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Godin et al.

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[45] **July 10, 1973**

[54] **HIGH PRECISION STELLAR POINTING DEVICE FOR SPACECRAFT**

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[51] **Int. Cl.** .. **F42b 15/02,** F42b 15/10, F42b 15/00

[58] **Field of Search** 244/3.18, 3.19

[56] **References Cited**

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Assistant Examiner—Thomas H. Webb
Attorney—Pierce, Scheffler & Parker

[57] **ABSTRACT**

A navigation apparatus for a stellar vehicle includes a support within the vehicle on which a pair of stellar detectors are fixedly mounted with their respective optical axes directed to different stars. Generators connected respectively with the detectors produce data corresponding to the error between the trajectory being followed by the vehicle and the directions of the stars, and processor means connected to the outputs of the generators function to compute the error data and deliver the necessary course correction signals to the propulsion and direction control system to the vehicle.

12 Claims, 7 Drawing Figures

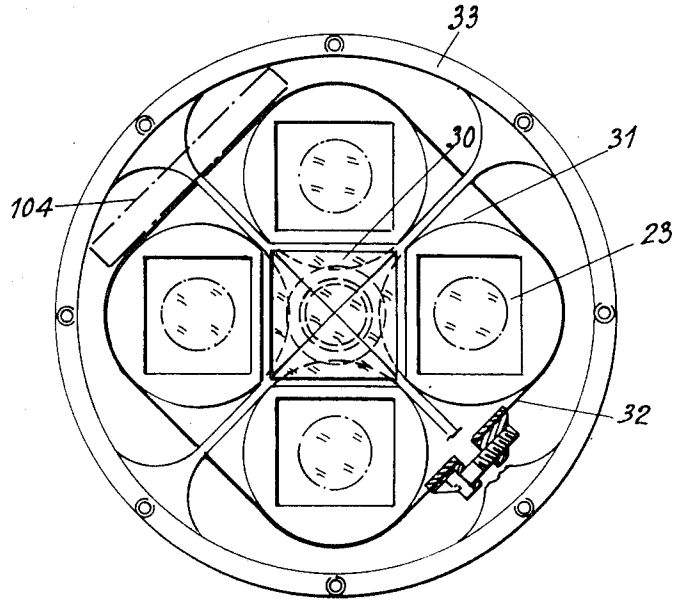


Fig.1A.

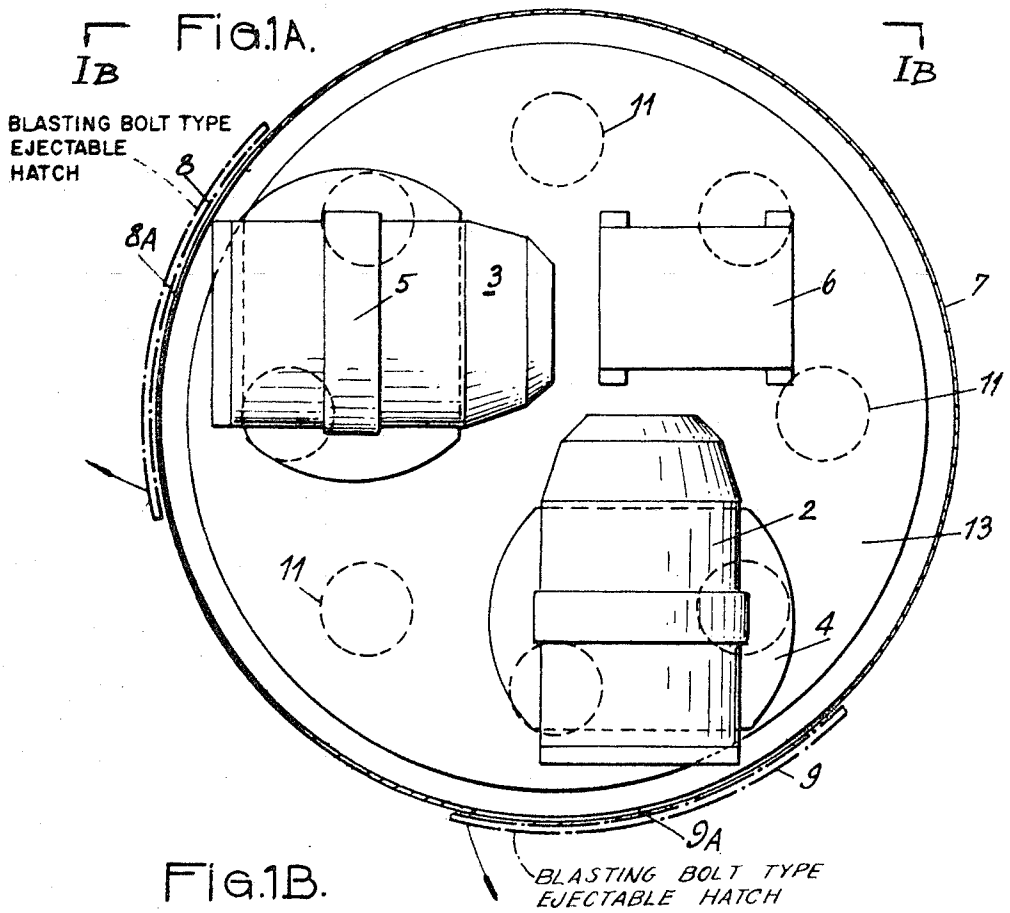

IB
IB
BLASTING BOLT TYPE EJECTABLE HATCH
8
8A
11
5
3
6
7
11
2
13
11
4
9
9A
BLASTING BOLT TYPE EJECTABLE HATCH

Fig.1B.

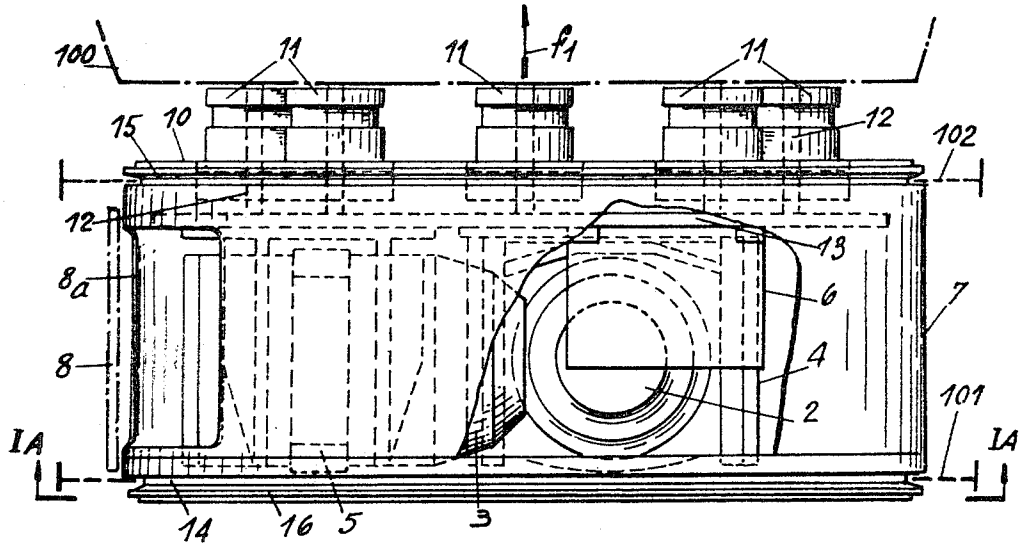

100
11
11
f1
11
15
10
12
102
12
13
8a
6
7
8
4
2
101
IA
IA
14
16
5
3

Fig.2.

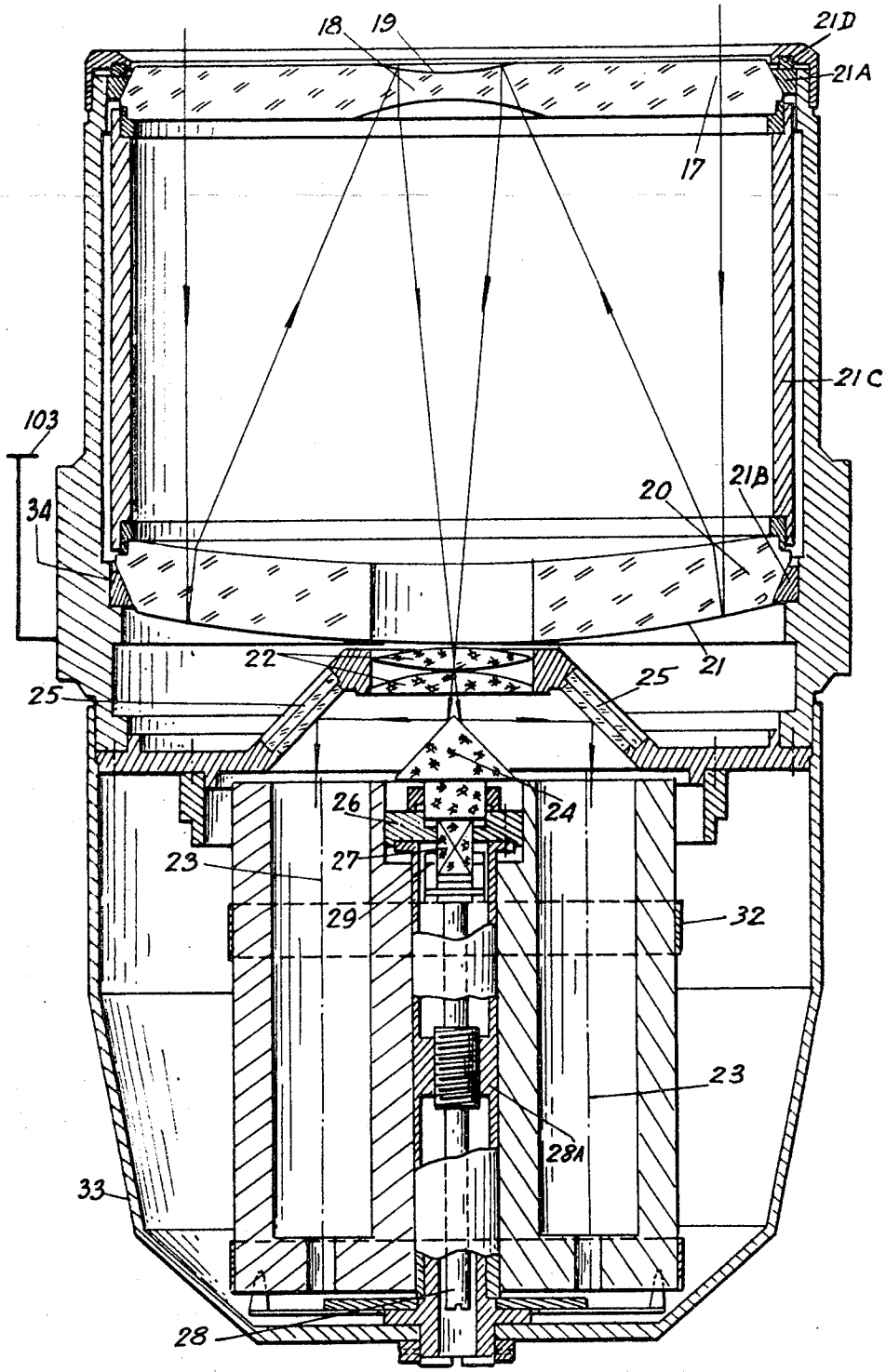

18
19
21D
21A
17
21C
103
34
20
21B
22
21
25
25
26
24
23
27
29
32
23
28A
33
28

Fig.3.

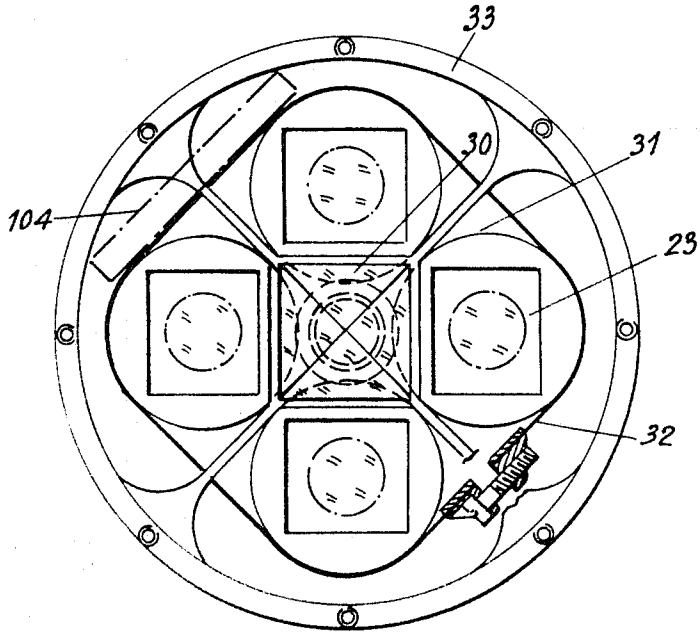


Fig.6.

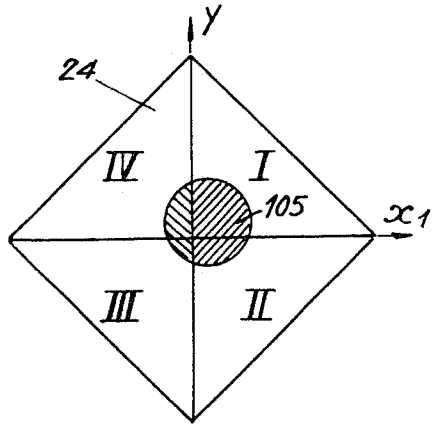


Fig.4.

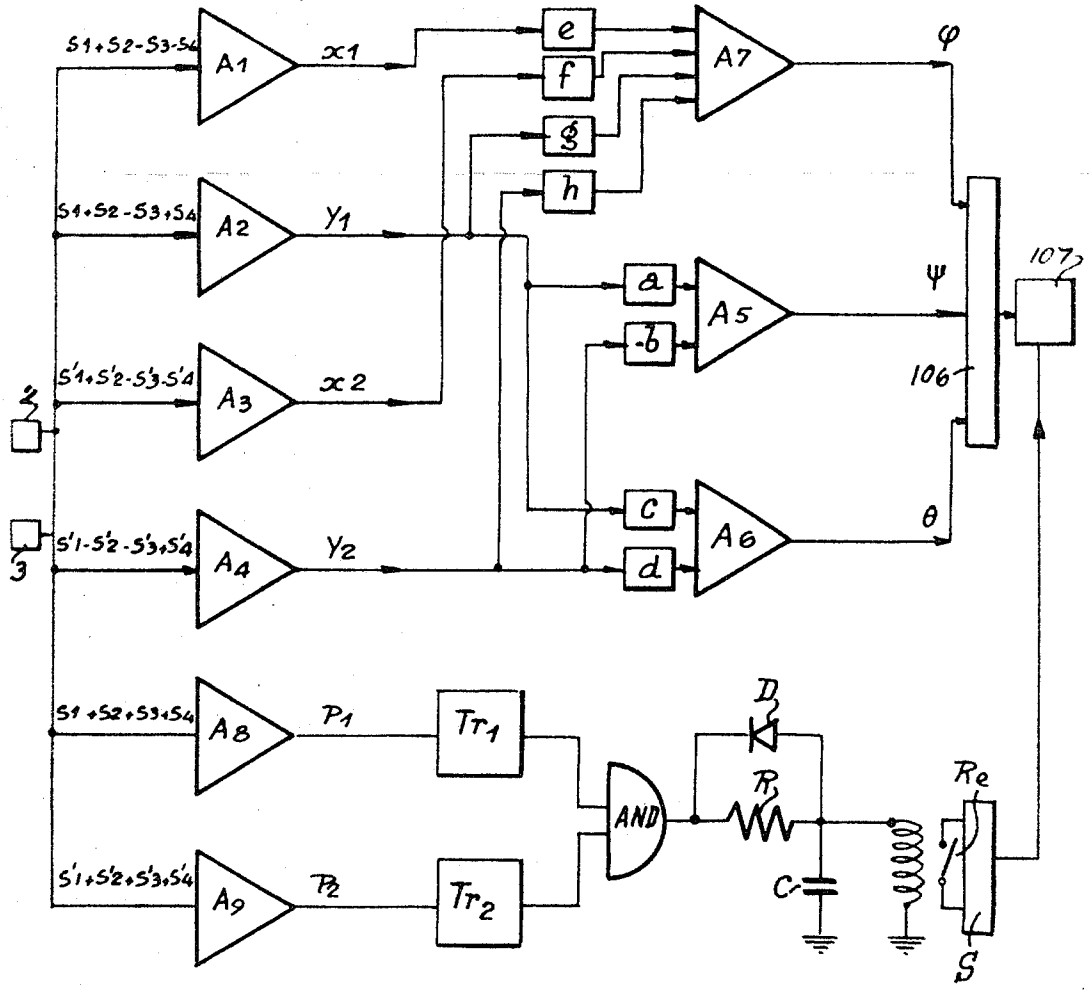
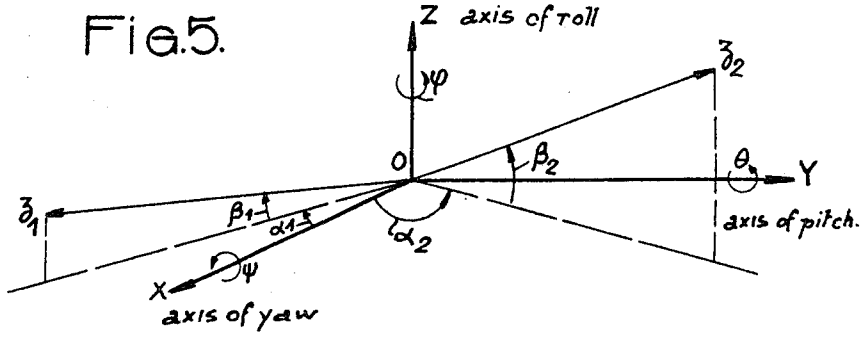

S1+S2-S3-S4
A1
x1
e
f
g
h
A7
φ
S1+S2-S3+S4
A2
Y1
a
-b
A5
Ψ
107
S'1+S'2-S'3-S'4
A3
x2
2
106
c
d
A6
θ
S'1-S'2-S'3+S'4
A4
Y2
3
S1+S2+S3+S4
A8
P1
Tr1
D
AND
R
Re
S'1+S'2+S'3+S'4
A9
P2
Tr2
C
S

Fig.5.


Z axis of roll
φ
∂2
0
β2
θ
Y
∂1
β1
α1
α2
axis of pitch.
X
Ψ
axis of yaw

HIGH PRECISION STELLAR POINTING DEVICE FOR SPACECRAFT

This invention relates to a stellar pointing device, particularly conceived for accurately pointing a space craft or a sounding rocket toward a given point of the sky.

Various processes are already known to ensure after the propulsive flight the direction of the three axes of pitching, rolling and yawing of the head of a sounding rocket. This may be effected, for example, by means of a gyroscope unit clamped in place on the rocket before the rocket is launched which serves to control the operation of a group of corrective acutators such as, for example, those of the jet operated type. These actuators, in the first place ensure, during the ballistic flight a minimization of the undesired rotation of the rocket about its rolling axis, and secondly minimization of the error in the two other directions mentioned. During the propulsion stage of flight, the rocket has a tendency to roll about its axis and such rotation must be arrested during the ballistic stage of flight, especially when accurate visual observations are to be made from the rocket.

The drifts of the gyroscopic unit amplified by the sustained accelerations together with inaccuracies in the sight collectors of the gyroscopes do not facilitate a directing of the roll axis of the rocket with an angular error of less than 1°. The same conditions and situations apply to the directional tolerance along the pitch and yaw axes. A directional accuracy of this magnitude makes it possible to sight upon one or two given stars by one or two stellar detectors provided that the detectors have a detection field of a half-angle at the apex within the range of about 1° and 30 feet. Under these conditions, it is possible to locate one or two reference-stars having the following characteristics.

1. — a magnitude large enough to allow the reception of an energy flow beam having enough power to create in photo-multipliers a current, the power of which is fairly above obscurity and noise currents, while requiring merely an inlet pupil having a reasonable surface. For guidance, an inlet pupil having a surface of approximately 15. sq. in. is suitable for stars having a magnitude equal to or smaller than 3.

2. — the stars surrounding the reference-star defined above, within a field ranging about 1° and 30 feet, have visual magnitudes equal at least to the magnitude of the reference-star increased by 2.5. It is agreed that such condition is acceptable for practically all stars having magnitudes equal to or smaller than 3.

When these requirements are satisfied, it is possible to work out stellar detectors basically formed of an inlet optical system which focusses light beams emitted by the reference stars, and of a beam separator disposed slightly in front of, or beyond, the focus of the optical system. According to this arrangement, the beam separator can divide into four beams the light rays thus received by dividing the light spot into four quadrants. The energy received by four photo-multipliers which then respectively collect the four beams is equal when the center of the separator coincides with the photometrical or energy center of the light spot. This center is quite close in position to the star image, provided that condition 2 above is satisfied. When the four beams have different energy values, two linear functions of the four photo-multiplier currents will indicate at least for low angular value the pointing variation according to the two directional sensitivities along the axis which defines the four quadrants of the separator.

A more specific object of the invention is the provision of a navigation apparatus utilizing such stellar detectors, and providing the generation of control signals for devices used, as contrasted with control signals derived from the gyroscopic unit, or of any other pointing means, once said devices have previously defined a course direction enabling the direction of light rays from the reference stars into the field of the stellar detectors.

The stellar pointing device according to one embodiment of the invention comprises an assembly having ejectable doors which may be fastened by means of straps to the other compartments of the rocket. This assembly is fitted with a rigid upper floor on which scientific equipment or other apparatus as may be incorporated in the system is supported on shock absorber mounts, and two stellar detectors. It further includes a plate rigidly connected to such scientific equipment or other apparatus on which two brackets are mounted for the adjustment, in a predetermined manner, of the field of the two stellar detectors for pointing towards a reference-star. Also provided is an electronic unit which includes a primary computer for processing from output signals of the stellar detectors, the error signals derived from the reference stars with respect to the sensitivity axis of the detectors, as well as the presence signals of each reference star. A secondary computer processes, from the signals of the primary computer and from the positioning angles of the detectors with respect to a specific guiding axis of the rocket, the pointing error with respect to such axis. Additionally provided in the system is a device for deriving the total presence signal of the two reference-stars, and a device which provides the signal changes required for accurate pointing.

Further apparatus is provided to produce control orders for actuation of the ejectable doors in accordance with signals from a programming unit.

It is believed that a full and more complete understanding of the present invention and the mode of operation thereof, will be better understood by reference to the following description and accompanying drawings which illustrate, as a non-restrictive example, a preferred embodiment of the invention.

With respect to the drawings:

FIG. 1A is a plan view of the detectors as seen along line 1A—1A of FIG. 1B;

FIG. 1B is a fragmentary side elevational view of FIG. 1A seen along 1B—1B, and corresponding to FIG. 1A;

FIG. 2 is a more detailed view of the stellar detector of FIG. 1A;

FIG. 3 shows the attachment of detector photo-multipliers of FIG. 2;

FIG. 4 is a diagram of the processor circuit of the apparatus.

FIG. 5 is a diagram of the specific axis of the rocket; and

FIG. 6 is an explanatory diagram.

With reference now to the drawings in detail, it is noted that FIG. 1B shows diagrammatically the apparatus of the invention wherein the direction of travel of the rocket on which it is supported is indicated by arrow f_1.

In order to better facilitate an understanding of FIG. 1A, the plate 16, illustrated on FIG. 1B, which forms the bottom of the device has been omitted.

The pointing unit of the device basically includes:

two stellar detectors 2 and 3, set respectively on two swivelling brackets 4 and 5 providing a two degree of freedom universal joint which includes a rotatable stand bearing two side plates and a rotation spindle,

an electronic unit 6, and an assembly which comprises the following components:

a cylindrical body 7 including inspection doors, not shown, and two ejectable hatches 8 and 9 closing off windows 8*a*, 9*a* behind which the stellar detectors 2 and 3 are respectively disposed;

a rigid upper plate 10 above the stellar detectors which is fitted with shock absorbers 11 to provide a resilient support between plate 10 and an experimental apparatus 100 which is thereby resiliently supported by the body of the rocket. Rods 12, connected to apparatus 100, pass through plate 10, and shock absorbers 11 and these rods support suspension frame 13 of the stellar detectors 2 and 3 which are thereby rigidly connected to the apparatus 100 while at the same time being free from the body of the rocket and, as a result, from such vibrations as the rocket body may sustain;

a bottom hoop 14 which provides increased rigidity of the assembly and ensures adequate fastening to a rocket compartment by means of a belt 101, the bottom hoop being closed by a plate 16 thereby providing light-proofing for the assembly before ejection of the hatches 8 and 9, which shield the scientific instruments from outside radiations, particularly from sun radiation before rocket-pointing is accomplished; and

a belt 102 which connects a circular groove in the upper plate 10 to the cap of the rocket.

The structural details of the stellar detector 2 (3) are illustrated in detail in FIG. 2. The frame of the detector includes a flange in one piece 34 providing a rigid fastening onto the swivelling brackets 4, 5 shown in FIGS. 1A and 1B. The component parts, hereinafter described, are connected to the flange by means of an assembly so designed as to minimize and make negligible the effects of temperature variation. The assembly also mounts an auto-collimation mirror 103 which serves to facilitate optical adjustment of the detector in the nose of the rocket before the rocket is launched.

Each stellar detector includes a port hole or entrance pupil 17 composed of quartz, or other suitable material which provides adequate sealing of the equipment as well as protection against adverse heat effects. The port hole forms the entrance pupil of a secondary catadioptrical lens 18 of a telescope, the coated reflective outer wall 19 forming a convex spherical mirror. A primary catadioptrical coated lens 20, also bearing two spherical surfaces having different radii is provided and an outer coated reflective surface 21 thereof forms the main concave mirror of the telescope. Centering and framing of the two catadioptrical lenses are effected respectively by conical rings 21A and 21B, and by a strut 21C made of a metal having a low expansion factor, and the efficiency of the assembly is improved by the use of a flexible ring 21D which increases resistance to shocks and acceleration while also ensuring a seal-tight structure.

Each detector also includes a twin lens condenser lens 22 which serves to project the image of the inlet port-hole of the telescope onto the photo-cathodes of four photo-multipliers 23, as shown in FIGS. 2 and 3, after division of the light into four beams by a pyramidal mirror 24 and reflection on reversing mirrors. A power supply and pre-amplifier electronic device 104 (FIG. 3) housed within casing 33 provides high voltage polarization of the photo-multipliers and amplification of their output current. The stand for the pyramidal mirror 24 is formed by a centering and guiding ring 26,27 respectively, securing the adjustment during rotation while permitting travel of the mirror 24. The travel of mirror 24 along the axis of the detector may be controlled from the rear side of the detector by means of a screw 28 located within a hollow bolt 28A which is secured in place by attachment to an end wall of casing 33 and which extends longitudinally of the axis of the detector 2 (3). Screw 28 is threaded through an internal threaded part of the hollow bolt 28A so that it moves longitudinally as it is turned. Once this adjustment will have given to the linear range of the photo-multiplier detector a suitable value, a tightening device 29, such as a bolt and a conical split screw, provides the final clamping of mirror 24.

In order to provide for an accurate setting of the photo-cathodes of the four photo-multipliers 23 as well as bring the latter together as closely as possible, a cluster type mount is provided and is illustrated in FIG. 3. Here it will be seen that each photo-multiplier 23 is located within a cylindric block 31 and these blocks are arranged in a cluster around the hollow bolt 28A and engaged in cut-out portions 30 in the wall of bolt 28A to establish a surface-to-surface contact therewith. The cluster of the four photo-multiplier receiving blocks 31 is retained in place by means of a belt 32 which encircles the blocks and is tightened by a screw-actuated clamp.

The diagram of the electronic unit is shown on FIG. 4. The output signals of eight preamps from the eight photomultipliers, arranged in two groups of four in the two stellars detectors 2 and 3 of the device, are indicated by letters : S_1, S_2, S_3, S_4 for the detector 2 and by : S'_1, S'_2, S'_3, S'_4 for the detector 3.

Algebric sum : $x_1 = S_1 + S_2 - S_3 - S_4$ is made by an operational amplifier A_1.

As shown on FIG. 6, which represents diagrammatically the projection of mirror 24 on its base, said x_1 value represents the displacement according to x coordinate of the light spot 105 of a star by comparison with the desired direction of said star. In fact, x_1 is equal to the difference between the output signals corresponding to the surface of the spot on areas I and II (i.e., $S_1 + S_2$) on the one hand, and of areas III and IV (i.e., $S_3 + S_4$) on the other hand.

In the same way, concerning respective operational amplifiers :

A_2 sums up : $y_1 = S_1 - S_2 - S_3 + S_4$

A_3 sums up : $x_2 = S'_1 + S'_2 - S'_3 - S'_4$

A_4 sums up : $y_2 = S'_1 - S'_2 - S'_3 + S'_4$

Calculation discloses that x_1, y_1 values are proportional to the projections of the angular error between the direction of the pointed star and the optical axis onto two orthogonal planes passing through the edges of pyramidal mirror 24 and the optical axis, as long as the light spot will surround the sharp point of said pyramid, i.e., a 5 minute angle, approximately.

x_2, y_2 have a similar definition for the second stellar detector.

Amplifiers A_1, A_2, A_3, A_4 form the primary computer of the electronic unit.

Besides α_1, β_1 and α_2, β_2 being the angles which determine respectively the position of optical axis Oz_1 of the first stellar detector and optical axis Oz_2 of the second stellar detector in the control axis system of the rocket shown on FIG. **5**, i.e., rolling OZ, pitching OY and yawing OX, the voltages corresponding to the mispointing angles ϕ, Θ, ψ, around said axis are formulated by the following relations, taking only into small angles under 5 minutes :

$$\phi = ay_1 - by_2$$
$$\Theta = cy_1 + dy_2$$
$$\psi = ex_1 + fx_2 + gy_1 + hy_2$$

in which coefficients a, b, c, d, e, f, g, h, are parameters bound up with the angles α_1, α_2, β_1, β_2 which are defined once the reference-star and the target to be pointed by the experimental apparatus have been selected. The informations in voltage form which correspond to mispointing angles are conveyed to a piloting device **106** which leads to and controls the jet actuators of a control and propulsion system **107** for the stellar vehicle known to the art and thus not disclosed in detail for the purpose of correcting mispointing errors in roll, pitch or yaw.

Operational amplifiers A_5, A_6, A_7 perform the linear arrangements indicated above and constitute the secondary computer of the electronic unit.

A signal indicating the full presence of both stars in the range of both detectors is required to allow the accurate pointing operation of the piloting system of the rocket.

For this purpose, two amplifiers A_8 and A_9 will elaborate the presence signals P_1 and P_2 which are defined by the following equations :

$$P_1 = S_1 + S_2 + S_3 + S_4$$
$$P_2 = S'_1 + S'_2 + S'_3 + S'_4$$

Presence signals P_1 and P_2 thus represent respectively the sum of the informations received from each of the detectors.

Signals P_1 and P_2 are both compared with a threshold in a logical circuit of the Schmidt trigger type Tr_1 and Tr_2 respectively, whose release threshold is so calculated as to eliminate the lighting of the vault of the sky with respect to the total flow supplied by each reference-star, and the outputs of two triggers Tr_1 and Tr_2 are connected to an AND gate. The output voltage of the AND gate feeds a relay Re indicating the full presence of the two reference-stars, through a resistor-capacitor time-delay circuit R.C. in the case of star appearing (closing of the relay), and through diode D if one or the other, or both reference-stars disappear (opening of the relay).

Said circuit thereby allows, through relay Re and a switching box S, the accurate pointing operation, i.e., under the control of the control and propulsion system **107** of the stellar vehicle of voltage signals corresponding to the angles ϕ, Θ, ψ a while after the appearance of the two stars in the range of the stellar detectors, and also controls quickly by the opening of relay Re, the return to gyroscopic control in the event that a reference-star falls outside of the range of its detector.

The electronic unit includes, in addition to the above described circuits, a blasting bolt control unit for the ejection of the hatches **8** , **9** after a predetermined time after launching through a signal delivered by the directional program of the rocket.

The invention is applicable particularly to sounding rockets and spacecraft launched for scientific purposes wherein an accurate pointing of a given point in the sky is required.

We claim :

1. A navigational apparatus incorporated in a stellar vehicle which comprises a support carried by said vehicle, a first stellar detector fixedly mounted on said support and having an optical axis directed toward a first star, a second detector also fixedly mounted on said support and having an optical axis which is directed toward a second star, said first and second detectors being offset from each other by a fixed known angle, means to control and propel said vehicle in accordance with a desired trajectory making predetermined angles with respect to the optical axes of said fixedly mounted detectors, a pair of generators connected respectively to said first and second detectors, each said generator serving to supply data corresponding to the error between the actual trajectory being followed by said vehicle and the direction of the corresponding star, processor means connected to the outputs of said generators for computing said data, and means connecting the output from said processor means to said controlling and propelling means for said vehicle.

2. A navigation apparatus as set forth in claim **1** comprising further a shock absorber inserted between said support and said vehicle.

3. A navigation apparatus as set forth in claim **1** comprising further adjustable means for fixedly mounting said stellar detectors and self-collimating means carried by each of said stellar detectors, whereby the optical axes of said first and second stellar detectors may be directed respectively toward said first and second stars before said detector is fixedly mounted on said support.

4. A navigation apparatus as set forth in claim **1** wherein said data processor means includes a first computer receiving data from said first and second stellar detectors and formulating a presence signal of the first and second stars within range of said first and second stellar detectors.

5. A navigation apparatus as set forth in claim **4** wherein said data processor means further includes a second computer receiving data from said first and second stellar detectors and formulating error signals of said first and second stars with respect to the optical axes of said first and second stellar detectors, said error signals being then processed with signals from said fixed known angle with respect to a specific guiding axis of the stellar vehicle for formulating pointing error signals with respect to said guiding axis.

6. A navigation apparatus as set forth in claim **1** wherein each of said first and second stellar detectors comprises a telescope with two catadioptric lenses, a pyramidal mirror having an axis parallel to the optical axis of the stellar detector and provided for separating a beam of light from each of said first and second stars in four pencil-like of light and four photo-multipliers receiving said four beams of light and constituting said generators receiving data corresponding to a direction of said first and second stars with respect to the optical axes of said first and second stellar detectors.

7. A navigation apparatus as set forth in claim **6**, wherein the two catadioptric lenses are mounted in a cylindrical structure by means of conical rings ensuring the centering thereof and a metallic strut with a low dilatation coefficient ensuring the mutual spacing of said

lenses, the assembly being maintained by means of a flexible ring whereby resistance to shocks and accelerations is obtained.

8. A navigation apparatus as set forth in claim **6**, wherein the pyramidal mirror is mounted on a support comprising means for adjusting said mirror in a position corresponding to a linear response of the photo multipliers

9. A navigation apparatus as set forth in claim **6**, wherein the photomultipliers of a stellar detector are embedded in blocks.

10. A pointing unit for a stellar vehicle comprising a cylindrical housing mounted in said stellar vehicle, a support in said housing, shock absorber means inserted between said support and said housing, said housing having two windows and ejectable hatches in front of said two windows, a first optical stellar detector fixedly mounted on said support in front of one of said two windows and having its optical axis directable toward a first star, a second optical stellar detector also fixedly mounted on said support in front of the other one of said two windows and having its optical axis directable toward a second star, said first and second detectors being offset from each other by a fixed known angle, means to control and propel said vehicle according to a desired trajectory making predetermined angles with respect to said optical axes of said fixedly mounted detectors, said first and second detectors each having a generator supplying data subsequent to ejection of said hatches corresponding to errors between the trajectory followed by said vehicle and the direction of said star, data processor means connected to the outputs of said generators for computing said data, and means connecting the output from said data processor means to said controlling and propelling means for guiding said vehicle along the desired trajectory.

11. A pointing unit as set forth in claim **10** wherein the optical axes of said first and second stellar detectors are respectively orthogonal and substantially perpendicular to the trajectory desired to be followed by said space craft.

12. A navigation apparatus as set forth in claim **6** wherein said pyramidal mirror is mounted at one end of an elongated support member and which includes means for adjusting said mirror longitudinally of said support member to a position corresponding to a linear response of said photo-multipliers, and wherein each said photo-multiplier is located within a cylindric block, said cylindric blocks being supported in a cluster about said elongated support member upon which said pyramidal mirror is mounted.

* * * * *