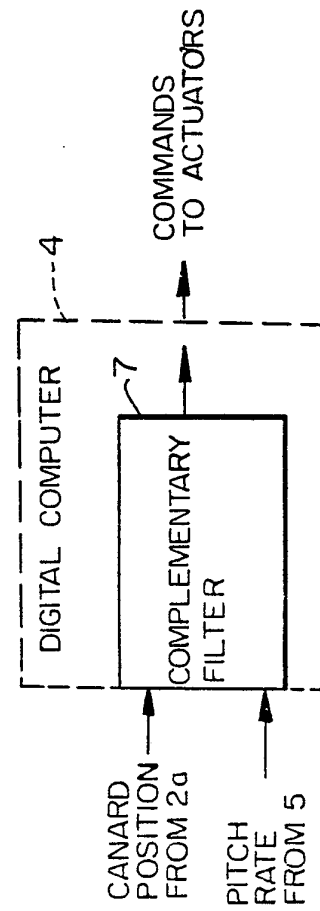
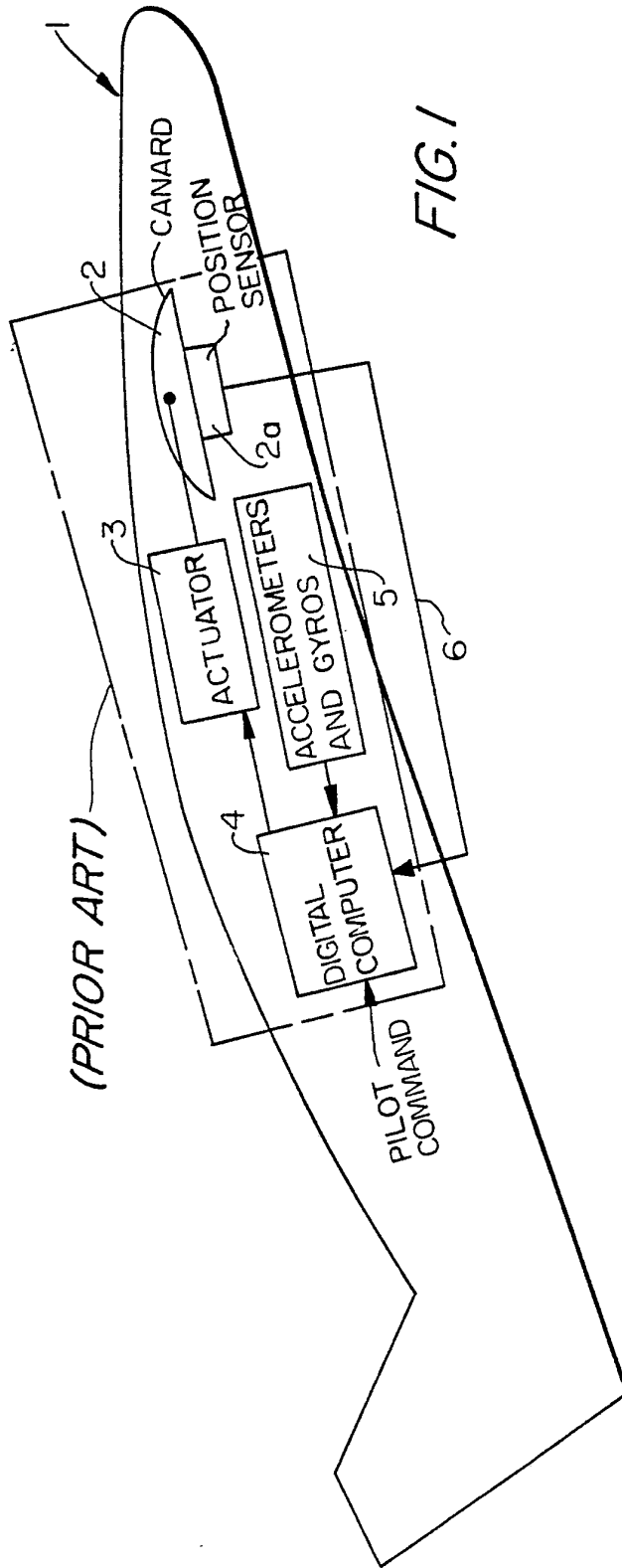
estimating a value of pitch rate from a two-point estimate; and integrating the estimated pitch rate with a time constant selected to maximize the stability margin for the aircraft.

5

10. The method set forth in claim 8 wherein the low-pass filtering further comprises the steps:

estimating a value of pitch rate from a two-point estimate; and integrating the estimated pitch rate with a time constant selected to maximize the stability margin for the aircraft.

5





# INTERNATIONAL SEARCH REPORT

International Application No PCT/US 86/02281

<b>I. CLASSIFICATION OF SUBJECT MATTER</b> (if several classification symbols apply, indicate all) <sup>3</sup>		
According to International Patent Classification (IPC) or to both National Classification and IPC		
INT. CL. <sup>4</sup> B64C 13/16		
US CL. 244/191		
<b>II. FIELDS SEARCHED</b>		
Minimum Documentation Searched <sup>4</sup>		
Classification System	Classification Symbols	
	244/75R, 75A, 76R, 76B, 76C, 175, 181, 191, 193, 194, 45R, 45A	
U.S.	364/434, 435, 572', 318/584, 619	
Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched <sup>5</sup>		
<b>III. DOCUMENTS CONSIDERED TO BE RELEVANT</b> <sup>14</sup>		
Category *	Citation of Document, <sup>16</sup> with indication, where appropriate, of the relevant passages <sup>17</sup>	Relevant to Claim No. <sup>18</sup>
A	US, A, 2,880,384, (SURTEES) 31 March 1959	
A	US, A, 2,958,483, (McRUER ET AL) 01 November 1960	
A	US, A, 3,073,554, (KAUFMAN) 15 January 1963	
A	US, A, 3,077,557, (JOLINE ET AL) 12 February 1963	
A	US, A, 3,109,970, (SMYTH) 05 November 1963	
Y	US, A, 3,137,459, (SMITH ET AL) 16 June 1964	1-10
A	US, A, 3,215,374, (OLSHAUSEN) 02 November 1965	
A	US, A, 3,240,447, (OLSHAUSEN) 15 March 1966	
A	US, A, 3,241,027, (ALBRIGHT) 15 March 1966	
A	US, A, 3,241,077, (SMYTH ET AL) 15 March 1966	
A	US, A, 3,246,220, (SHINNERS) 12 April 1966	
A	US, A, 3,250,897, (VASA ET AL) 10 May 1966	
Cont.		
<p>* Special categories of cited documents: <sup>15</sup></p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> <p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.</p> <p>"&amp;" document member of the same patent family</p>		
<b>IV. CERTIFICATION</b>		
Date of the Actual Completion of the International Search <sup>2</sup>	Date of Mailing of this International Search Report <sup>2</sup>	
15 January 1987	09 FEB 1987	
International Searching Authority <sup>1</sup>	Signature of Authorized Officer <sup>20</sup>	
ISA/US	Galen Barefoot	

## III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)

Category *	Citation of Document, <sup>16</sup> with indication, where appropriate, of the relevant passages <sup>17</sup>	Relevant to Claim No <sup>18</sup>
A	US, A, 4,326,253, (COOPER ET AL) 20 April 1982	
A	US, A, 4,385,362, (ARCA) 28 May 1982	
A	JP, A, 136,299, (KIMURA) 28 November 1978	
Y	N, "Gust Alleviator and Rigidity Augmentor for Supersonic Airplanes", issued 22 January 1962, Andrew et al.	1-10

**FURTHER INFORMATION CONTINUED FROM THE SECOND SHEET**

A	US, A, 3,250,898, (VASA) 10 May 1966	
A	US, A, 3,251,982, (KEMMER ET AL) 17 May 1966	
A	US, A, 3,279,725, (ANDREW ET AL) 18 October 1966	
A	US, A, 3,470,430, (YOUNKIN) 30 September 1969	
A	US, A, 3,648,031, (NEAL) 07 March 1972	
A	US, A, 3,902,686, (WYKES ET AL) 02 September 1975	
Y	US, A, 4,161,300, (SCHWAERZLER) 17 July 1979	3-6

**V.  OBSERVATIONS WHERE CERTAIN CLAIMS WERE FOUND UNSEARCHABLE <sup>10</sup>**

This international search report has not been established in respect of certain claims under Article 17(2) (a) for the following reasons:

1.  Claim numbers ..... , because they relate to subject matter <sup>12</sup> not required to be searched by this Authority, namely:

2.  Claim numbers ..... , because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out <sup>13</sup>, specifically:

**VI.  OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING <sup>11</sup>**

This International Searching Authority found multiple inventions in this international application as follows:

1.  As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims of the international application.

2.  As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims of the international application for which fees were paid, specifically claims:

3.  No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim numbers:

4.  As all searchable claims could be searched without effort justifying an additional fee, the International Searching Authority did not invite payment of any additional fee.

**Remark on Protest**

- The additional search fees were accompanied by applicant's protest.  
 No protest accompanied the payment of additional search fees.