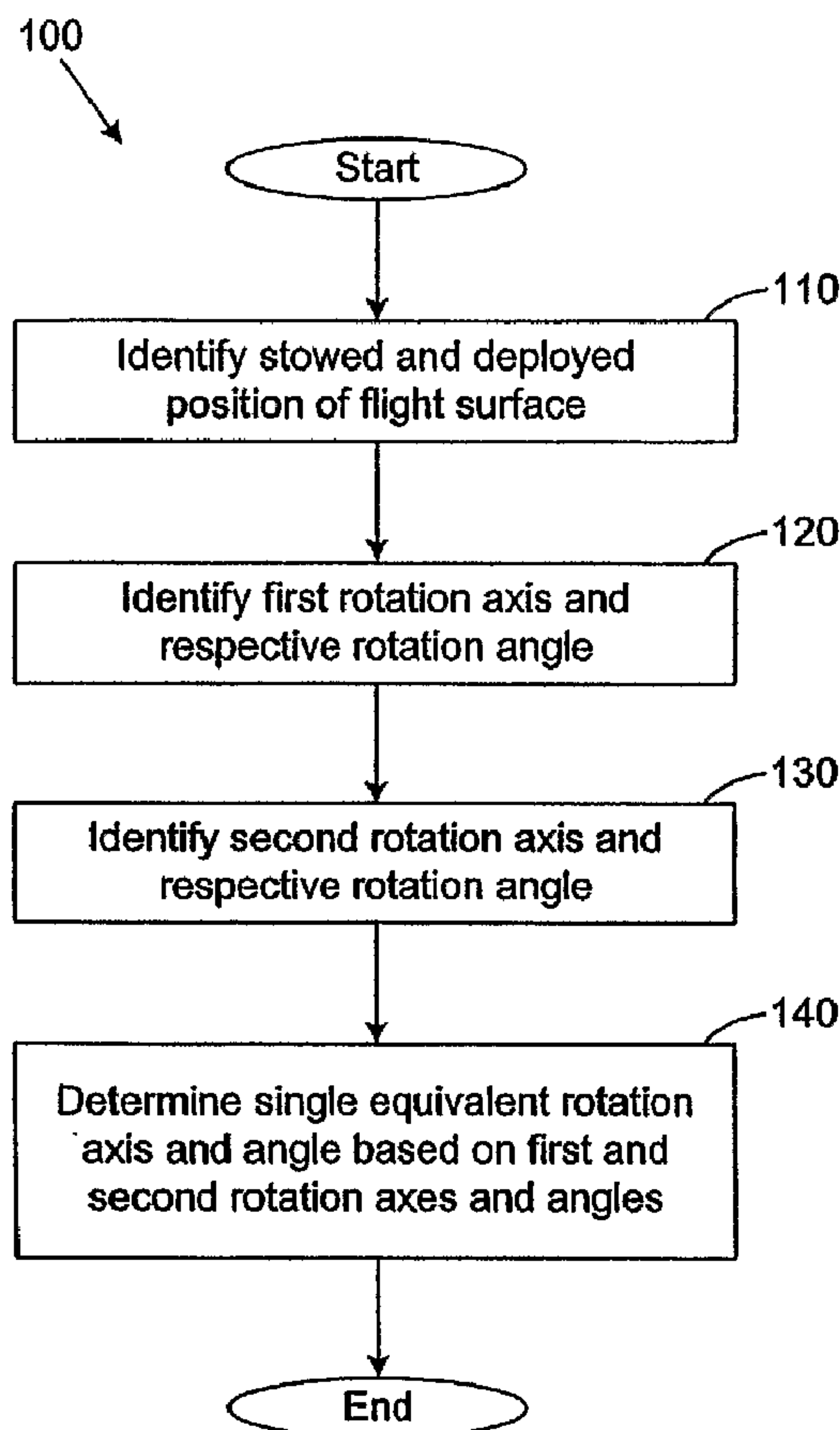




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(54) Title: METHOD FOR DESIGNING A FIN DEPLOYMENT MECHANISM



(57) Abrégé/Abstract:

The present invention concerns a method for designing a deployment mechanism for a flight surface on an airborne body, including the steps of determining a stowed position of the flight surface, determining a deployed position of the flight surface,

(57) **Abrégé(suite)/Abstract(continued):**

identifying a first rotation axis and respective rotation angle and a second rotation axis and respective rotation angle about and through which the flight surface is rotatable in sequence to move the flight surface from the stowed position to the deployed position, or vice versa, and using the identified first and second rotation axes and rotation angles to determine a single equivalent rotation axis and angle, about and through which the flight surface can be rotated from the stowed position to the deployed position, or vice versa.

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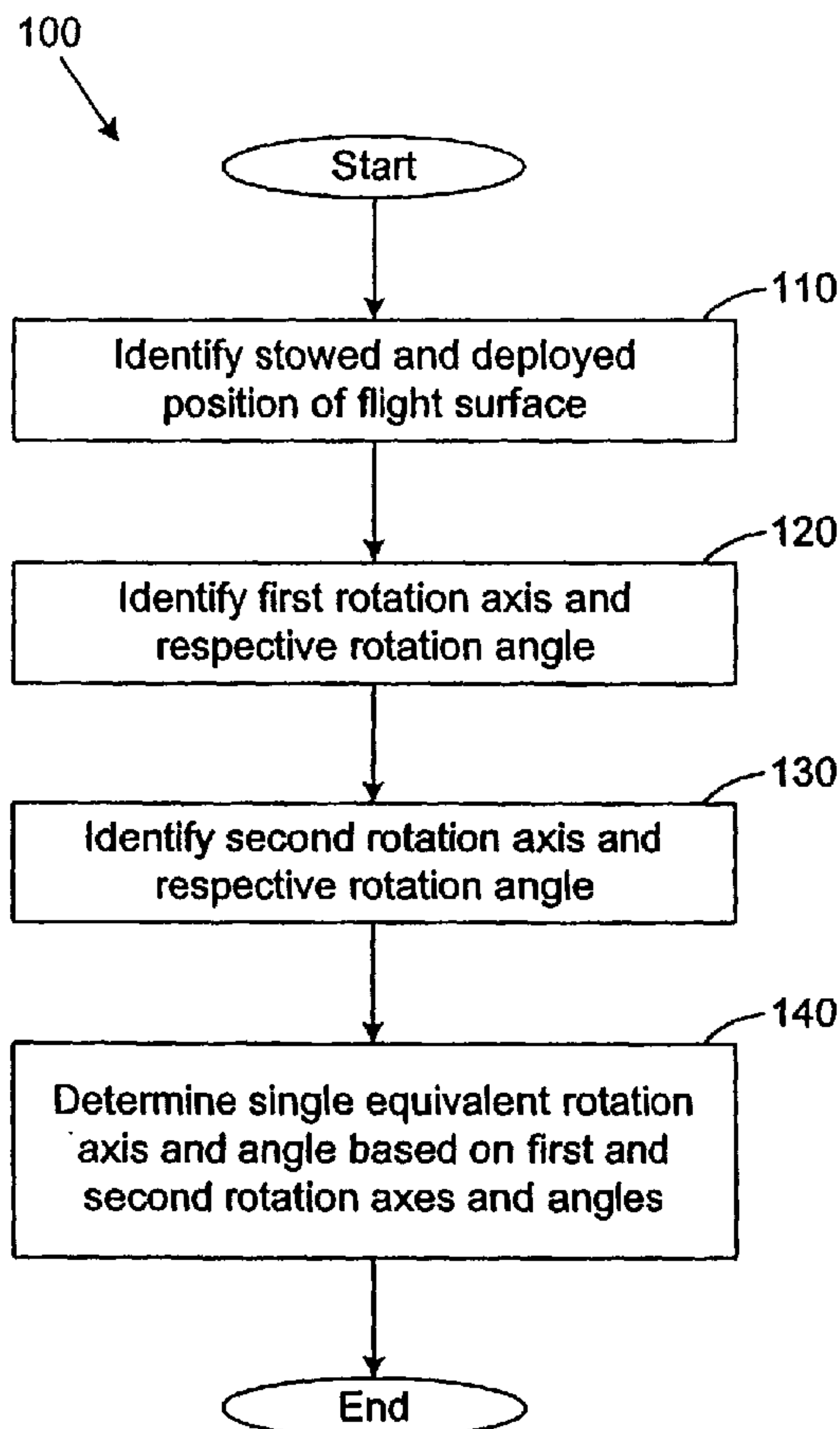
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(54) Title: METHOD FOR DESIGNING A FIN DEPLOYMENT MECHANISM



(57) **Abstract:** The present invention concerns a method for designing a deployment mechanism for a flight surface on an airborne body, including the steps of determining a stowed position of the flight surface, determining a deployed position of the flight surface, identifying a first rotation axis and respective rotation angle and a second rotation axis and respective rotation angle about and through which the flight surface is rotatable in sequence to move the flight surface from the stowed position to the deployed position, or vice versa, and using the identified first and second rotation axes and rotation angles to determine a single equivalent rotation axis and angle, about and through which the flight surface can be rotated from the stowed position to the deployed position, or vice versa.

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METHOD FOR DESIGNING A FIN DEPLOYMENT MECHANISM

5

FIELD OF THE INVENTION

The invention relates to a method for designing a deployment mechanism for a flight surface on a guided projectile, or a guided airborne body such as a bomb,
10 dispenser, munition or missile.

BACKGROUND OF THE INVENTION

Guided airborne bodies such as munitions or missiles are routinely constructed with flight surface deployment systems to provide control and extended
15 range capability. These systems include one or more control mechanisms for moving a foldable and/or retractable flight surface to move the flight surface from a stowed position to an active or deployed position.

Recently, because of volume constraints inside the airborne body, designs of airborne bodies have required the flight surface and/or control mechanism to be
20 stored on, or partially on, the exterior of the airborne body. This has increased the complexity of deployment systems, in particular, those in which the flight surface is rotated, in sequence, about multiple axes to, for example, position the flight surface at a sweep angle or other obliquity relative to the airborne body axis. Such deployment systems include a complex arrangement of parts such as actuators and
25 lock mechanisms to enable achievement of the desired active or deployed position of the flight surface.

To reduce the number of rotations and axes about which the surface is rotated and, consequently, the number of parts of the deployment system, attempts have been made to simulate the multiple axes rotations with a single equivalent axis
30 and single rotation. Although satisfactory, such attempts have not been without difficulty. For example, according to at least one known method, numerous axes and angles are attempted on a trial and error basis until a suitable single axis and single rotation angle are obtained. Such a method is inefficient and tedious.

Thus, a need exists for an effective method for designing a deployment mechanism for a flight surface on an airborne body. Such a method preferably minimizes intrusive volume, the number of parts, and the complexity of the deployment mechanism. Moreover, such a method preferably simplifies the manner by which a single axis and single rotation angle may be obtained about and through which a flight surface is rotatable.

SUMMARY OF THE INVENTION

The present invention concerns a method for designing a deployment mechanism for a flight surface on an airborne body, comprising the steps of:
 10 determining a stowed position of the flight surface;
 determining a deployed position of the flight surface;
 identifying a first rotation axis (k) and respective rotation angle (ϵ) and a second rotation axis (k') and respective rotation angle (ϵ') about and through
 15 which the flight surface is rotatable in sequence to move the flight surface from the stowed position to the deployed position, or vice versa; and
 using the identified first and second rotation axes (k , k') and rotation angles (ϵ , ϵ') to determine a single equivalent rotation axis (k_r) and angle (ϵ_r), about and through which the flight surface can be rotated from the stowed position to the
 20 deployed position, or vice versa;

wherein the equivalent rotational angle (g) is obtained from the equation:

$$\epsilon_r = 2 \cos^{-1} \left[\cos \frac{\epsilon}{2} \cos \frac{\epsilon'}{2} - \sin \frac{\epsilon}{2} \sin \frac{\epsilon'}{2} \cos \theta \right]$$

wherein the equivalent rotation axis (k_r) is obtained from the equation:

$$k_r = k \frac{\sin \frac{\epsilon}{2} \cos \frac{\epsilon'}{2}}{\sin \frac{\epsilon_r}{2}} + k' \frac{\sin \frac{\epsilon'}{2} \cos \frac{\epsilon}{2}}{\sin \frac{\epsilon_r}{2}} + k' \times k \frac{\sin \frac{\epsilon}{2} \sin \frac{\epsilon'}{2}}{\sin \frac{\epsilon_r}{2}},$$

25 where θ is the angle between the rotation axes k and k' .

The foregoing and other features of the invention are hereinafter more fully described and particularly pointed out in the claims, the following description and the annexed drawings setting forth in detail illustrative embodiments of the invention, such being indicative, however, of but a few of the various ways in
5 which the principles of the invention may be employed.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a flow chart of a method for designing a deployment mechanism for a flight surface in accordance with the present invention.

10 Figs. 2-7 schematically illustrate an embodiment of first and second rotation axes and respective rotation angles about and through which the flight surface is rotatable in sequence to move the flight surface from a stowed position to a deployed position.

Figs. 8 and 9 schematically illustrate the coordinate systems of the first and
15 second rotation axes shown in Figs. 2-7 transposed relative to one another.

Figs. 10 and 11 schematically illustrate a single equivalent rotation axis and single equivalent rotation angle based on the first and second rotation axes and respective rotation angles of Figs. 2-7, about and through which the flight surface may be rotated from the stowed position to the deployed position, or vice versa, in
20 accordance with the invention.

Figs. 12-15 schematically illustrate another embodiment of first and second rotation axes and respective rotation angles about and through which the flight surface is rotatable in sequence to move the flight surface from a stowed position to a deployed position.

25 Fig. 16 schematically illustrates the coordinate systems of the first and second rotation axes shown in Figs. 12-15 transposed relative to one another.

Figs. 17 and 18 schematically illustrate a single equivalent rotation axis and

5 single equivalent rotation angle based on the first and second rotation axes and respective rotation angles of Figs. 12-15, about and through which the flight surface may be rotated from the stowed position to the deployed position, or vice versa, in accordance with the invention.

10 DETAILED DESCRIPTION

Referring now in detail to the drawings, and initially to Fig. 1, there is shown a flow chart 100 of a method for designing a deployment mechanism for a flight surface in accordance with the present invention. Initially, at step 110, a stowed position and a deployed position of the flight surface are identified. Figs. 2 and 12, which are described in greater detail below, show exemplary stowed positions and Figs. 7 and 15, which also are described in greater detail below, show exemplary deployed positions.

In step 120, a first rotation axis and a respective rotation angle are identified about and through which the flight surface may be rotated from the stowed position towards the desired deployed position. In step 130, a second, or successive, rotation axis and a respective rotation angle are identified about and through which the flight surface may be rotated to position the flight surface in the deployed position. In step 140, a single equivalent rotation axis and angle are determined based on the first and second rotation axes and rotation angles, about and through which the flight surface may be rotated to achieve the deployed position.

Several advantages are realized by the method according to the present invention. Because two axes and successive rotations are replaced by a single equivalent axis and rotation, the amount of parts and, consequently, the volume occupied by the deployment mechanism, is minimized. Moreover, by minimizing the number of parts, the structure of the deployment mechanism may be simplified. Also, the method simplifies the manner by which a single axis and single rotation angle may be obtained about and through which a flight surface is rotatable.

The following examples demonstrate the method according to the present

5 invention and the advantages associated therewith.

Example 1

10 Figs. 2-7 schematically illustrate an embodiment of a flight surface 204 rotated in sequence from a stowed position to a deployed position. To facilitate describing the invention, the flight surface 204 is shown transposed in a cube with three of its sides marked with, respectively, the letters A, B and C. Fig. 2 shows the flight surface 204 in a stowed position. As is shown in Fig. 2, an orthogonal coordinate system (axes i , j and k) is assigned to the flight surface 204, the coordinate system representing the flight surface 204 in its stowed position. When the flight surface 204 is in its stowed position, the flight surface 204 lies in a plane parallel to the i and j axes, and a proximal end 206 of the flight surface 204 is parallel to the j axis and perpendicular to the plane defined by the i and k axes. The coordinate system serves as a reference datum from which a first rotation of the flight surface 204 is measured.

20 Referring to Fig. 3, k and ϵ represent the first rotation axis and the respective first rotation angle about and through which the flight surface 204 is rotated from the stowed position to a position intermediate the stowed position and the desired deployed position. In the illustrated embodiment, the first rotation angle ϵ is measured counterclockwise about the k axis. Once rotated, an orthogonal coordinate system (axes $i1$, $j1$ and k) is assigned to the flight surface 204, wherein $i1$ and $j1$ represent unit vectors obtained by rotating i and j , respectively, through the angle ϵ . The $i1$, $j1$ and k coordinate system represents the flight surface 204 in the first, or intermediate, rotated position. The first rotation is one of two successive rotations in which the flight surface 204 is moved from its stowed position (Fig. 2) to its extended or deployed position (Fig. 7). Fig. 4 shows the flight surface 204 rotated through an exemplary first rotation angle ϵ of 90 degrees counterclockwise about the k axis.

30 Referring now to Fig. 5, a second orthogonal coordinate system (axes i' , j' and k') is assigned to the flight surface 204. The Fig. 5 coordinate system also represents the flight surface 204 in its intermediate position but serves as a

5 reference datum from which a second rotation of the flight surface 204 is measured. As is described in greater detail below, assigning the i' , j' and k' coordinate system to the intermediate position facilitates analyzing the relationship of the stowed and deployed positions relative to the intermediate position of the flight surface 204.

10 In a manner similar to the identification of the first rotation axis k and first rotation angle ϵ , as shown in Fig. 6, a second rotation axis k' and a respective second rotation angle ϵ' about and through which the flight surface 204 is rotated from the intermediate position to the desired deployed position, are identified. In the illustrated embodiment, the second rotation angle ϵ' is measured counterclockwise about the k' axis. Once rotated, an orthogonal coordinate system (axes $i'1$, $j'1$ and k') (Figs. 6 and 7) is assigned to the flight surface 204, wherein $i'1$ and $j'1$ represent unit vectors obtained by rotating i' and j' , respectively, through the angle ϵ' . The $i'1$, $j'1$ and k' coordinate system represents the flight surface 204 in a second rotated position (i.e., the deployed position). The second rotation is the second of the two successive rotations in which the flight surface 204 is moved from its stowed position (Fig. 2) to its extended or deployed position (Fig. 7). In Fig. 7, the flight surface 204 is shown rotated through an exemplary second rotation angle ϵ' of 105 degrees counterclockwise about the k' axis.

25 Having identified the first and second rotation axes k and k' and respective rotation angles ϵ and ϵ' about and through which the flight surface 204 is successively rotated, a single equivalent rotation axis and rotation angle may then be determined. One way to determine the single axis and rotation angle is by application of Euler's Theorem, which provides that a single axis and rotation angle may be derived from two axes and respective successive rotations. To facilitate use of Euler's Theorem in the present embodiment, the aforementioned $i1$, $j1$ and k intermediate coordinate system (Fig. 4) and the i' , j' and k' intermediate coordinate system (Fig. 5) are transposed relative to one another according to the manner shown in Fig. 8. As is shown in Fig. 8, $i1$ coincides with i' , and $i1$ and i' are perpendicular to k and k' . In this way, $j1$ and j' are in the plane of k and k' . The angle θ represents the angle between k and k' .

5 Referring to Fig. 9, assuming that the first and second rotations ϵ and ϵ' are about mutually perpendicular axes, then the angle θ between k and k' is 90 degrees (i.e., axes k and k' , are perpendicular). Applying Euler's Theorem, a single equivalent angle (ϵ_r) may be obtained from the equation:

$$\epsilon_r = 2 \cos^{-1} \left[\cos \frac{\epsilon}{2} \cos \frac{\epsilon'}{2} - \sin \frac{\epsilon}{2} \sin \frac{\epsilon'}{2} \cos \theta \right]$$

10

and a single equivalent rotation axis (k_r) may be obtained from the equation:

$$k_r = k \frac{\sin \frac{\epsilon}{2} \cos \frac{\epsilon'}{2}}{\sin \frac{\epsilon_r}{2}} + k' \frac{\sin \frac{\epsilon'}{2} \cos \frac{\epsilon}{2}}{\sin \frac{\epsilon_r}{2}} + k' \times k \frac{\sin \frac{\epsilon}{2} \sin \frac{\epsilon'}{2}}{\sin \frac{\epsilon_r}{2}},$$

where ϵ is the first rotation angle, ϵ' is the second rotation angle, and θ is the angle between the first and second rotation axes k and k' .

15 Based on the foregoing, for a first rotation angle ϵ of 90 degrees, a second rotation angle ϵ' of 105 degrees, and an angle θ of 90 degrees between the first and second rotation axes k and k' , the single equivalent rotation is:

$$\epsilon_r = 129 \text{ degrees}$$

20

and the single equivalent rotation axis is:

$$k_r = 0.477 k + 0.622 k' + 0.622 k' \times k$$

25 However, from the relationships of the above coordinate systems, the following equations are applicable:

$$j1 \sin \theta = k \cos \theta - k',$$

$$j' \sin \theta = k - k' \cos \theta, \text{ and}$$

$$i \sin \theta = k \times k'$$

Thus, transposing the equivalent axis to the coordinate system i, j and k of the stowed position results in the following single equivalent axis:

$$k_r = 0.622 i - 0.622 j + 0.477 k$$

Fig. 10 shows the single equivalent axis k_r transposed in the i, j and k coordinate system with the flight surface 204 in a stowed position. Fig. 11 shows the flight surface 204 rotated through the single equivalent rotation angle ϵ_r of 129 degrees counterclockwise about the single equivalent axis k_r . As can be seen by comparing Figs. 7 and 11, the same result obtains if the flight surface 204 is successively rotated about and through first and second rotation axes and respective rotation angles (Figs. 2-7), than if the flight surface 204 is rotated about and through a single equivalent rotation axis and rotation angle (Figs. 10 and 11).

Example 2

Figs. 12-15 schematically illustrate another embodiment of a flight surface 304 rotated in sequence from a stowed position to a deployed position. To facilitate describing the invention, the flight surface 304 is shown transposed in a cube with three of its sides marked with, respectively, the letters A, B and C. Fig. 12 shows the flight surface 304 in a stowed position. As is shown in Fig. 12, an orthogonal coordinate system (axes i, j and k) is assigned to the flight surface 304, the coordinate system representing the flight surface 304 in its stowed position. When the flight surface 304 is in its stowed position, the flight surface 304 lies in a plane parallel to the i and j axes, and a proximal end 306 of the flight surface 304 is parallel to the j axis and perpendicular to the plane defined by the i and k axes. The coordinate system serves as a reference datum from which a first rotation of the flight surface 304 is measured.

5 Referring to Fig. 13, k and ϵ represent the first rotation axis and the
respective first rotation angle about and through which the flight surface 304 is
rotated from the stowed position to a position intermediate the stowed position and
the desired deployed position. Here, the flight surface 304 is rotated through an
exemplary first rotation angle ϵ of 75 degrees counterclockwise about the k axis. An
10 orthogonal coordinate system (axes $i1$, $j1$ and k) is assigned to the flight surface
304, and represents the flight surface 304 in the first, or intermediate, rotated
position.

As shown in Fig. 14, a second orthogonal coordinate system (axes i' , j' and k')
is assigned to the flight surface 304 which represents the flight surface 304 in its
15 intermediate position but serves as a reference datum from which a second rotation
of the flight surface 304 is measured. Referring to Fig. 15, a second rotation axis k'
and a respective second rotation angle ϵ' about and through which the flight surface
304 is rotated from the intermediate position to the desired deployed position, are
identified. Here, the flight surface 304 is shown rotated through an exemplary
20 second rotation angle ϵ' of 50 degrees counterclockwise about the k' axis. Once
rotated, an orthogonal coordinate system (axes $i'1$, $j'1$ and k') (Fig. 15) is assigned to
the flight surface 304, wherein $i'1$ and $j'1$ represent unit vectors obtained by rotating
 i' and j' , respectively, through the angle ϵ' . The $i'1$, $j'1$ and k' coordinate system
represents the flight surface 304 in a second rotated position (i.e., the deployed
25 position).

Having identified the first and second rotation axes k and k' and respective
rotation angles ϵ and ϵ' about and through which the flight surface 304 is
successively rotated, a single equivalent rotation axis and rotation angle may then
determined. To facilitate use of Euler's Theorem, the $i1$, $j1$ and k coordinate system
30 (Fig. 13) and the i' , j' and k' coordinate system (Fig. 14) are transposed relative to
one another according to the manner shown in Fig. 16. As is shown in Fig. 16, $i1$
coincides with i' , and $i1$ and i' are perpendicular to k and k' . In this way, $j1$ and j' are
in the plane of k and k' . The angle θ represents the angle between k and k' .

Referring to Fig. 16, assuming that the first and second rotations ϵ and ϵ' are

about mutually perpendicular axes, then the angle θ between k and k' is 90 degrees (i.e., axes k and k' , are perpendicular). Applying Euler's Theorem, for a first rotation angle ϵ of 75 degrees, a second rotation angle ϵ' of 50 degrees, and an angle θ of 90 degrees between the first and second rotation axes k and k' , the single equivalent rotation is:

$$\epsilon_r = 88 \text{ degrees}$$

and the single equivalent rotation axis is:

$$k_r = 0.794 k + 0.482 k' + 0.370 k' \times k$$

From the relationships of the above coordinate systems, transposing the equivalent axis to the coordinate system i, j and k of the stowed position results in the following single equivalent axis:

$$k_r = 0.482 i - 0.370 j + 0.794 k$$

Fig. 17 shows the single equivalent axis k_r transposed in the i, j and k coordinate system with the flight surface 304 in a stowed position. Fig. 18 shows the flight surface 304 rotated through the single equivalent rotation angle ϵ_r of 88 degrees counterclockwise about the single equivalent axis k_r . As can be seen by comparing Figs. 15 and 18, the same result obtains if the flight surface 304 is successively rotated about and through first and second rotation axes and respective rotation angles (Figs. 12-15), than if the flight surface 304 is rotated about and through a single equivalent rotation axis and rotation angle (Figs. 17 and 18).

Although the invention has been shown and described with respect to certain preferred embodiments, equivalent alterations and modifications will occur to others skilled in the art upon reading and understanding this specification and the annexed

5 drawings. In particular regard to the various functions performed by the above
described integers (components, assemblies, devices, compositions, etc.), the terms
(including a reference to a "means") used to describe such integers are intended to
correspond, unless otherwise indicated, to any integer which performs the specified
function of the described integer (i.e., that is functionally equivalent), even though
10 not structurally equivalent to the disclosed structure which performs the function in
the herein illustrated exemplary embodiment or embodiments of the invention. In
addition, while a particular feature of the invention may have been described above
with respect to only one of several illustrated embodiments, such feature may be
combined with one or more other features of the other embodiments, as may be
15 desired and advantageous for any given or particular application.

What is claimed is:

1. A method for designing a deployment mechanism for a flight surface on an airborne body, comprising the steps of:

determining a stowed position of the flight surface;

determining a deployed position of the flight surface;

identifying a first rotation axis (k) and respective rotation angle (ϵ) and a second rotation axis (k') and respective rotation angle (ϵ') about and through which the flight surface is rotatable in sequence to move the flight surface from the stowed position to the deployed position, or vice versa; and

using the identified first and second rotation axes (k , k') and rotation angles (ϵ , ϵ') to determine a single equivalent rotation axis (k_r) and angle (ϵ_r), about and through which the flight surface can be rotated from the stowed position to the deployed position, or vice versa;

wherein the equivalent rotational angle (ϵ_r) is obtained from the equation:

$$\epsilon_r = 2 \cos^{-1} \left[\cos \frac{\epsilon}{2} \cos \frac{\epsilon'}{2} - \sin \frac{\epsilon}{2} \sin \frac{\epsilon'}{2} \cos \theta \right]$$

wherein the equivalent rotation axis (k_r) is obtained from the equation:

$$k_r = k \frac{\sin \frac{\epsilon}{2} \cos \frac{\epsilon'}{2}}{\sin \frac{\epsilon_r}{2}} + k' \frac{\sin \frac{\epsilon'}{2} \cos \frac{\epsilon}{2}}{\sin \frac{\epsilon_r}{2}} + k' \times k \frac{\sin \frac{\epsilon}{2} \sin \frac{\epsilon'}{2}}{\sin \frac{\epsilon_r}{2}},$$

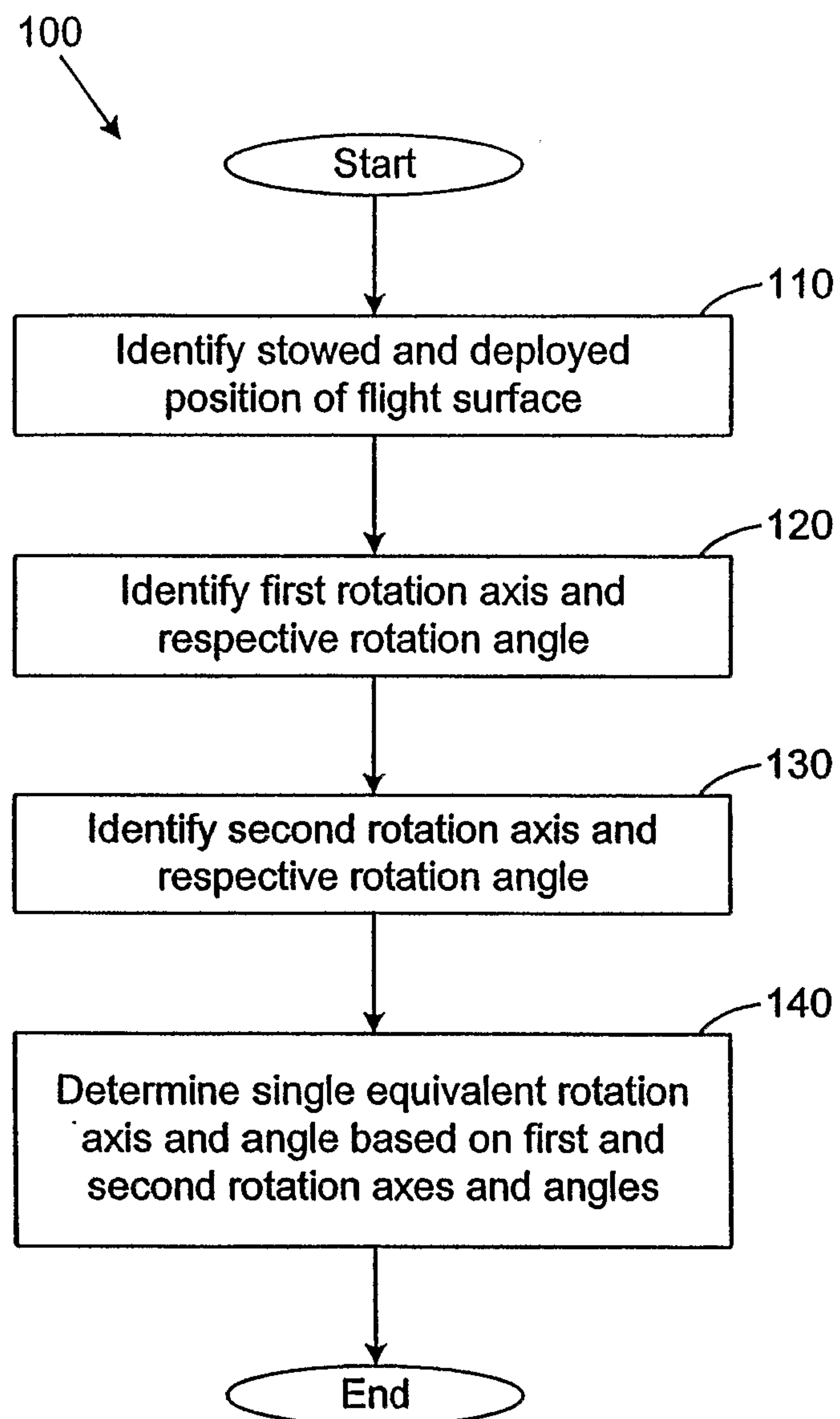
where θ is the angle between the rotation axes k and k' .

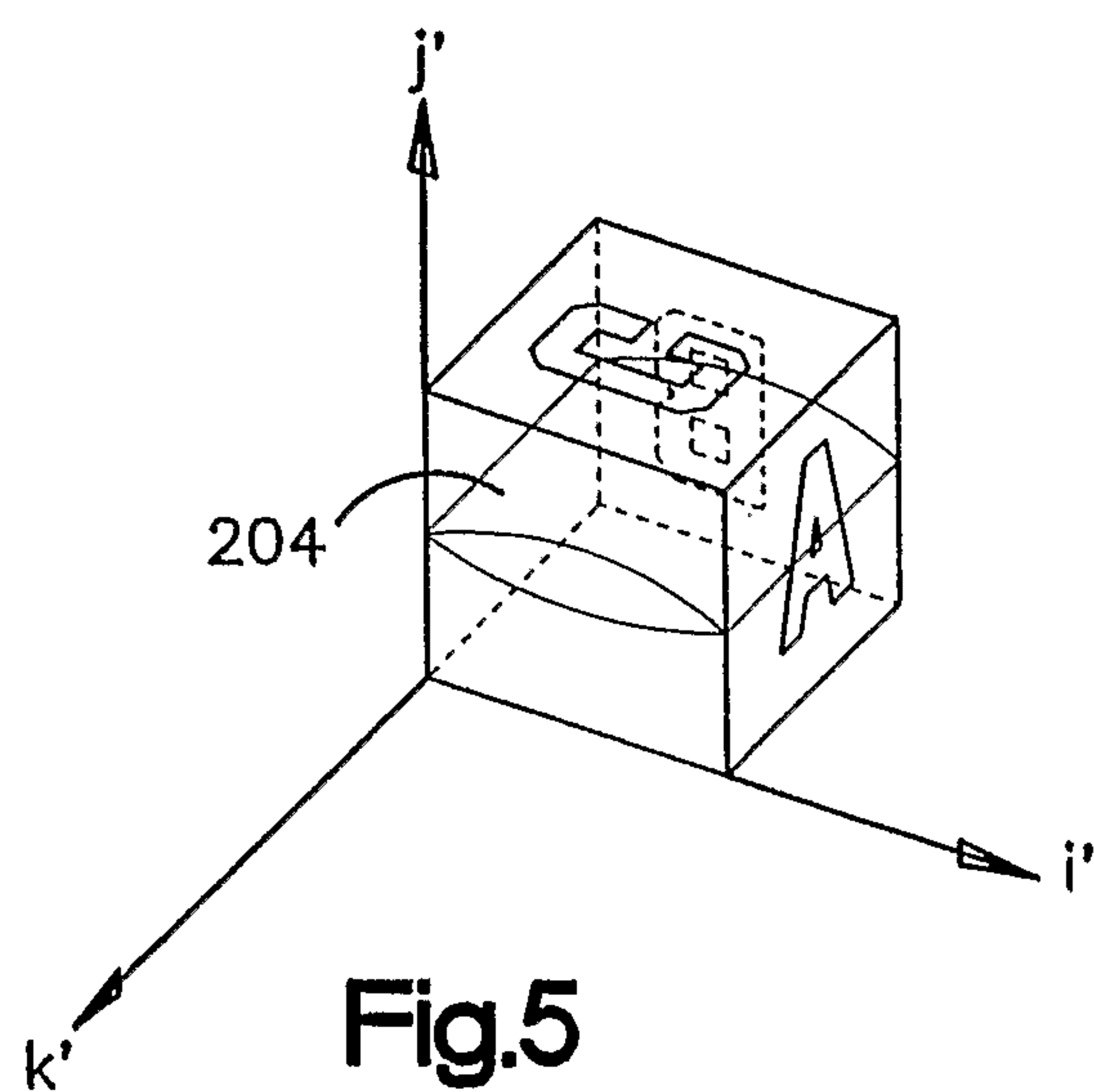
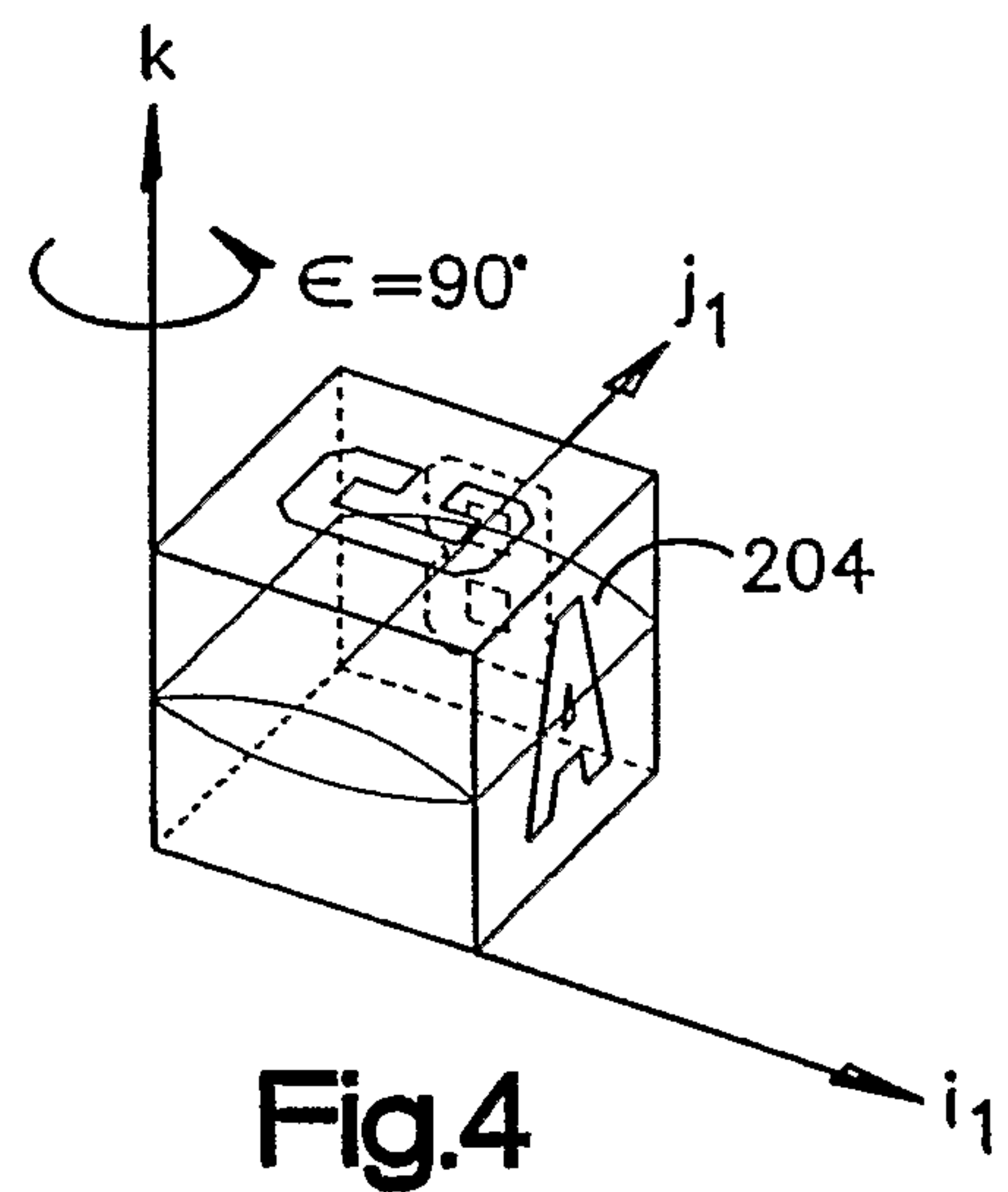
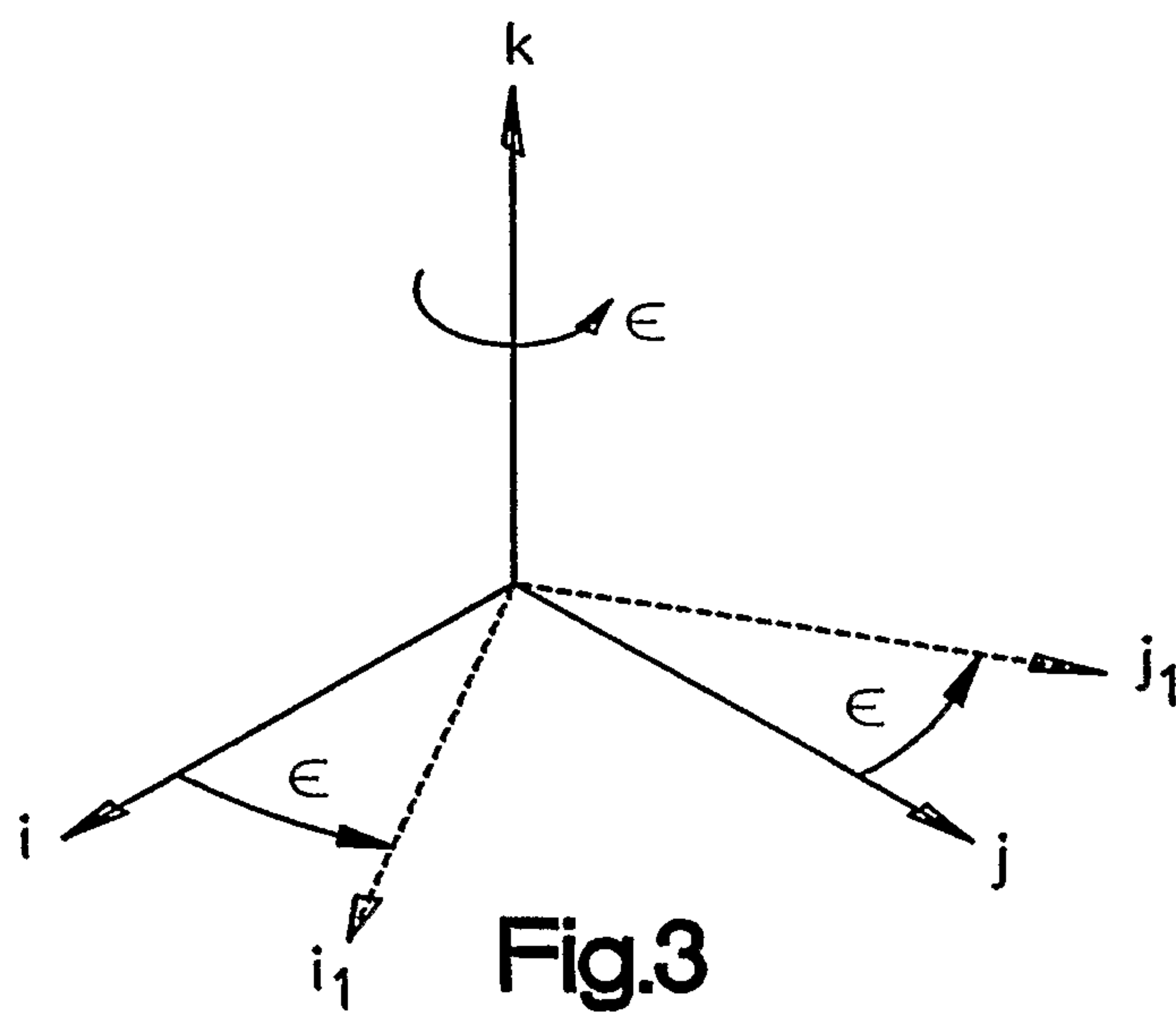
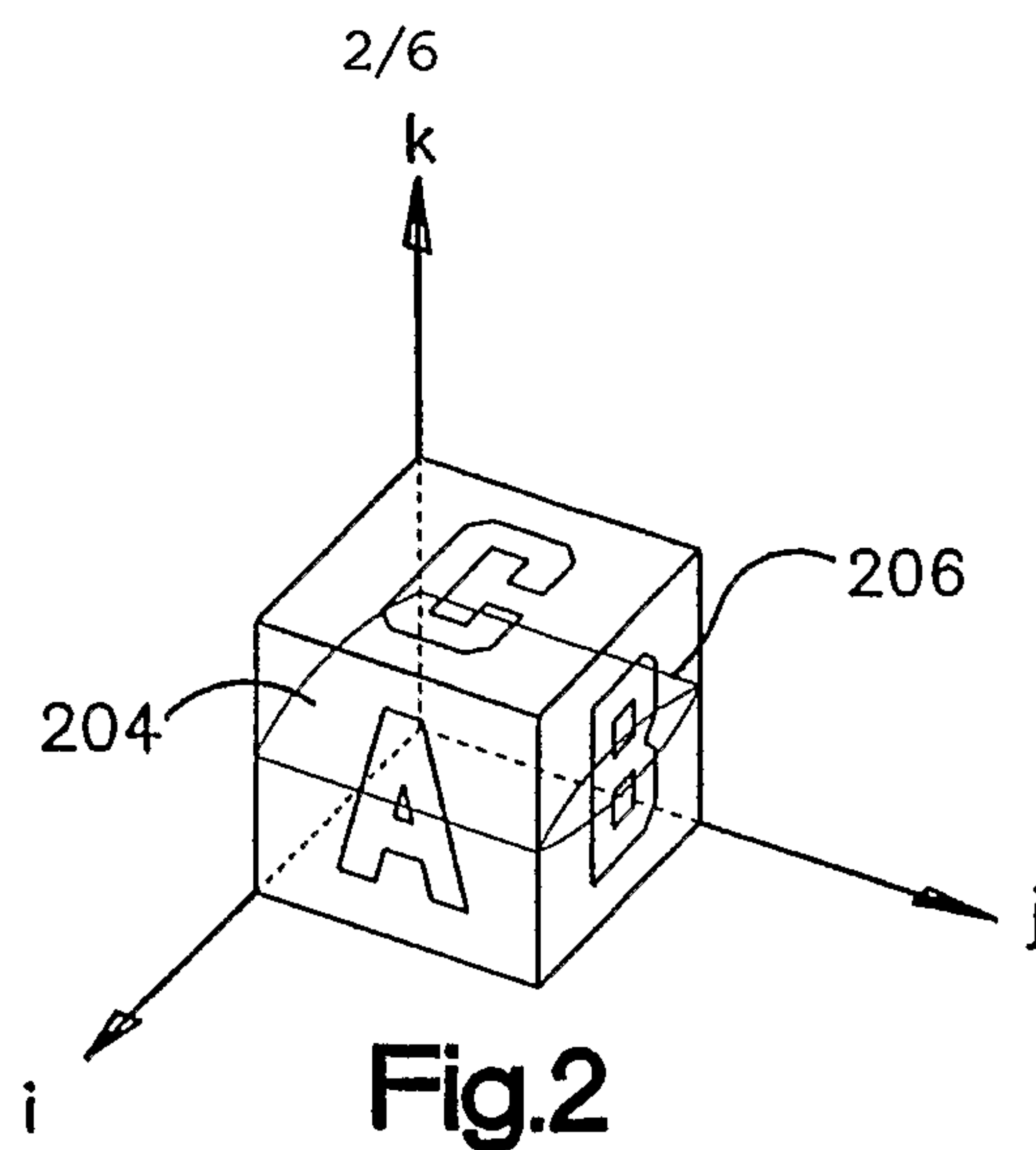
2. A method as set forth in claim 1, wherein the flight surface is positioned at a sweep angle or other obliquity relative to the axis of the airborne body.

3. A method as set forth in claims 1 to 2, wherein the flight surface is stored at least partially on the exterior of the airborne body.

4. A method as set forth in one of claims 1 to 3, wherein the first rotational angle (ϵ) is 90° .
5. A method as set forth in any one of claims 1 to 4, wherein the angle between the rotational axes (θ) is 90° .
6. A method as set forth in any one of claims 1 to 5, wherein the second rotational angle (ϵ') is oblique.

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**FIG. 1**



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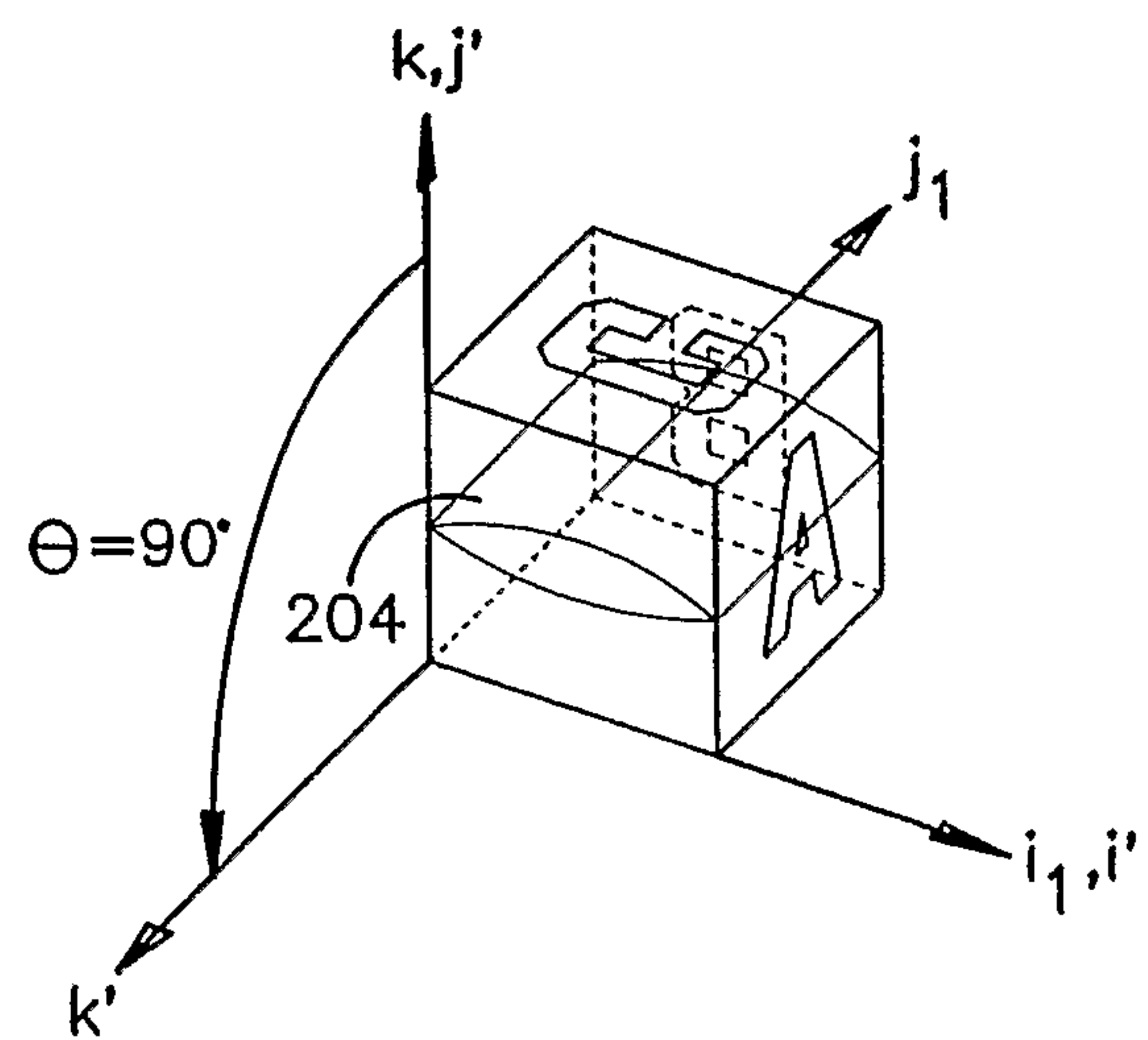
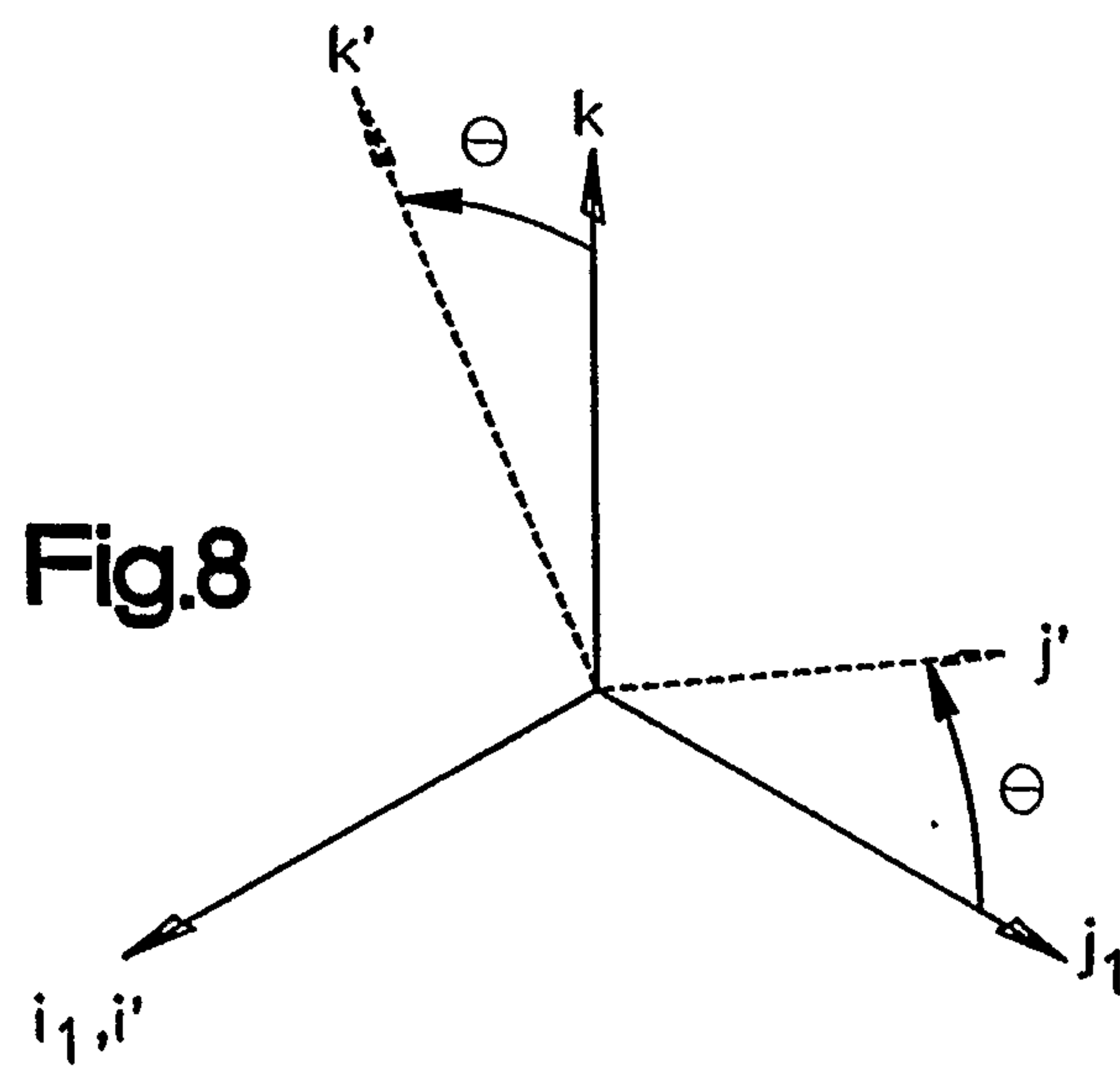
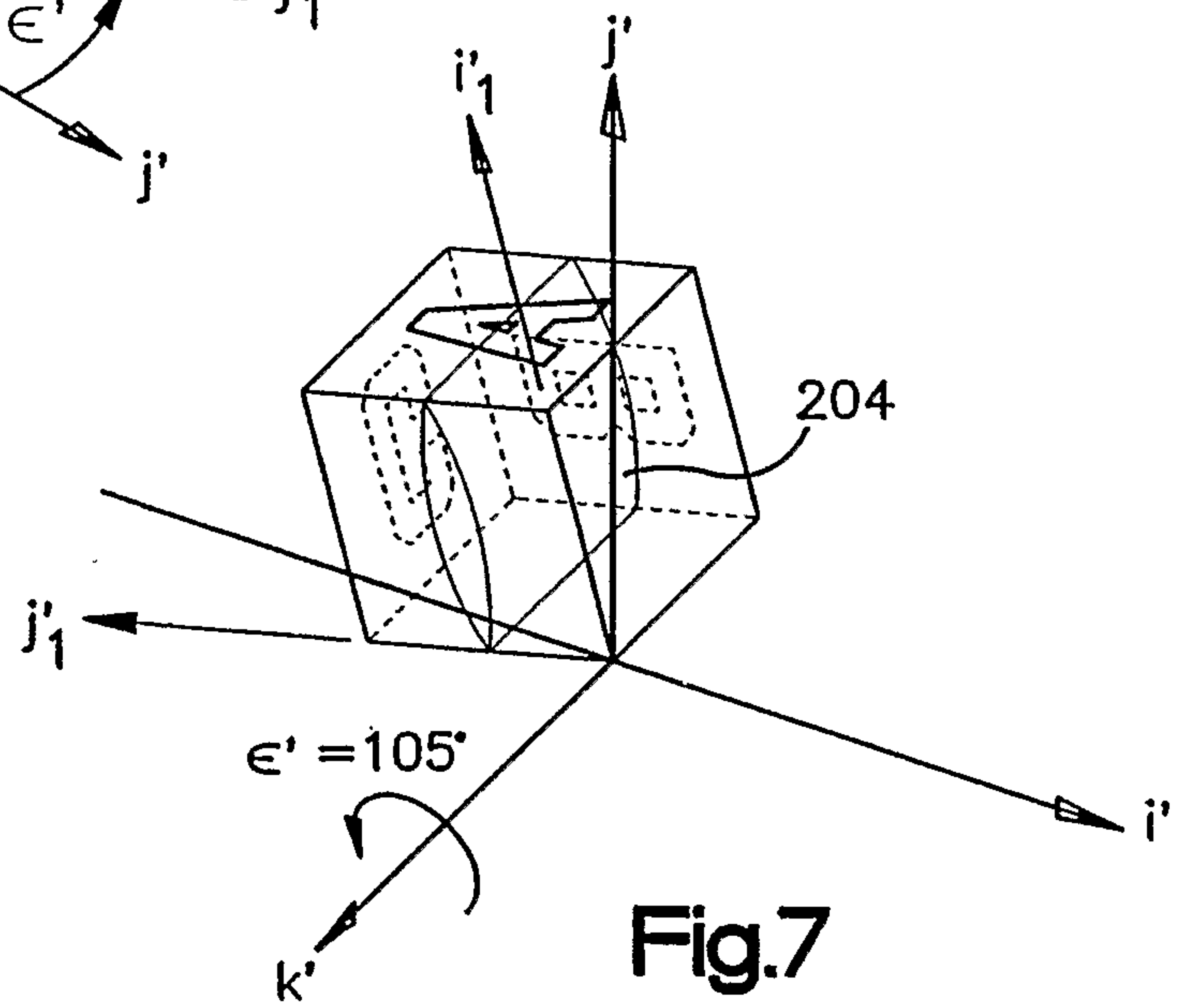
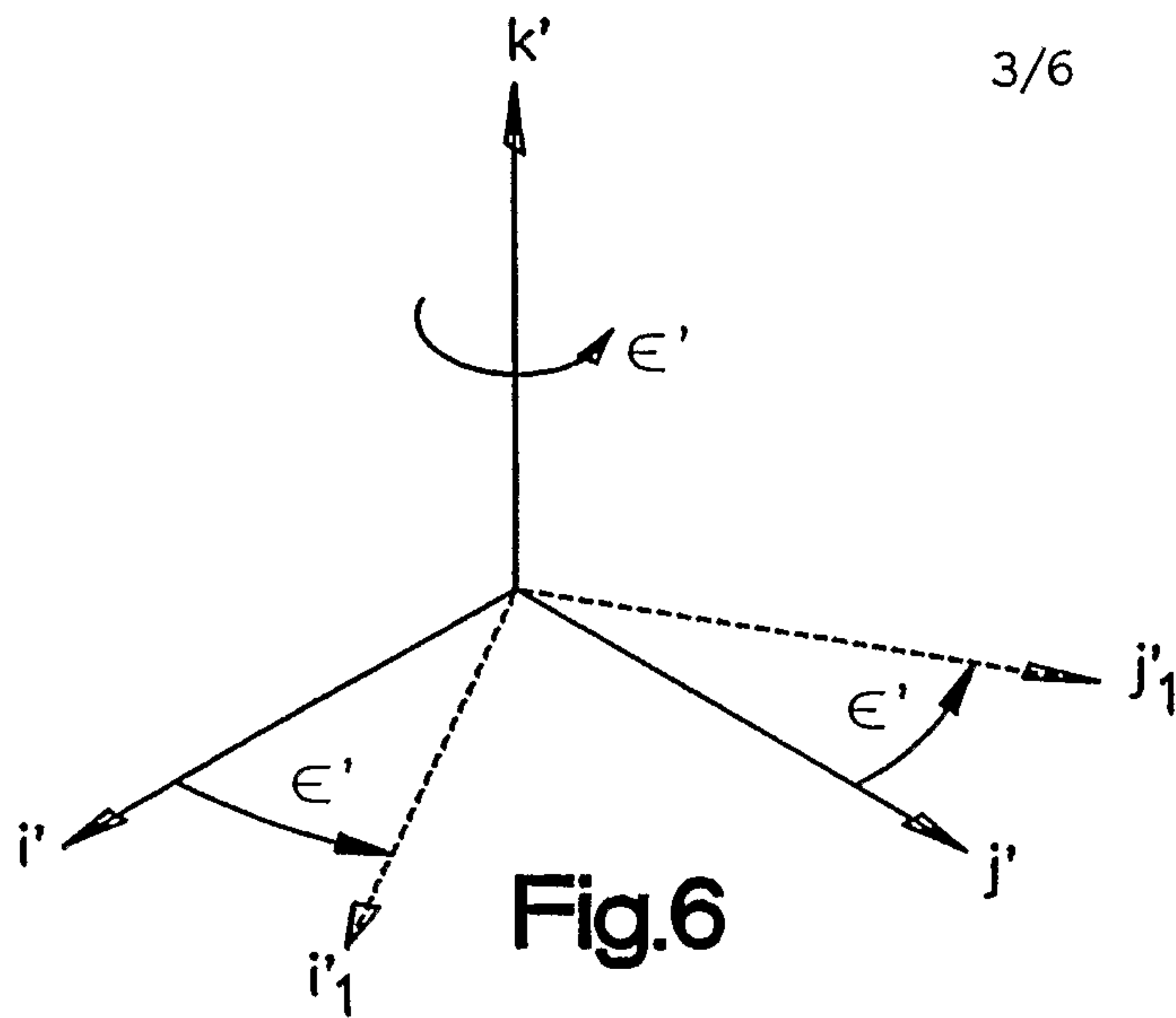
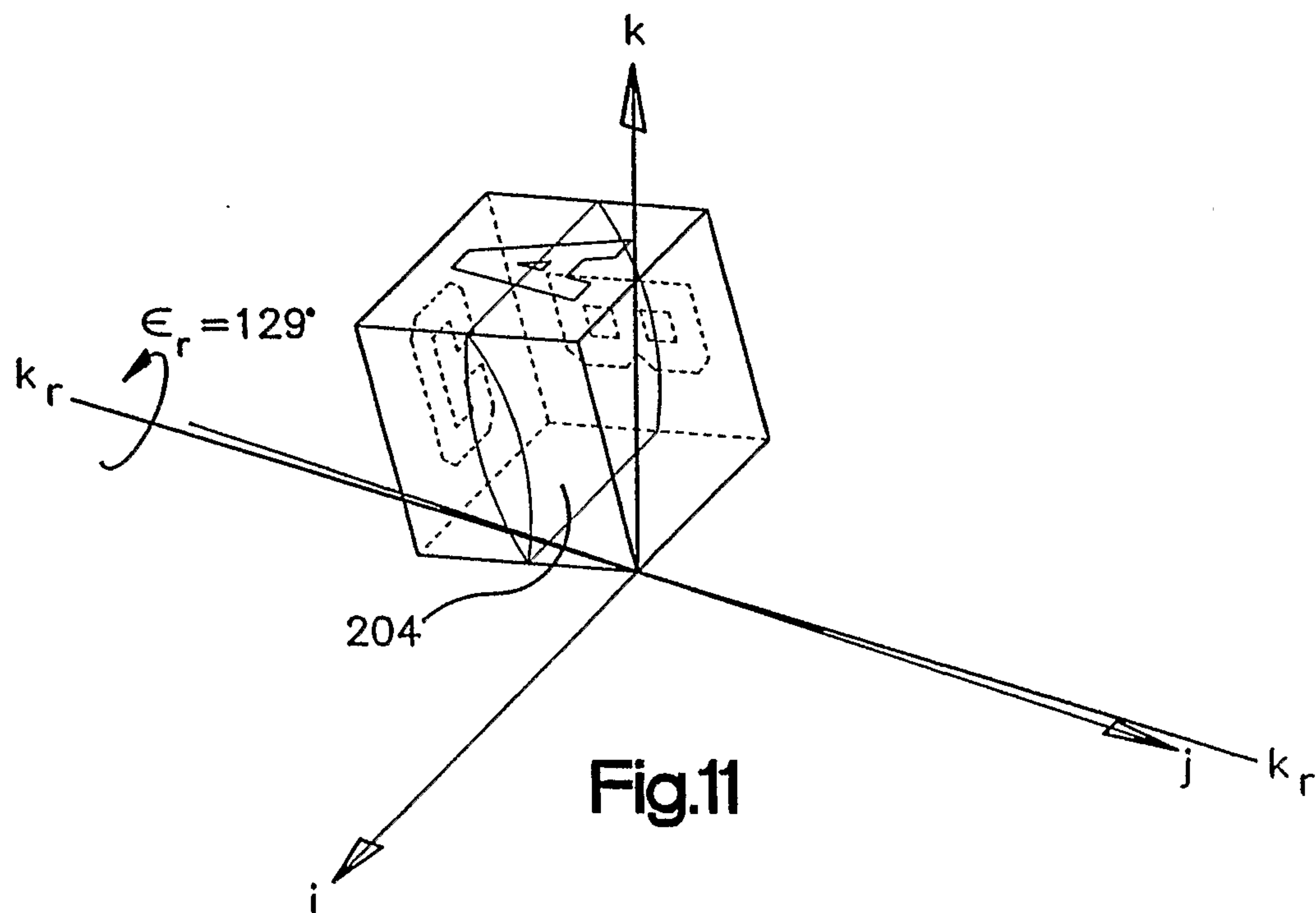
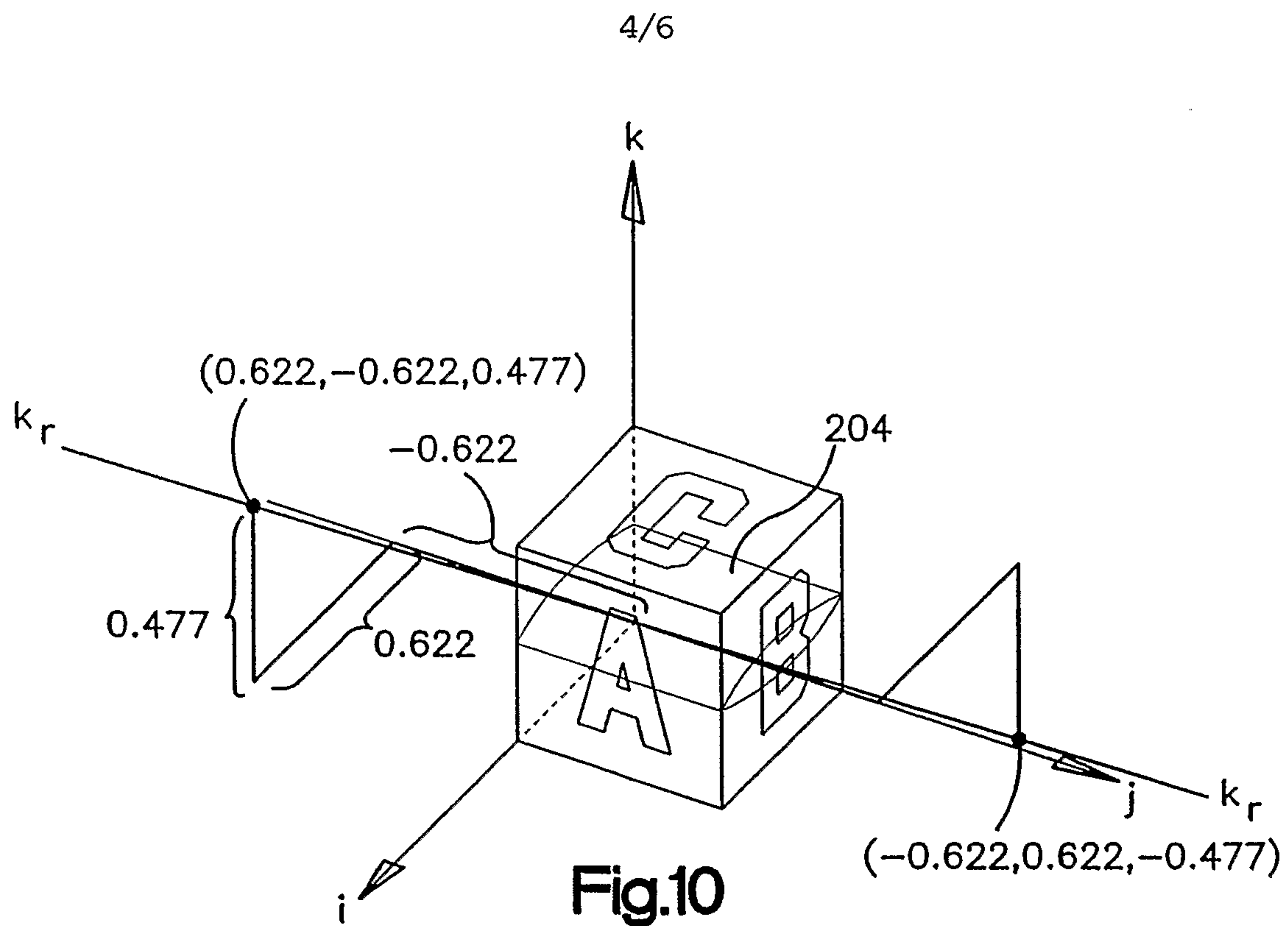


Fig.9



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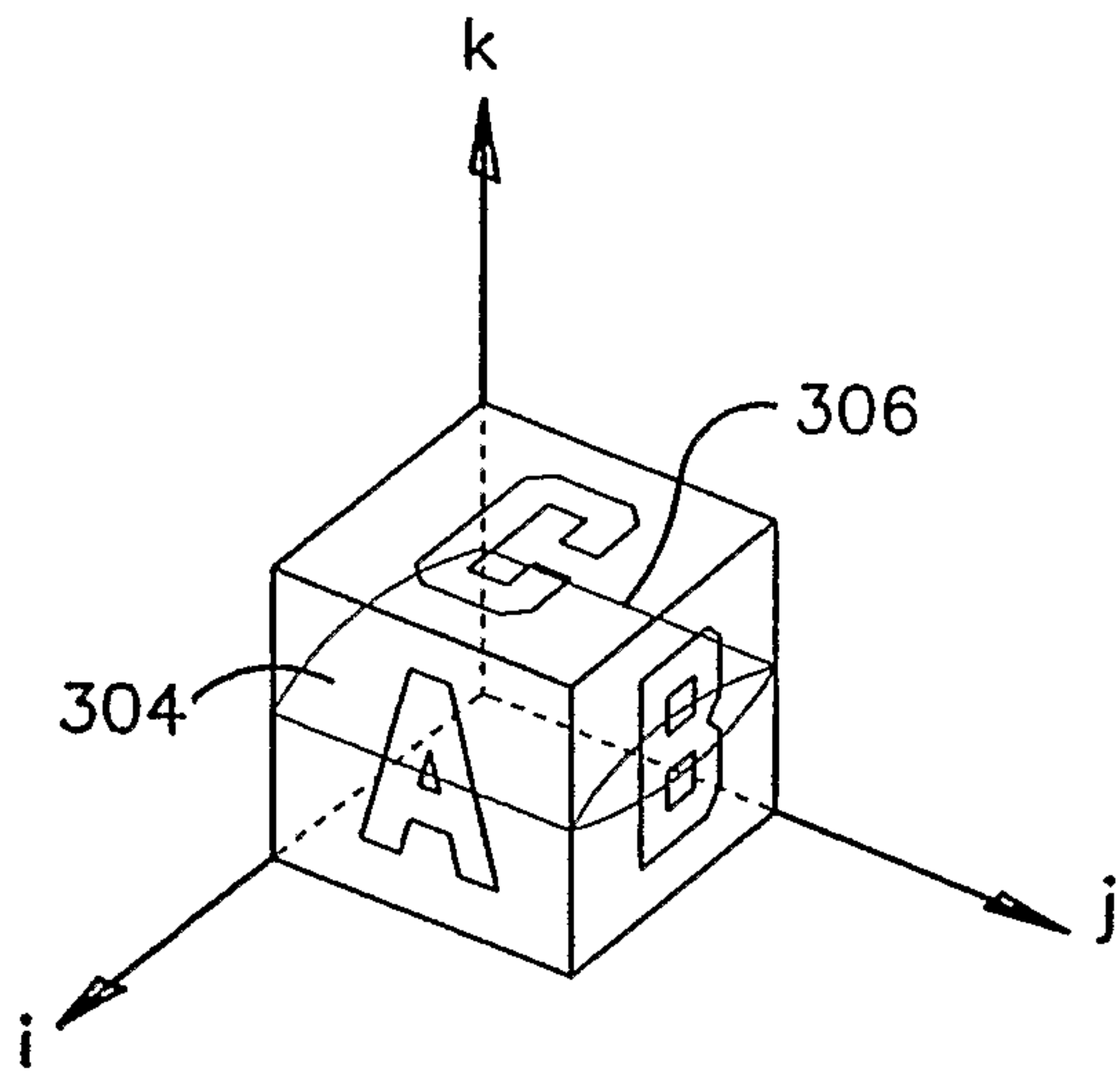


Fig.12

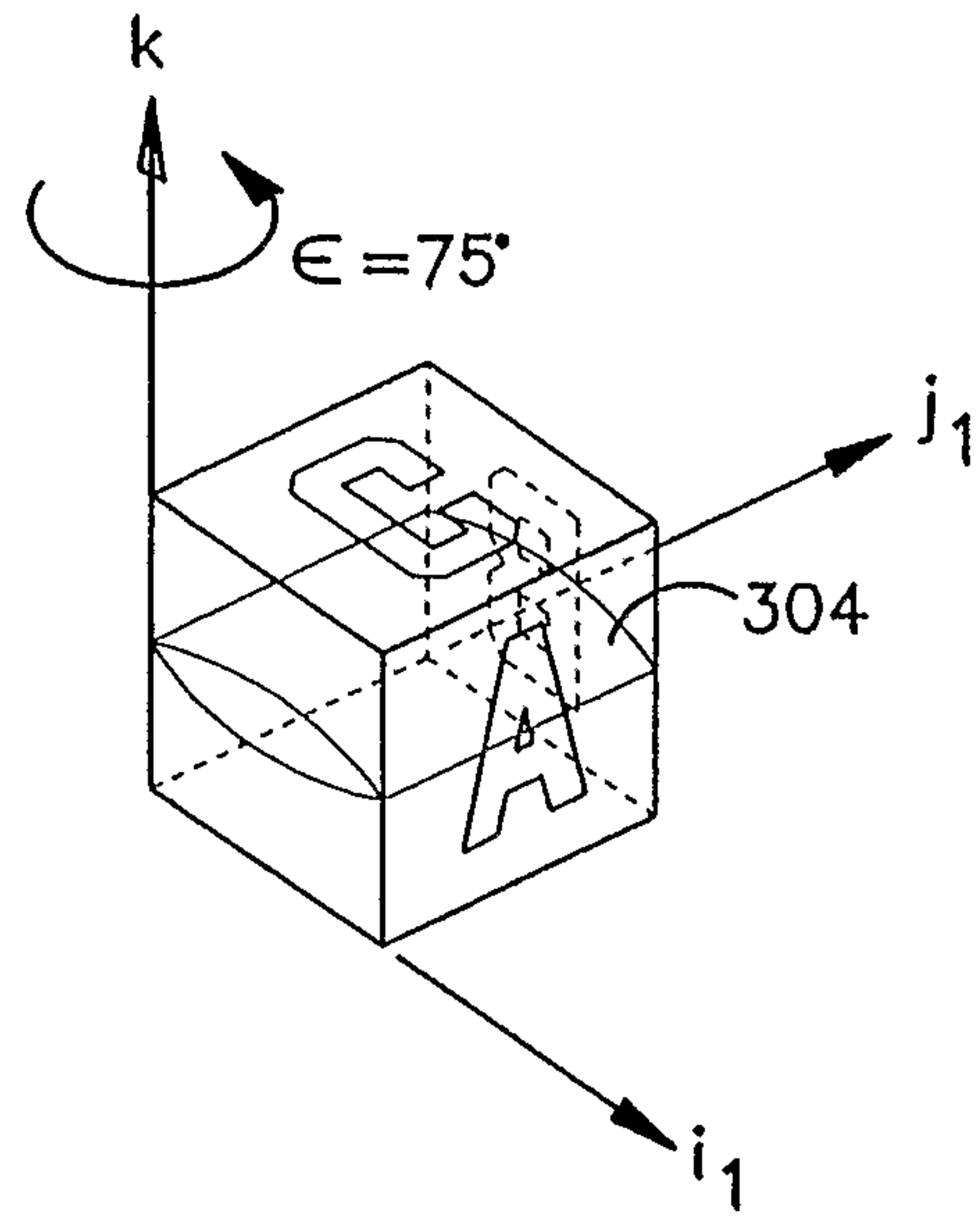


Fig.13

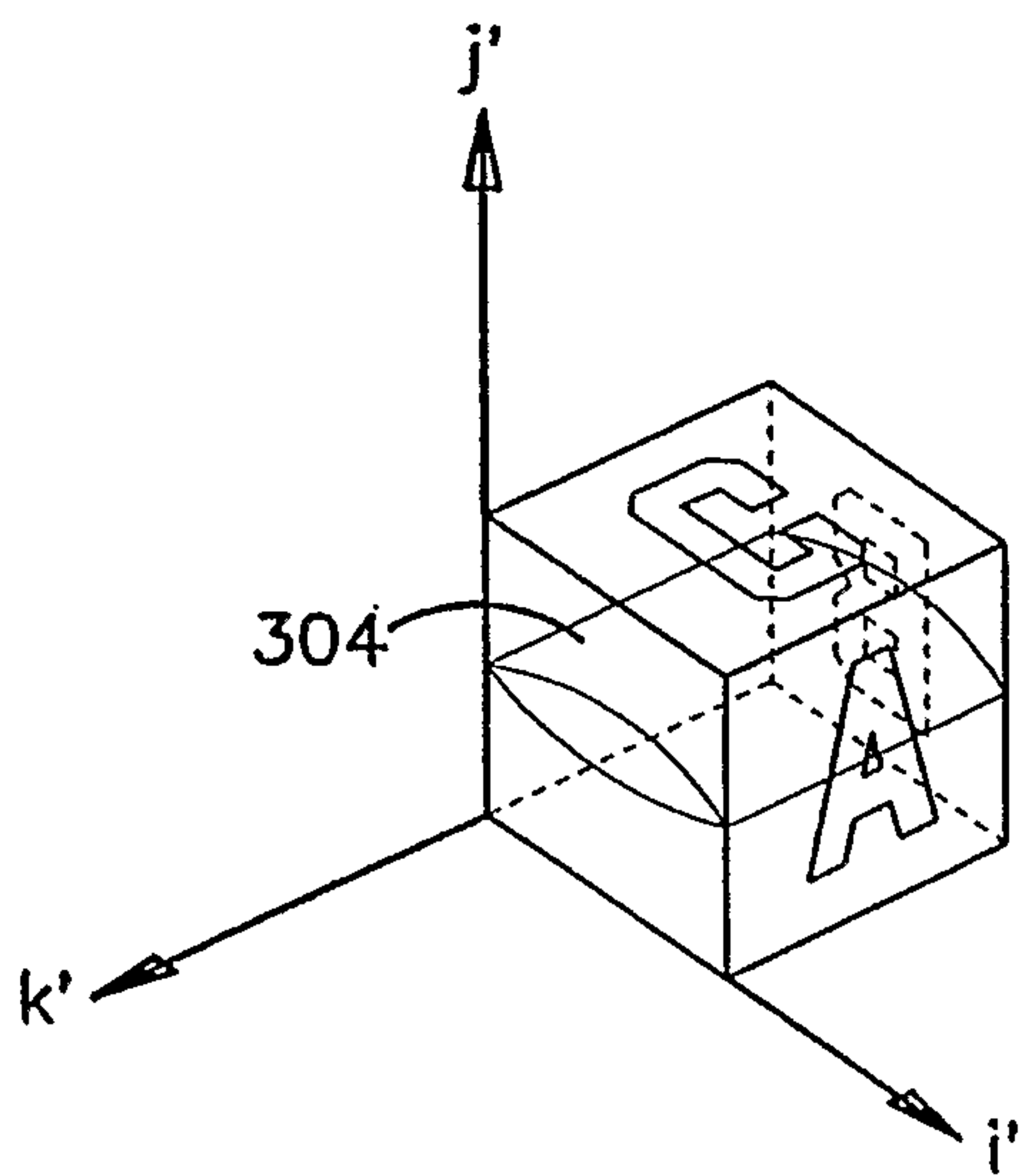


Fig.14

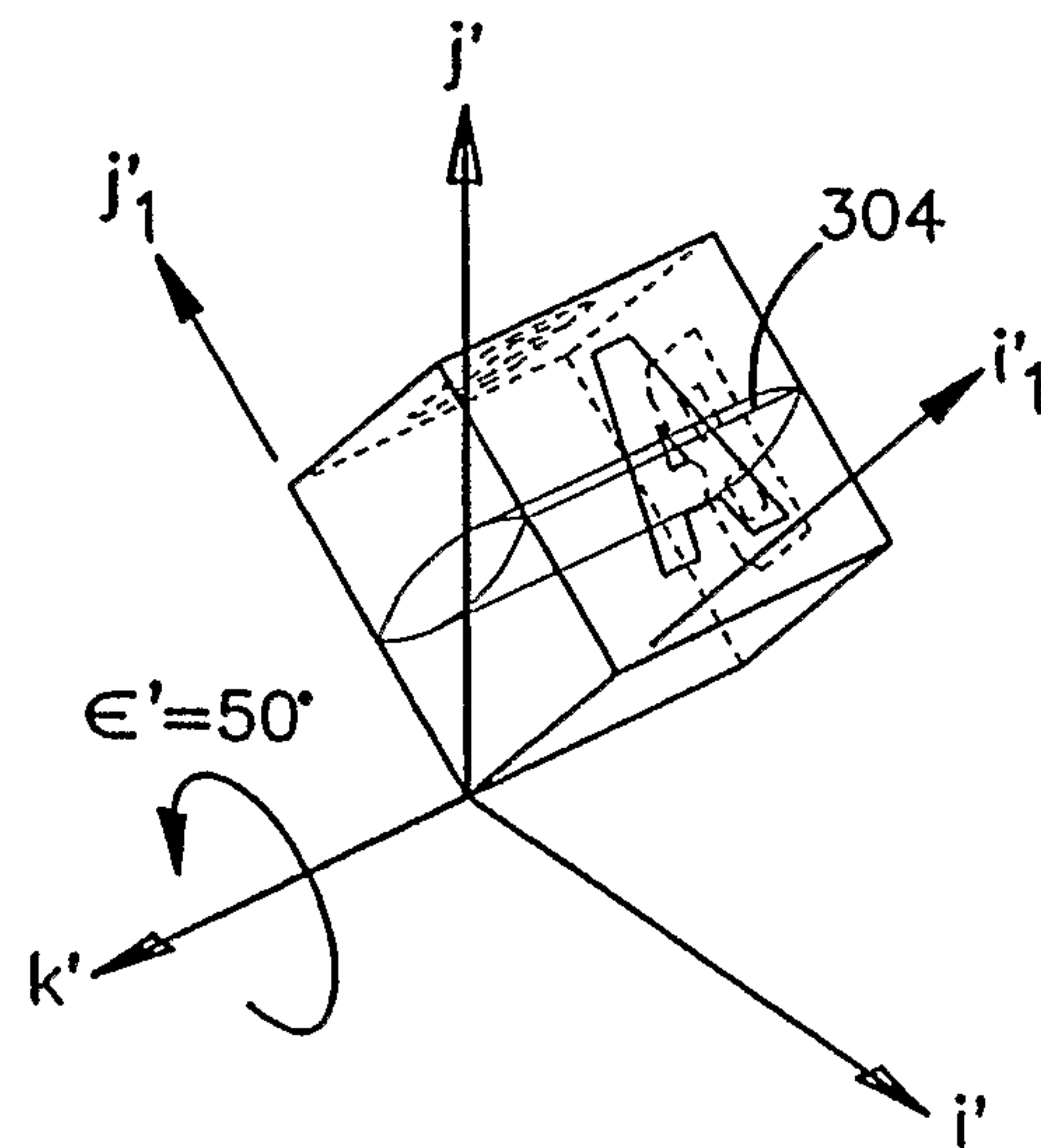
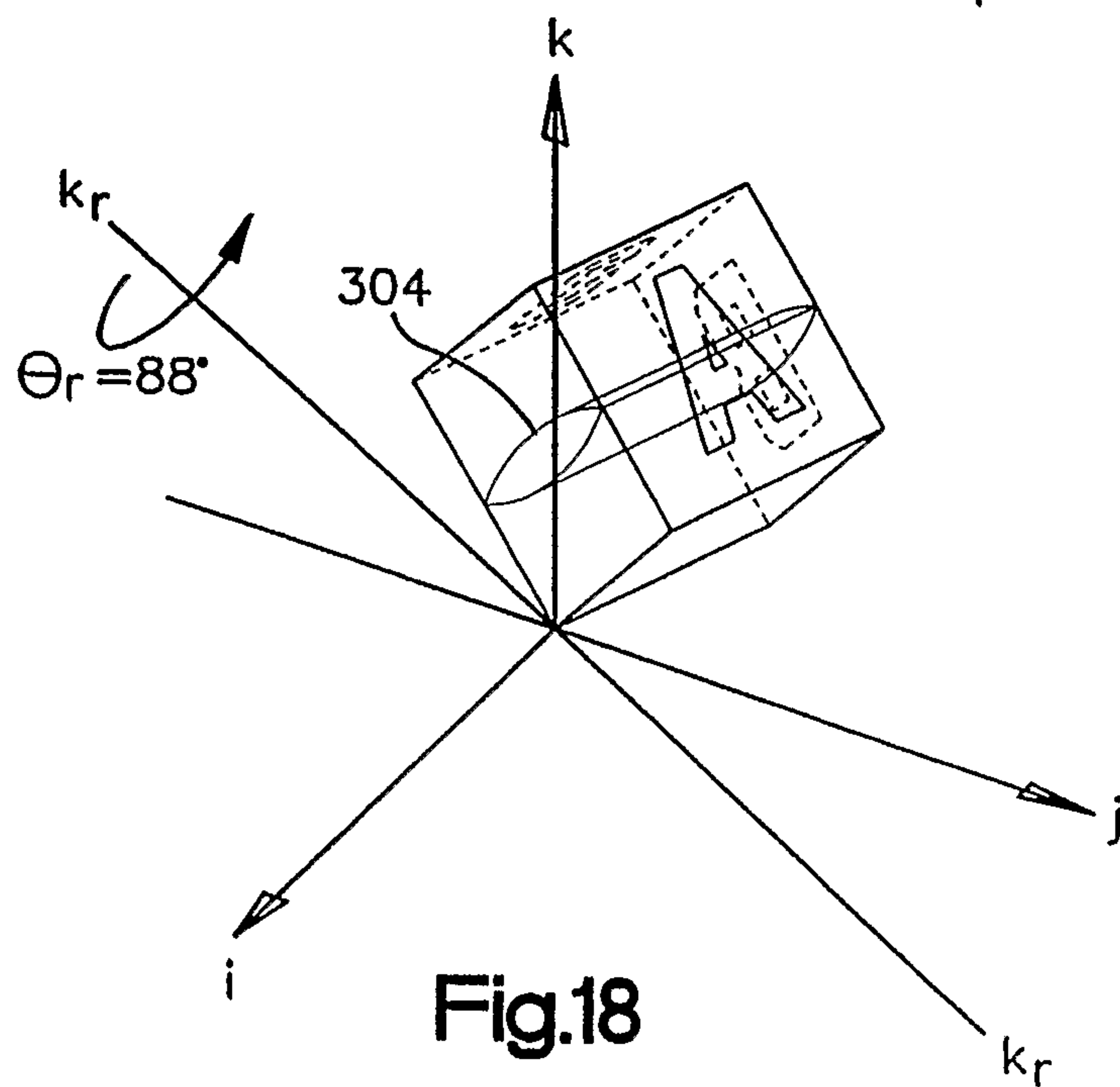
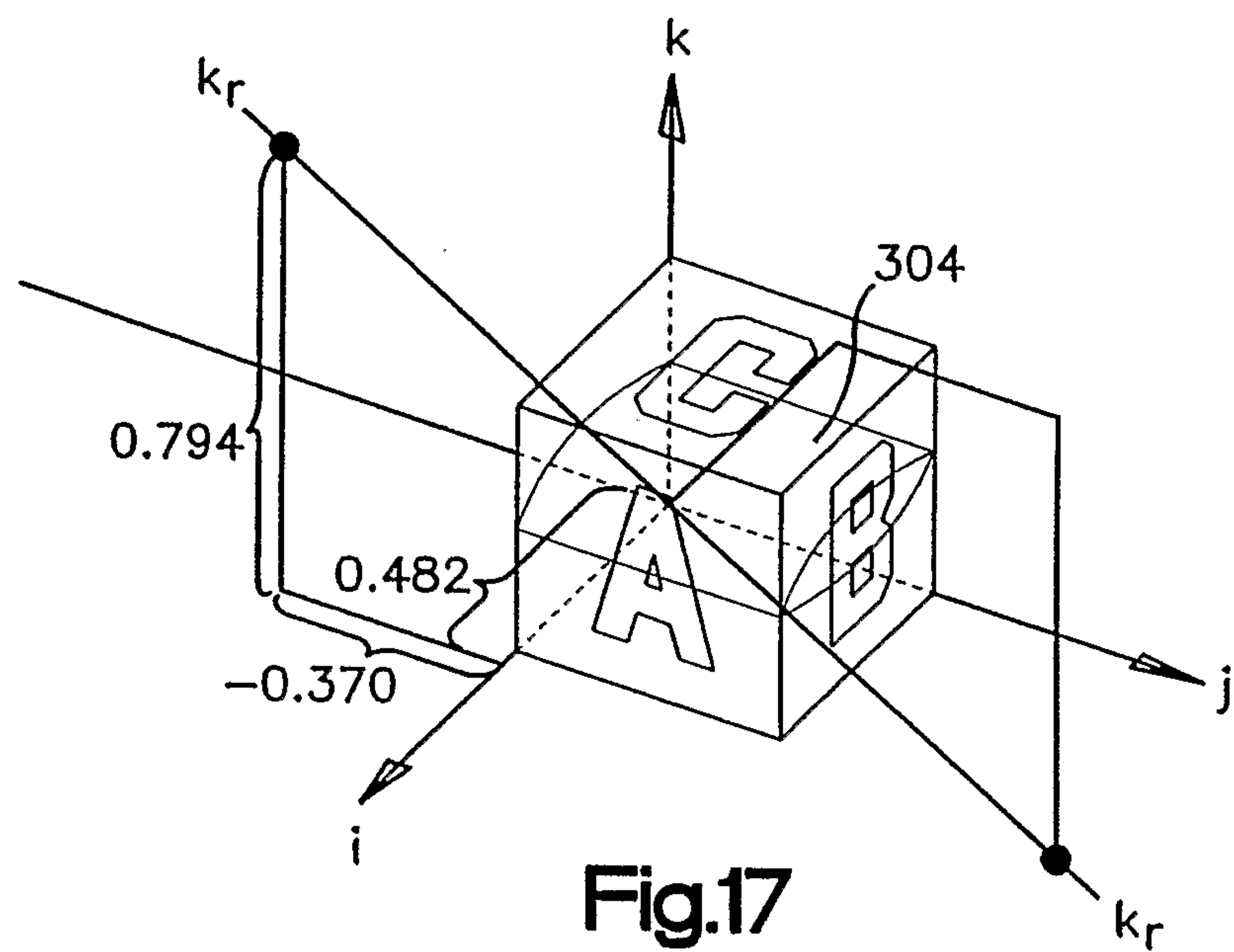
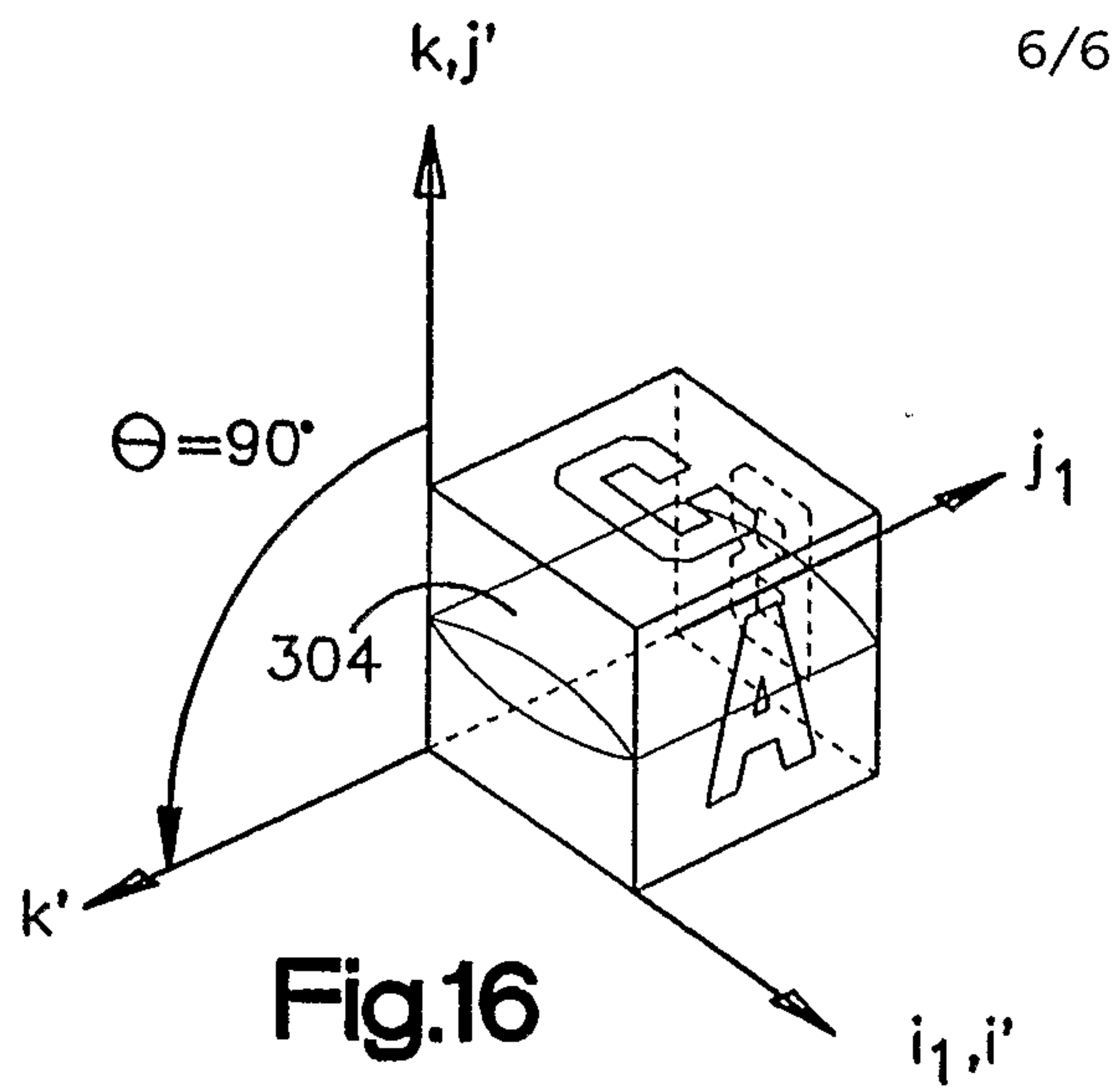


Fig.15



100

Start

Identify stowed and deployed
position of flight surface

110

Identify first rotation axis and
respective rotation angle

120

Identify second rotation axis and
respective rotation angle

130

Determine single equivalent rotation
axis and angle based on first and
second rotation axes and angles

140

End

