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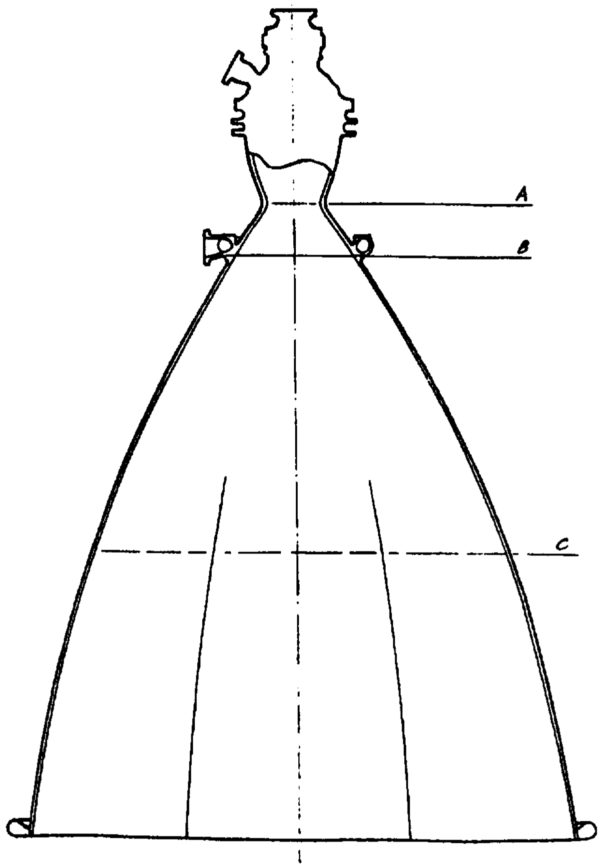
With amended claims.

(54) Title: ROCKET ENGINE NOZZLE

(57) Abstract

The invention refers to a rocket engine nozzle with an outlet portion having a curved profile in axial section. In order to enable a control of the flow separation occurring within the nozzle outlet, it is suggested that, circumferentially, said outlet portion in axial section has a radius, the length of which varies.



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Rocket engine nozzle

The present invention refers to a rocket engine nozzle with an outlet portion or thrust chamber having a curved profile in axial section.

During start-up and stop transients in sea-level rocket engines significant dynamic loads usually occur. These loads are generally attributed to the disordered flow characteristics of the flow during flow separation.

The outlet portion of nozzles for liquid propellant rocket engines often operate at conditions where the main jet exhausts into a non-negligible ambient pressure. Examples of such rocket engines are large liquid propellant sea-level rocket engines for boosters and core stages that are ignited at sea-level and upper stage rocket engines ignited during stage separation.

Dynamic loads are due to the instationary nature of the thrust chamber flow during start and stop transients and during steady-state operation with separated flow in the nozzle. The rules for and effects of such flow separation have been studied and presented at the 30th AIAA/ASME/SAE/ASEE Joint Propulsion Conference, June 1994, Indianapolis, IN, USA in a paper "Aero-elastic Analysis of Side Load in Supersonic Nozzles with Separated Flow", Volvo Aero Corporation, to which may be referred. The dynamic loads are generally of such a magnitude, e.g. of the order of 50-100 kN, that they present life-limiting constraints for the design of thrust chamber components. These constraints result in higher weight for thrust chamber structural elements. Furthermore the largest possible area ratio that can be used on the nozzle extension is limited by the requirement of attached flow during steady-state operation.

The final consequences of the dynamic loads are constraints on the overall performance-to-weight ratio of the thrust chambers and a subsequent limitation of the amount of pay-load that can be delivered into orbit by the rocket launcher.

For eliminating the drawbacks of prior nozzles a great number of techniques have been suggested which all, however, have turned out to have themselves significant drawbacks in various respects. The main difficulties refer to the function, performance, cooling and reliability.

Thus traditional bellshaped nozzles give a limited function and substantial start and stop transient loads. A dual bell nozzle also suffers from severe transient dynamic loads. External expansion nozzles have been suggested but not been sufficiently tested. A bell nozzle equipped with trip rings reduces dynamic loads but with too large a performance loss. Said nozzles also suffer from difficult cooling problems. Finally, extendible nozzles and ventilated nozzles have been suggested but both require mechanisms with functions that are not possible to verify prior to flight.

The main object of the present invention now is to suggest a rocket engine nozzle structure which provides for an advantageous flow control within the diverging outlet portion of the nozzle which makes it possible to reduce the weight of the rocket engine nozzle and to gain increased performance.

According to the invention this is achieved by a nozzle which is substantially distinguished in that, circumferentially, said outlet portion in axial section has a radius, the length of which varies. Preferably, the radius length varies periodically and most preferably periodically so as to create a polygonal circumferential shape of the nozzle.

According to the invention, the separated flow can be controlled satisfactorily by this very limited non-axisymmetric modification of the nozzle wall contour. This modification exhibits no significant negative effects on performance, reliability, cooling and manufacturing aspects of the nozzle outlet portion.

The invention thus provides for the design of a sea-level rocket engine nozzle with significantly higher vacuum performance through a larger nozzle area ratio and reduced weight.

The invention will be further described below with reference to the accompanying drawing, in which Figure 1 illustrates in a perspective view the diverging outlet portion of a nozzle according to the invention, Fig. 2 illustrates a similar but opened or broken-up perspective view of a similar nozzle, and Fig. 3 is an axial section of a rocket engine with an outlet portion according to the invention.

With reference to Fig. 3 the invention will be described applied to a known sea-level rocket engine. From the minimum nozzle area A in which the exhaust gases have sonic speed, the diverging or outlet portion of the nozzle can be considered to extend from the level B having an inlet area ratio of 5. Under many conditions such as in the moments of starting and stopping and when atmospheric pressure resides, the flow will separate from the inner wall of said diverging portion of the nozzle. This phenomenon occurs spontaneously and randomly and causes instationary gas loads in transversal direction. Said phenomenon will imply restrictions as to the expansion ratio in the outlet portion and the length of the latter along which the requirement of attached flow during steady state operation can be fulfilled. According to the invention, a new nozzle shape is suggested which will provide for an effective control of the flow separation in a reliable way such that the expansion ratio might be increased and thus the power of the rocket engine without the flow separation phenomenon causing unacceptable side-loads.

The present invention, leaving the prior axisymmetric shape of the nozzle wall and having the radius varying in length circumferentially, and preferably to form a polygonal contour, will drastically improve the behaviour of the movements of the flow separation line and reduce the side-loads and hence allow a higher expansion ratio.

In Fig. 1 has been illustrated only the diverging or outlet portion of the inventive nozzle. In said Figure, the axisymmetric contour of the nozzle portion has been modified from the prior pure circular shape indicated by e.g. lines D, by letting, in accordance with the invention, the radius length vary periodically and preferably so as to form a polygon with e.g. eight sides S1, S2... The polygon being circumscribed the circular line D, an area augmentation of maximum e.g. 6% can be achieved.

In a preferred embodiment, the contour at the inlet of said diverging nozzle portion, i.e. at the level B, see Fig. 3, will be circular, thus with constant length of the radius, and the radius length then starting progressively to vary with increasing distance axially from the level B and to reach its greatest variations close to the end of the diverging nozzle portion.

In Fig. 2 the perspective view of the nozzle has been broken in order to show the flow separation lines F. From said Figure it is evident that the flow separation lines will form curved portions extending from each corner of the polygonal contour and being curved downstream to about the center line of each polygon side. This implies that the flow separation can be effectively controlled and the detrimental side-loads avoided almost entirely. The inventive polygonal contour will thus induce a non-axisymmetric pressure distribution of the inner wall surface of the nozzle outlet portion. In Fig. 2, the lines of flow separation have been illustrated for a set of chamber pressures during a start transient. Like the embodiment shown in Fig. 1, also in this embodiment the polygonal shape has eight (8) sides and provides an area augmentation by 6% over the circular area circumscribed by the polygon.

The number of sides in the polygon can be varied from 5 to 15, 8, 10 and 12 having been subject to tests. In analyses no affects on the performance data have been observed.

As an example, the measures of a prior nozzle might be exemplified as follows, viz.:

Length	1,8 m
Inlet diameter	0,6 m
Exit diameter	1,8 m
Inlet area ratio	5
Exit area ratio	45.

Contrary to this, the measures of a nozzle according to the invention might be exemplified as follows, viz.:

Length section A to exit	3,3 m
Inlet diameter	0,6 m
Exit diameter	2,7 m
Inlet area ratio	5
Exit area ratio	100

As can be seen from the above dimensional example the exit area ratio can be increased to 100 and thus provides for a higher expansion ratio and hence improved performance of the nozzle since the separation lines now can be effectively controlled and moved further downstream of the outlet portion of the nozzle to about a level C as illustrated in Fig. 3. This also allows an increase in length of the nozzle outlet portion and improved flow conditions during steady state operation.

C l a i m s

1. A rocket engine nozzle with an outlet portion having a curved profile in axial section, c h a r a c t e r i z e d i n that, circumferentially, said outlet portion in axial section has a radius, the length of which varies.

2. Rocket engine nozzle according to claim 1, c h a r a c t e r i z e d i n that the length of the radius varies periodically.

3. Rocket engine nozzle according to claim 2, c h a r a c t e r i z e d i n that the radius length varies periodically such that a polygonal circumferential shape is obtained.

4. Rocket engine nozzle according to claim 3, c h a r a c t e r i z e d i n that said polygonal shape has between 5 and 15 sides.

5. Rocket engine nozzle according to claim 2, c h a r a c t e r i z e d i n that the periodical variation of the length of the radius is small or almost none closest to the smallest cross-sectional area of the nozzle and then progressively increases to the maximum desired final value towards the mouth of said outlet portion.

AMENDED CLAIMS

[received by the International Bureau on 16 December 1996 (16.12.96); original claims 1-5 replaced by amended claims 1-3 (1 page)]

1. A rocket engine nozzle with an outlet portion having a curved profile in axial section, which outlet portion in axial section has a radius, the length of which varies periodically in circumferential direction, c h a r a c t e r i z e d i n that the radius length varies periodically such that a polygonal circumferential shape is obtained.

2. Rocket engine nozzle according to claim 1, c h a r a c t e r i z e d i n that said polygonal shape has between 5 and 15 sides.

3. Rocket engine nozzle according to claim 1, c h a r a c t e r i z e d i n that the periodical variation of the length of the radius is small or almost none closest to the smallest cross-sectional area of the nozzle and then progressively increases to the maximum desired final value towards the mouth of said outlet portion.

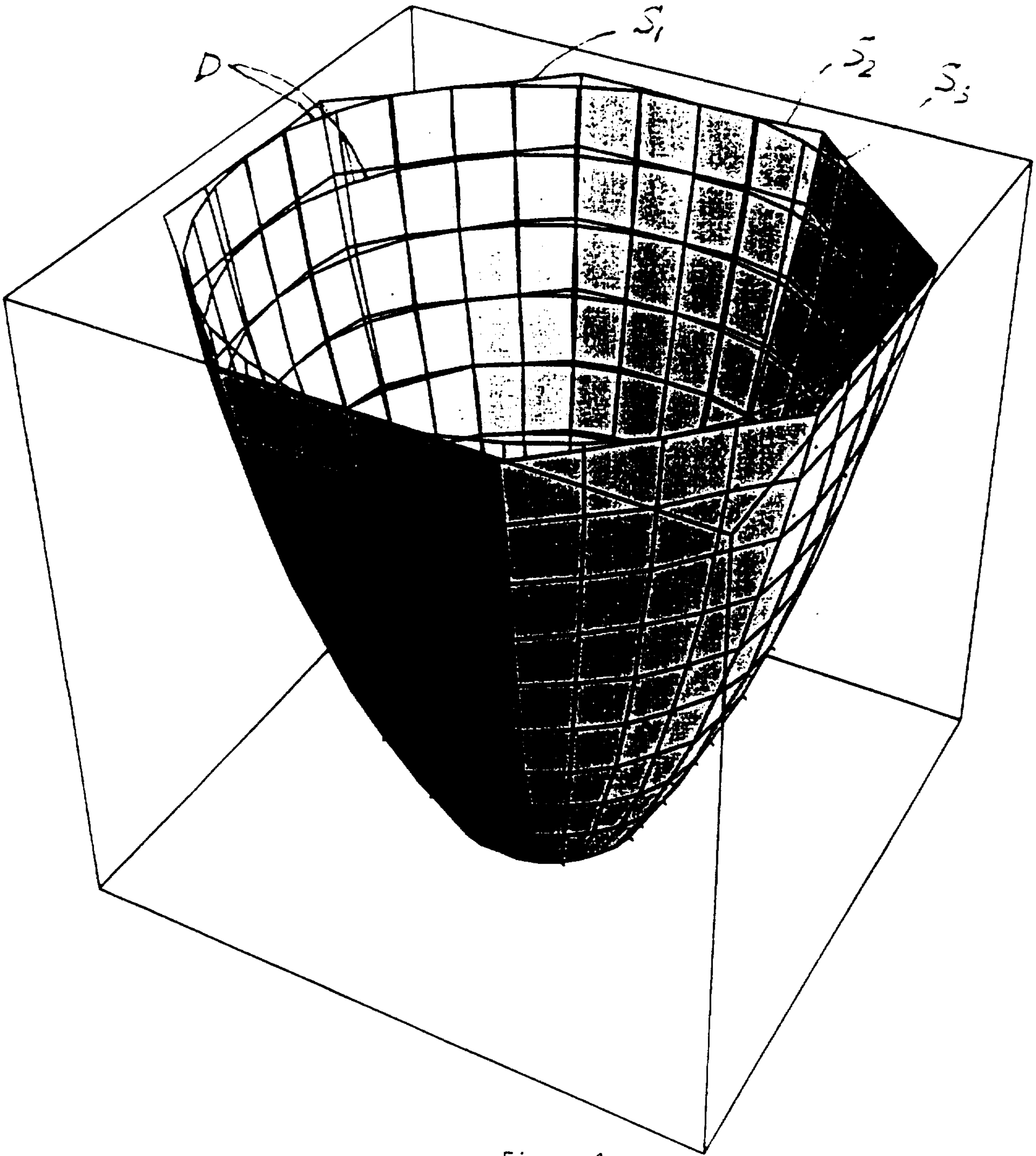

Figure 1

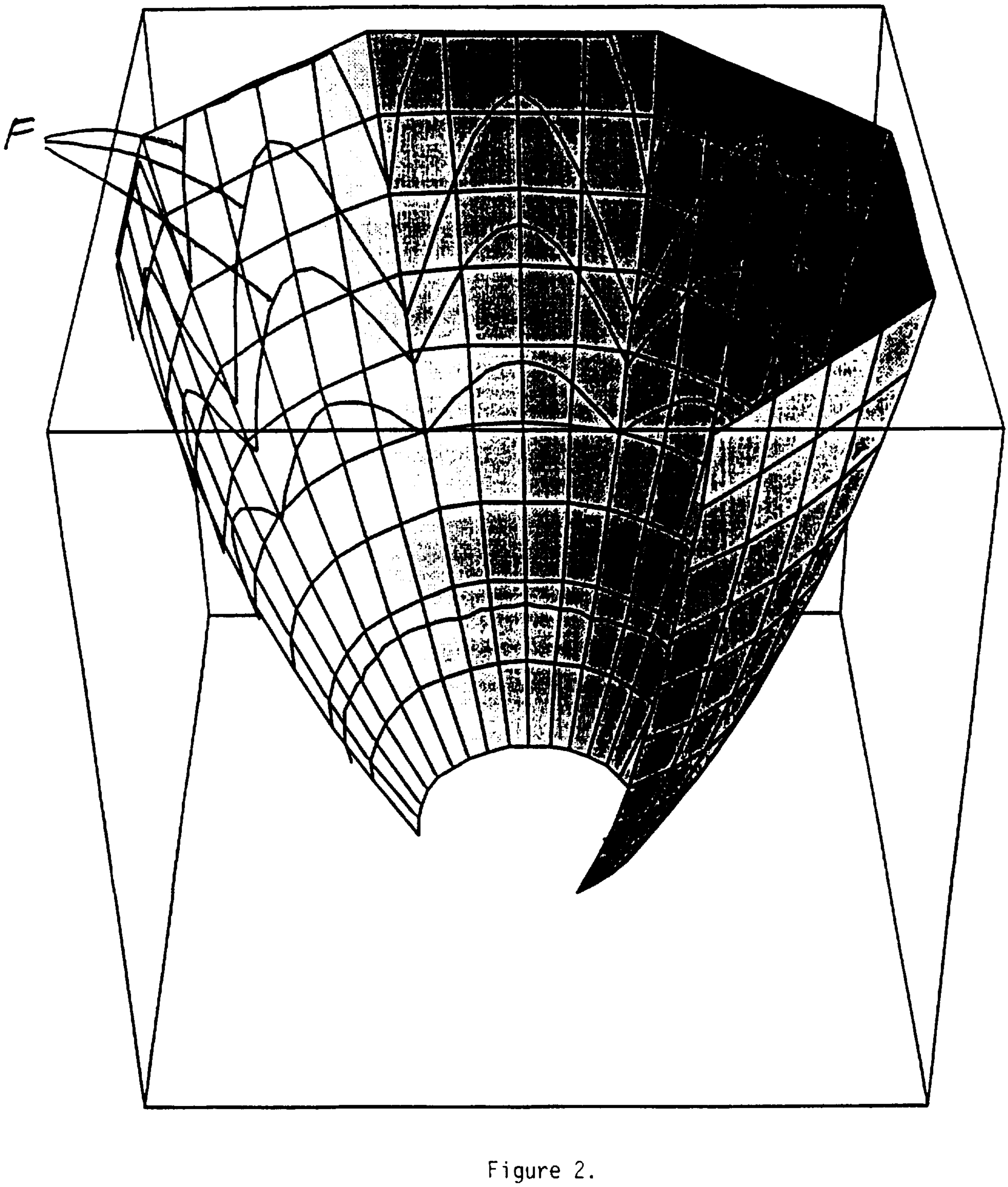

Figure 2.

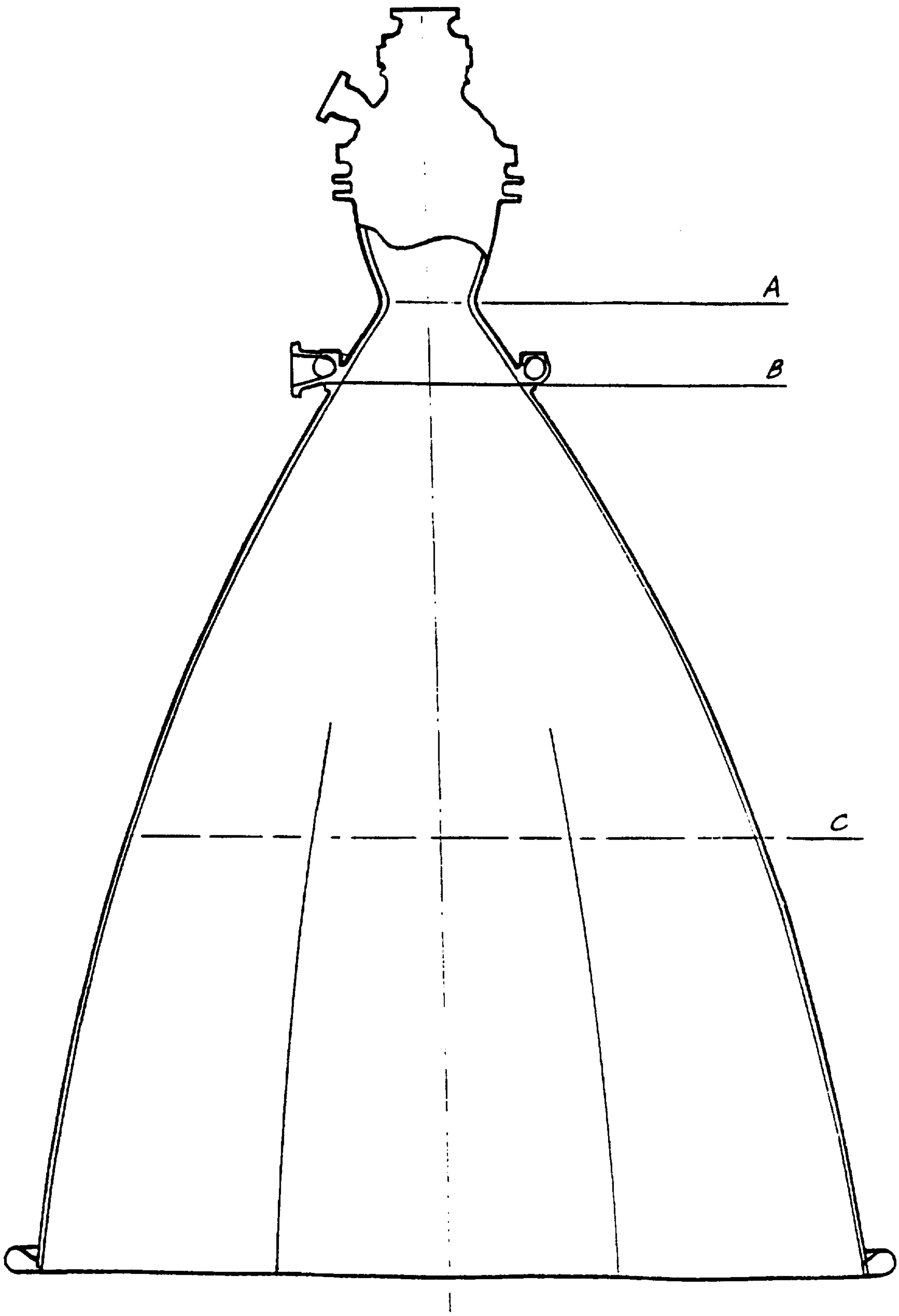

Figure 3.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 96/00176

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: F02K 9/97
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: F02K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 3292865 A (F.R. SHORT ET AL), 20 December 1966 (20.12.66)	1,2,5
Y		3,4
	--	
Y	US 5343698 A (L. PORTER ET AL), 6 Sept 1994 (06.09.94), column 2, line 54 - line 64	3,4
	--	
A	US 4707899 A (V. SINGER), 24 November 1987 (24.11.87)	1-5
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☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

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13 Sept 1996	18 -09- 1996
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INTERNATIONAL SEARCH REPORT

Information on patent family members

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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A- 3292865	20/12/66	NONE	
US-A- 5343698	06/09/94	EP-A- 0622539	02/11/94
		JP-A- 6346795	20/12/94
US-A- 4707899	24/11/87	FR-A- 2586455	27/02/87
		GB-A,B- 2179277	04/03/87
		JP-C- 1632666	26/12/91
		JP-B- 2056177	29/11/90
		JP-A- 62077135	09/04/87
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