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(54) **ROCKET NOZZLE ASSEMBLY WITH
SEPARABLE NOZZLE EXTENSION**

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CPC **F02K 9/978** (2013.01)

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CPC F02K 9/976; F42B 15/36; F42B 15/38
See application file for complete search history.

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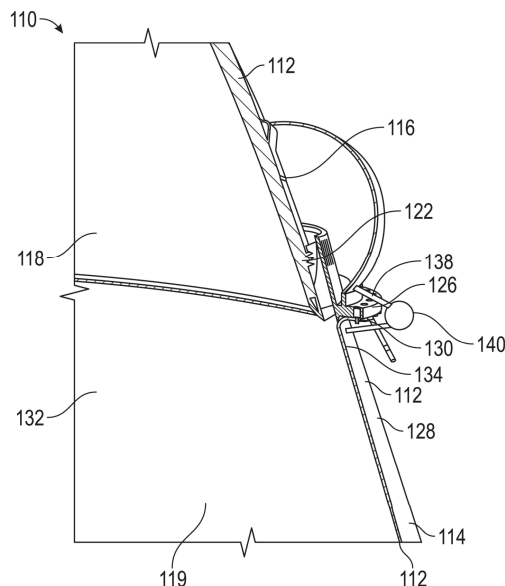
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(57) **ABSTRACT**

Rocket nozzle assembly having a separable outboard nozzle
extension for transitioning from a vacuum-optimized to an
atmospheric-optimized configuration. The nozzle assembly
includes an inboard divergent nozzle section attached at an
interface with a detachable outboard divergent nozzle exten-
sion. The nozzle and extension are removably attached via
a connector, such as a clamp and strap. An actuator causes
the connector to release and thereby allow the extension to
separate from the nozzle in flight. The nozzle assembly may
be used with a reusable second stage rocket that lands on the
ground or an ocean platform. The nozzle extension may be
replaced in between flights.

14 Claims, 14 Drawing Sheets



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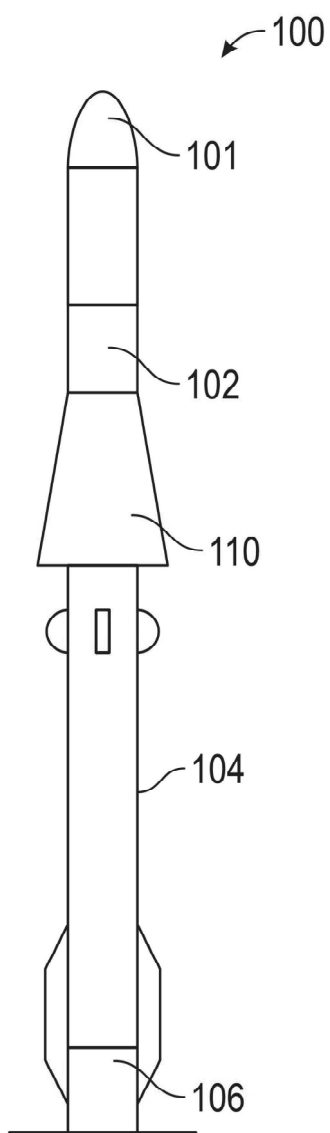
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**FIG. 1**

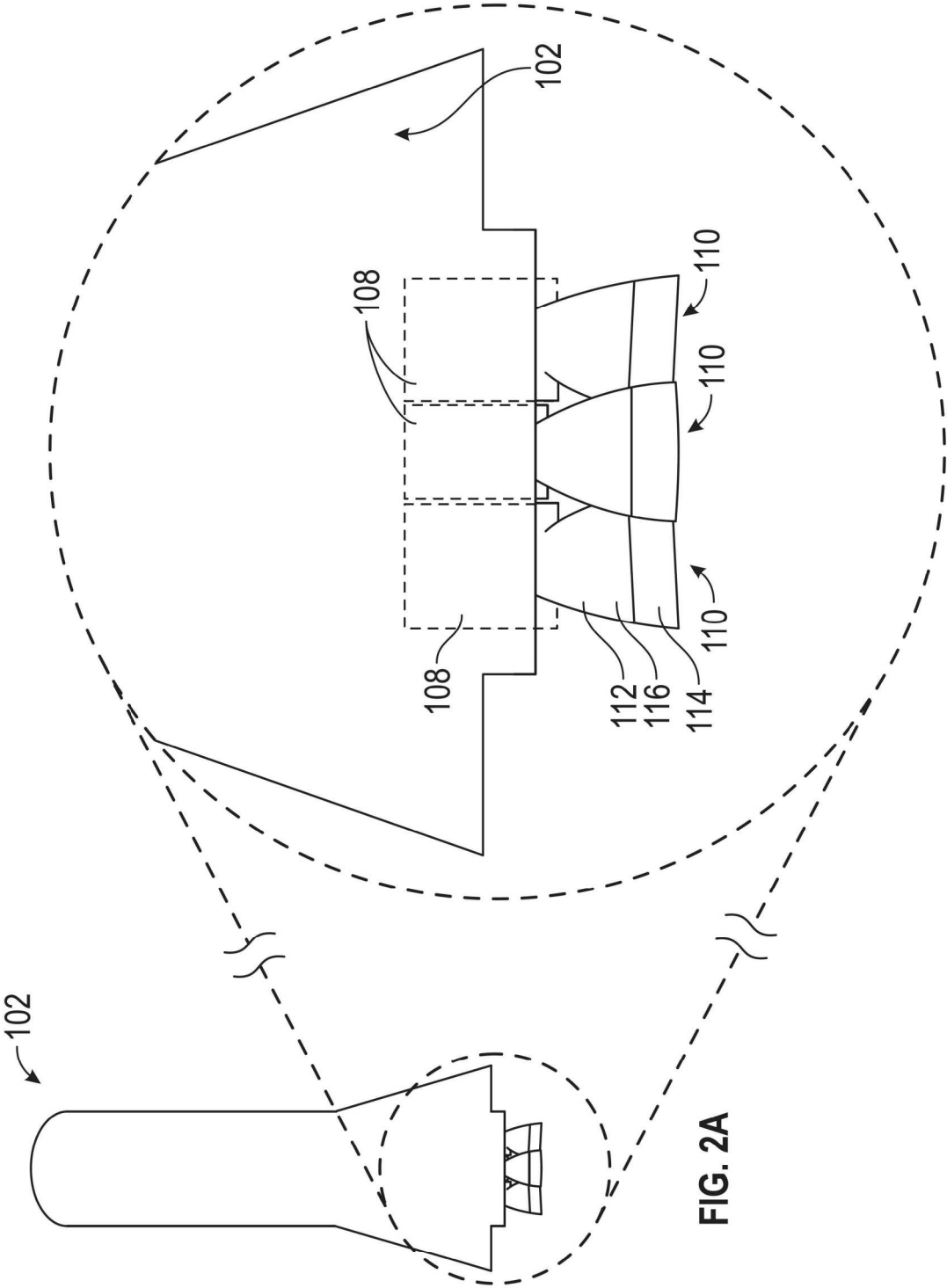


FIG. 2B

FIG. 2A

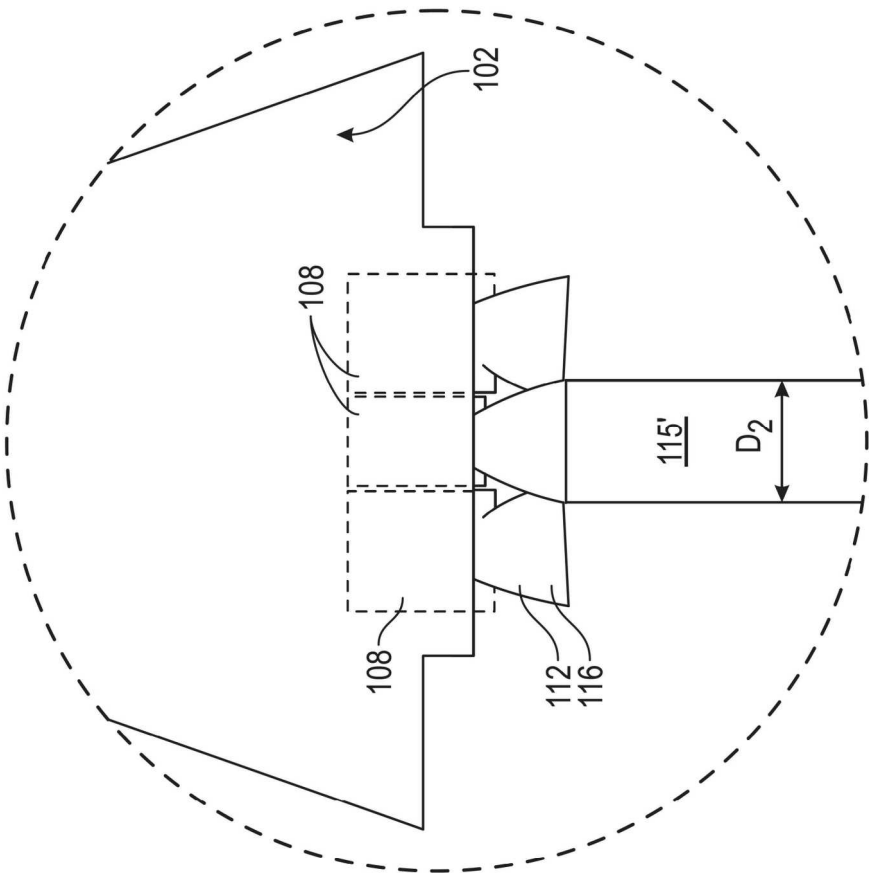


FIG. 2D

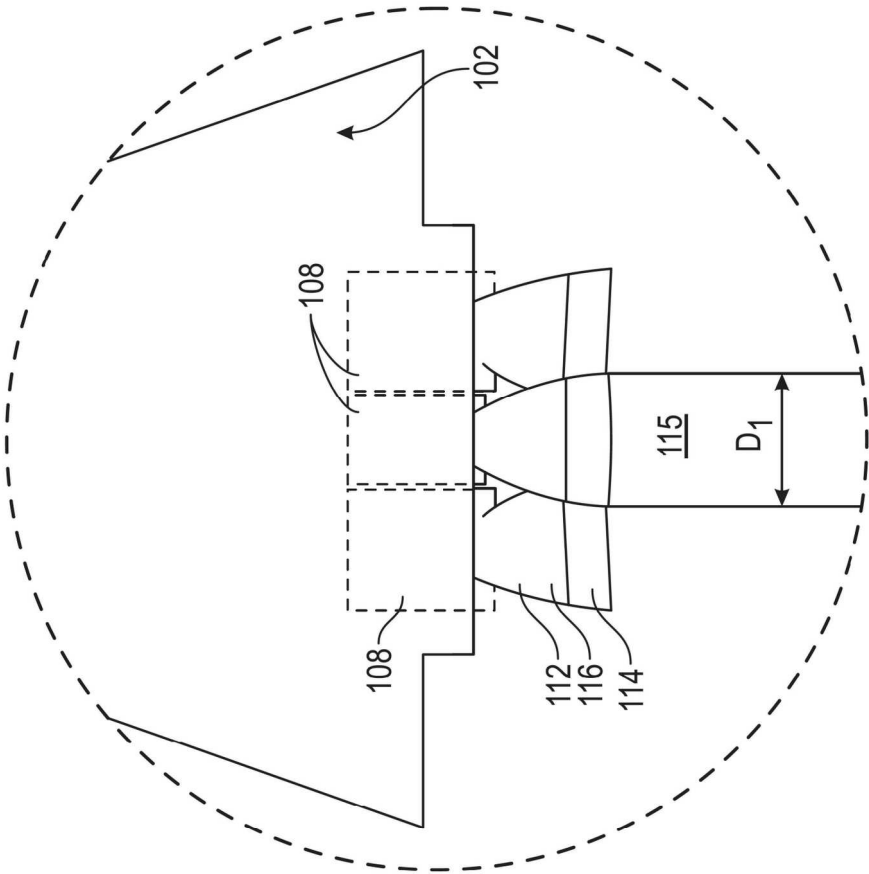


FIG. 2C

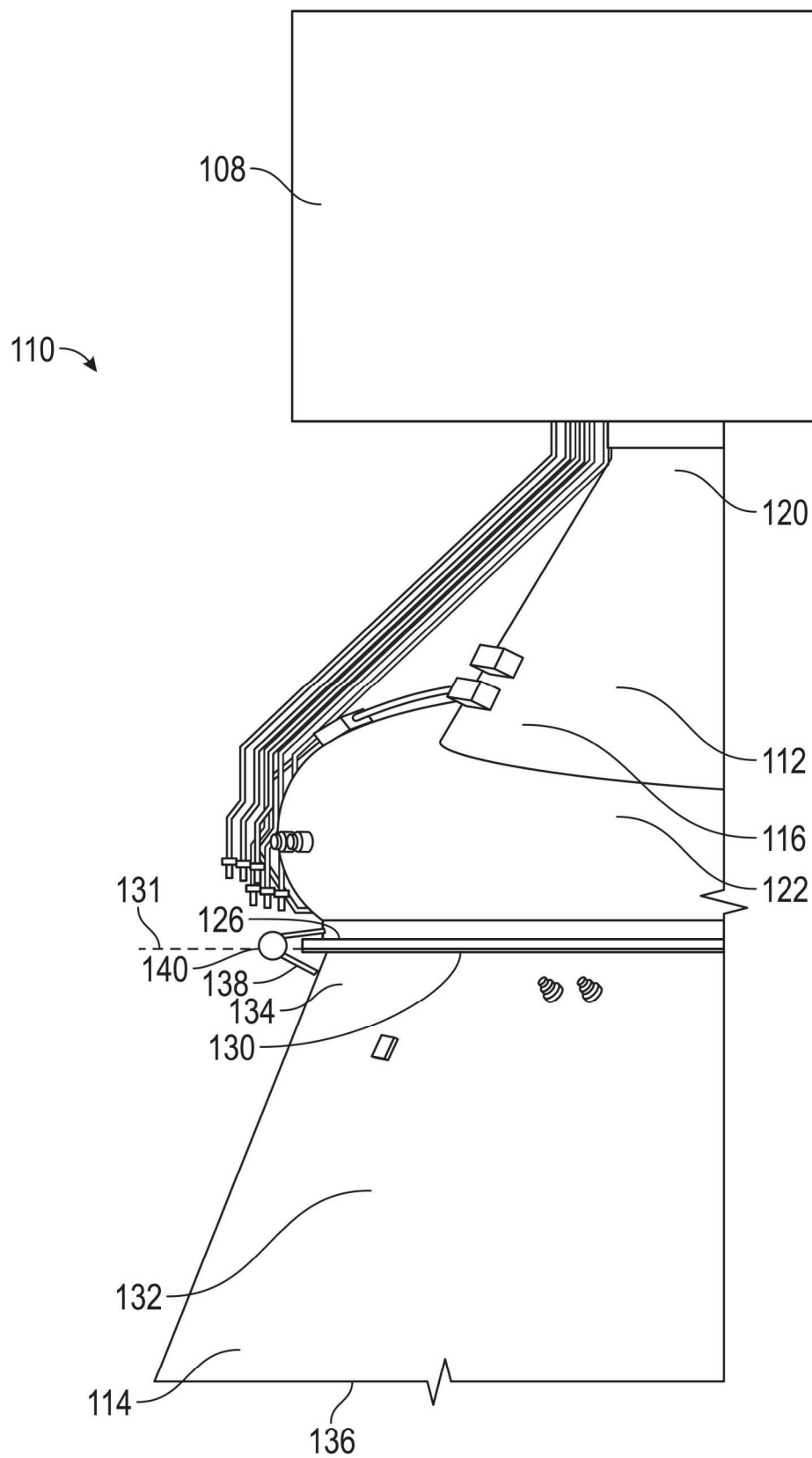


FIG. 3A

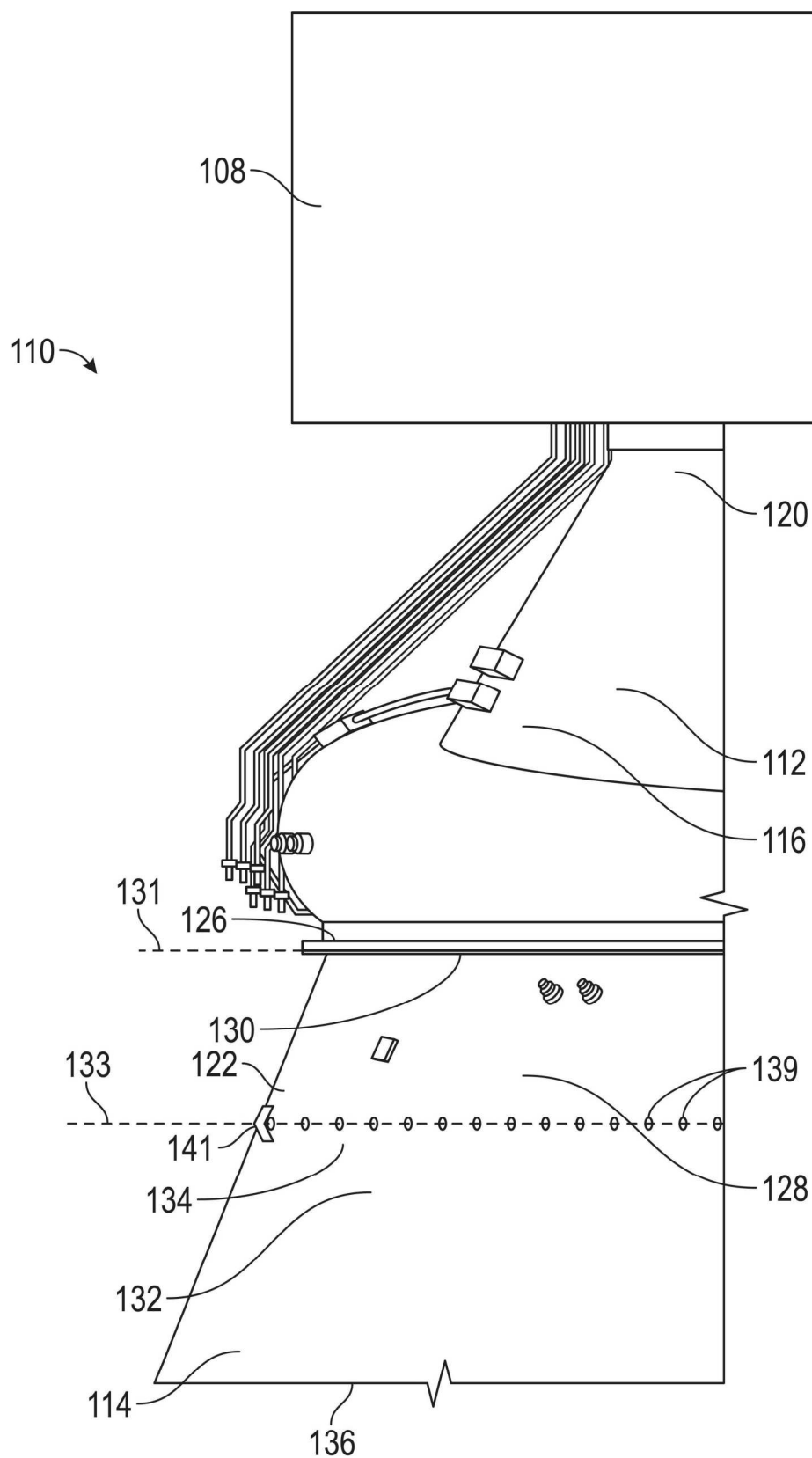


FIG. 3B

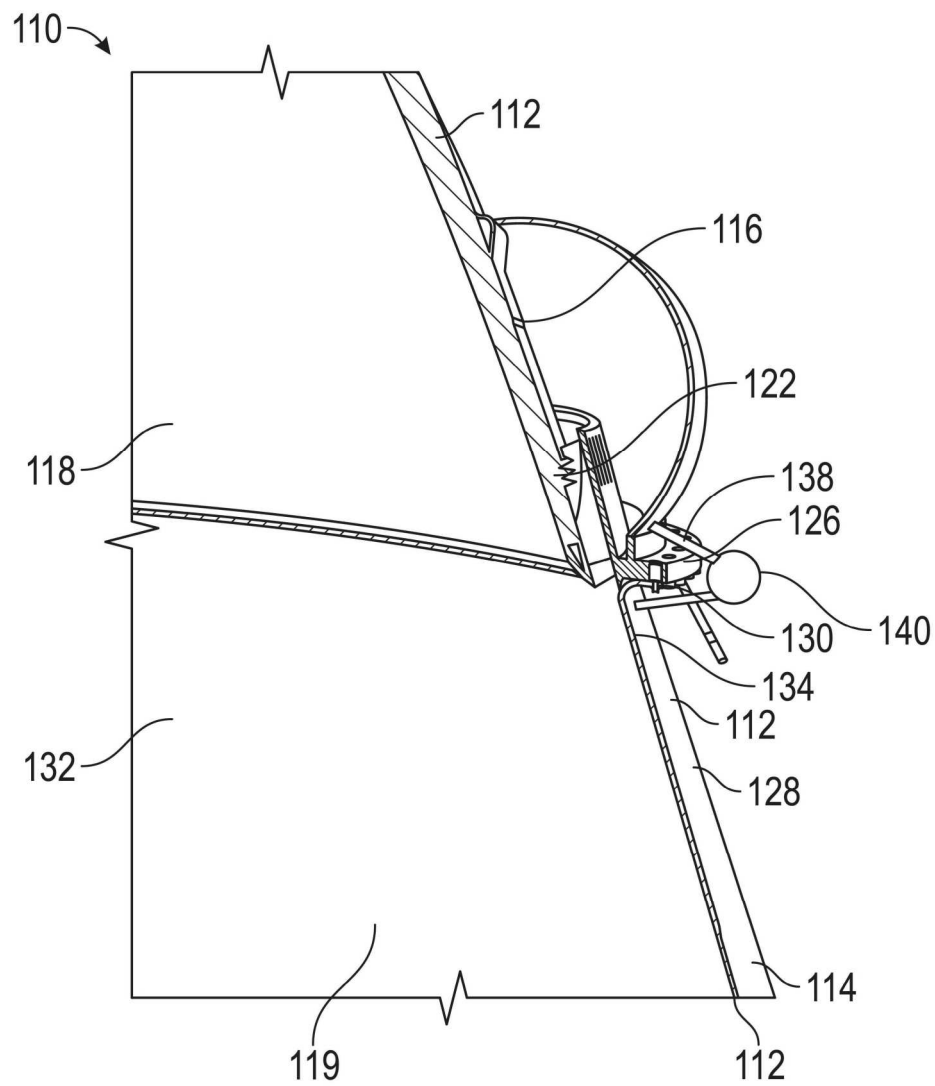


FIG. 3C

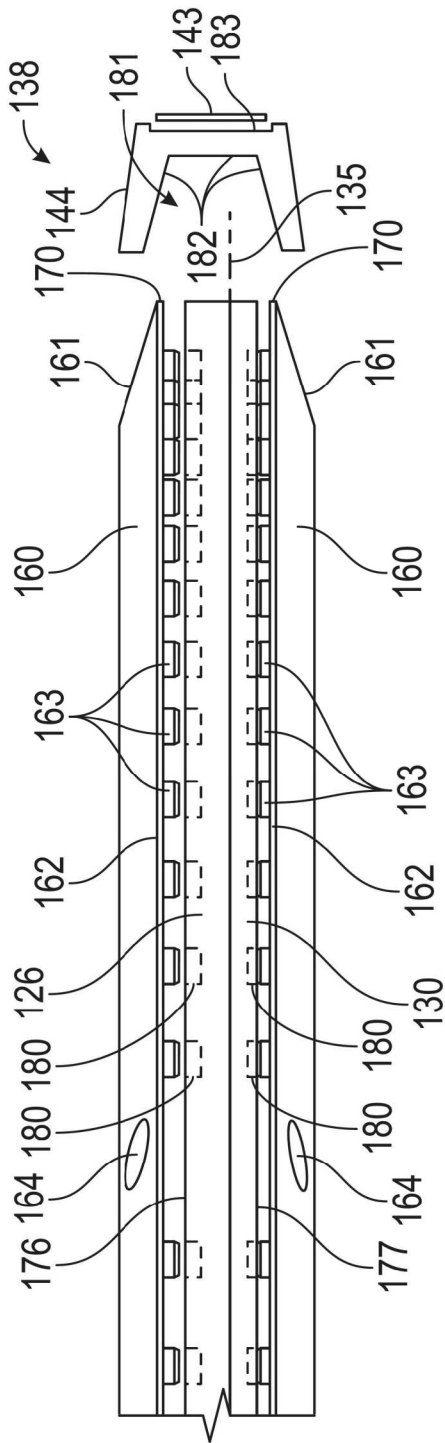


FIG. 4A

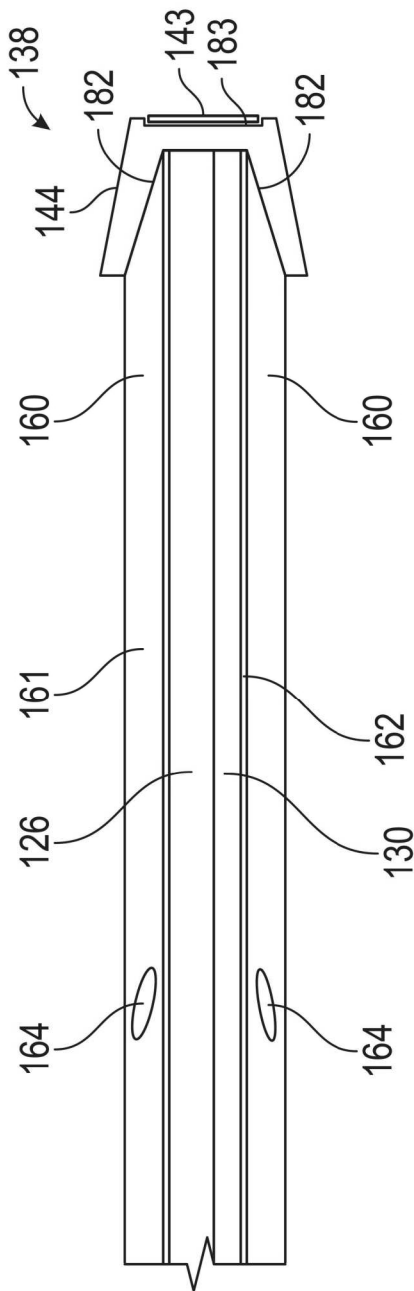
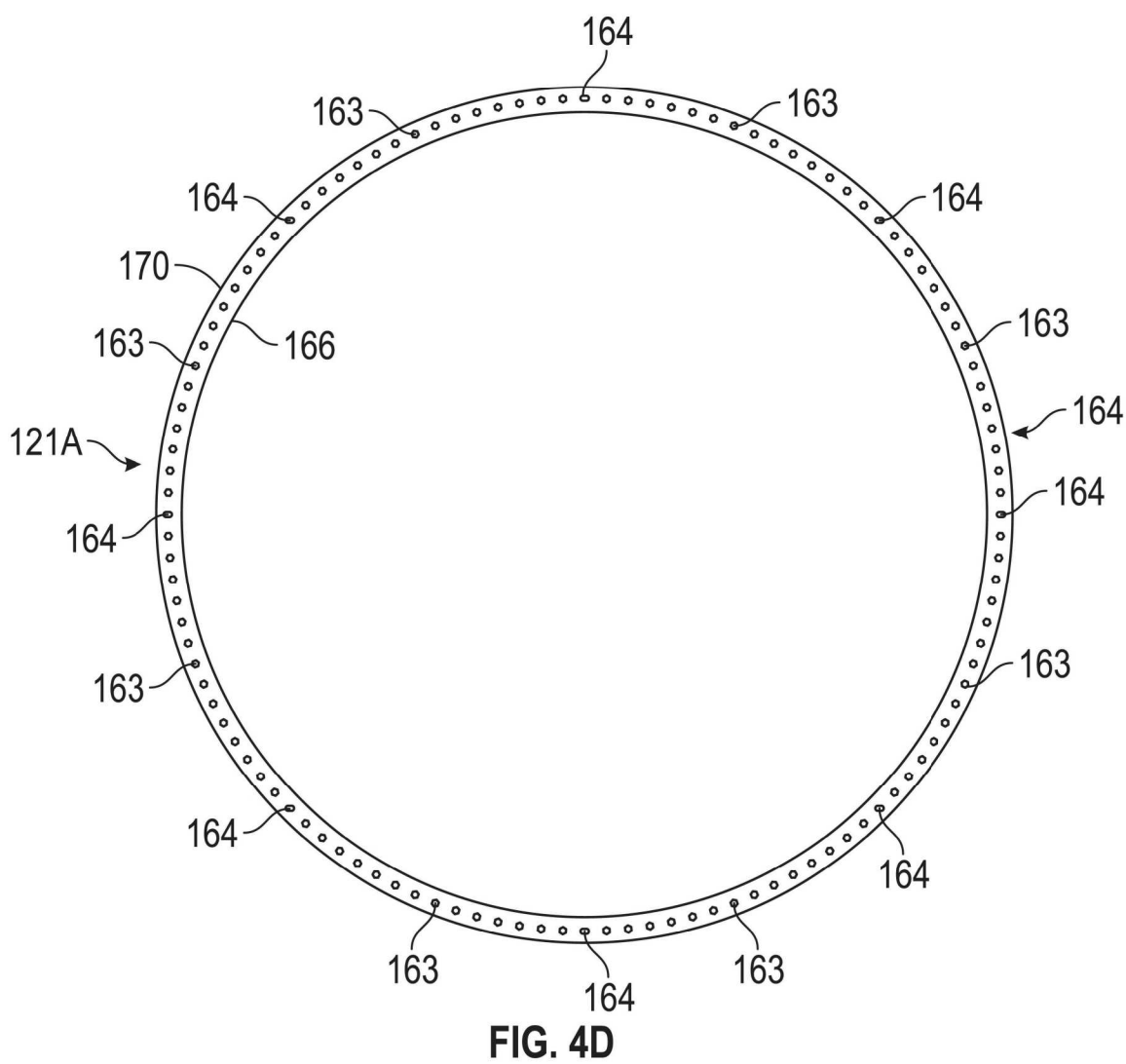
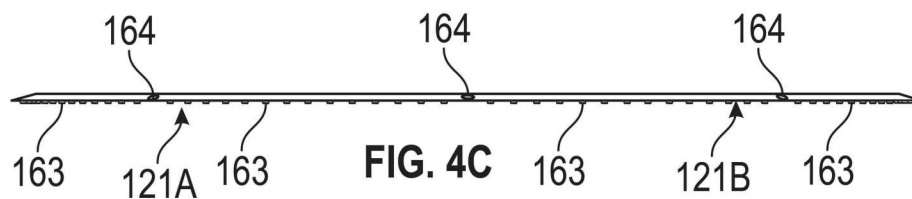


FIG. 4B



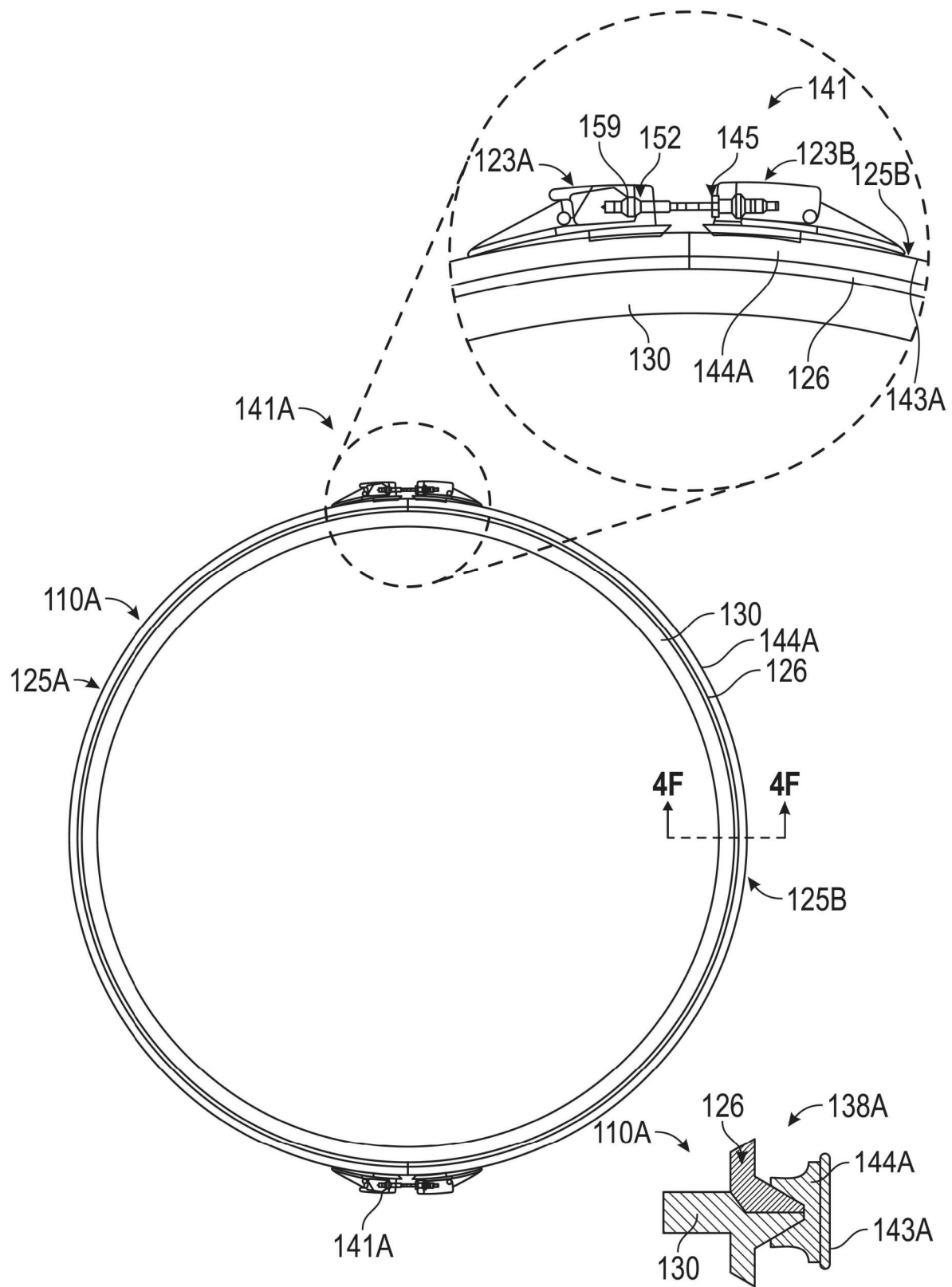


FIG. 4E

FIG. 4F

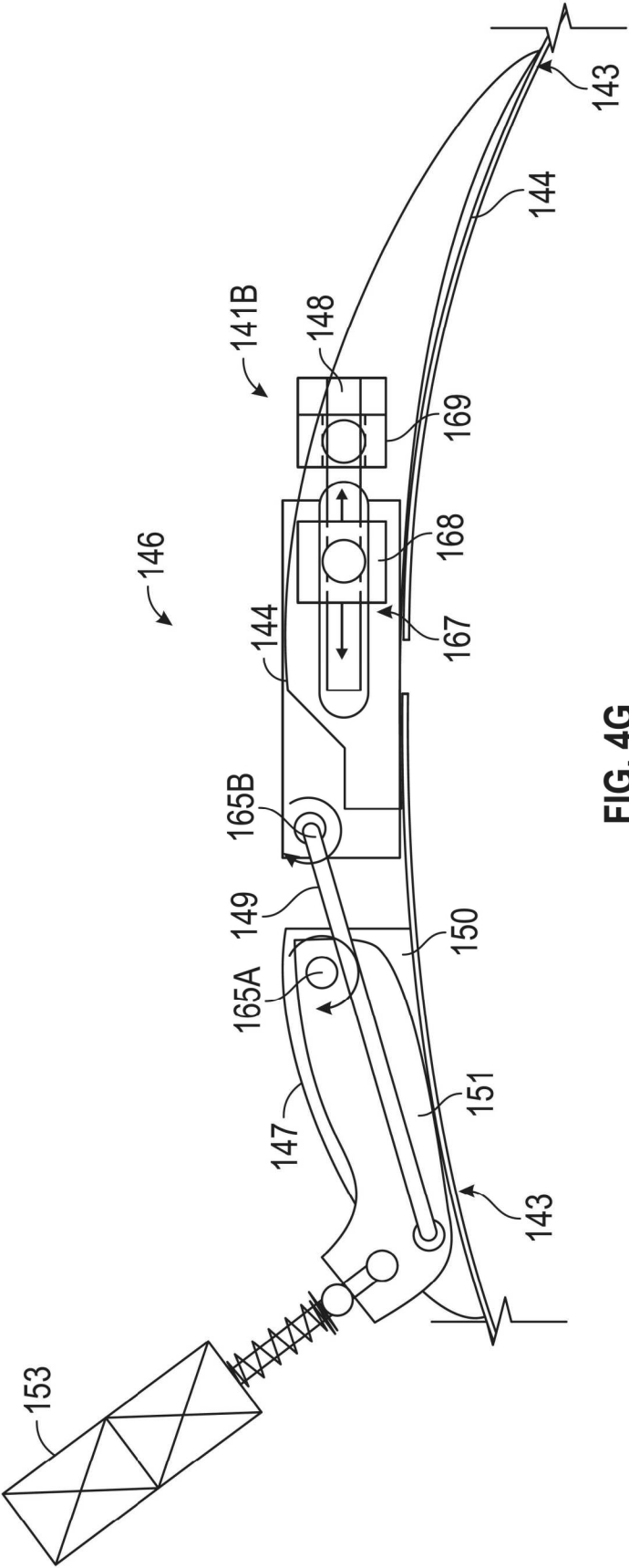


FIG. 4G

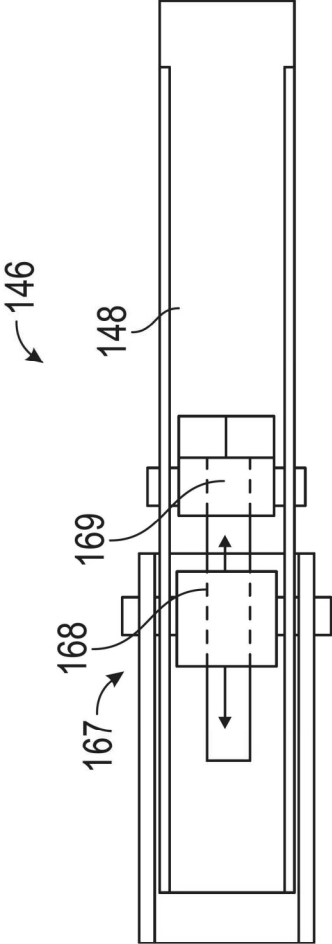
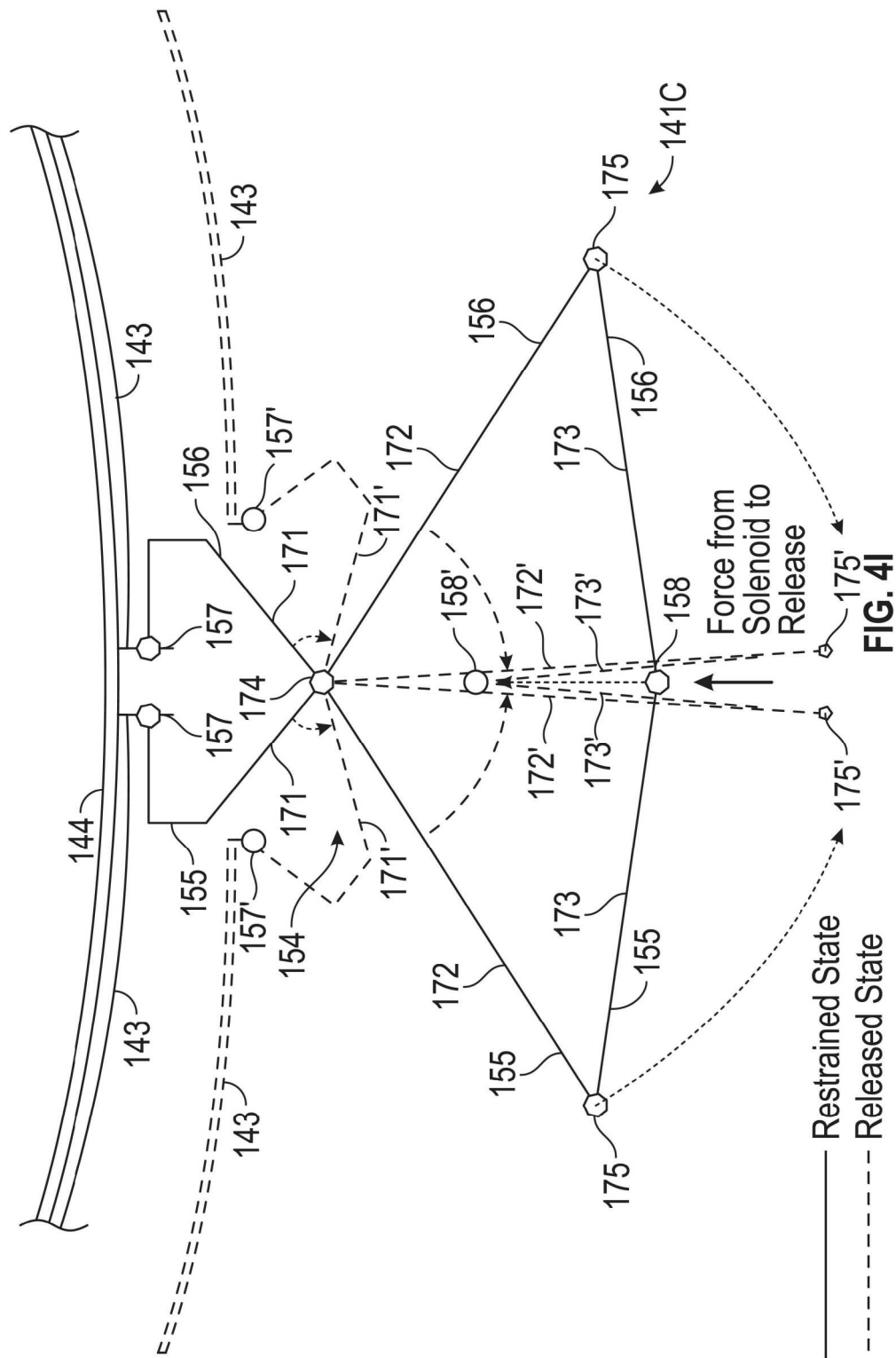


FIG. 4H



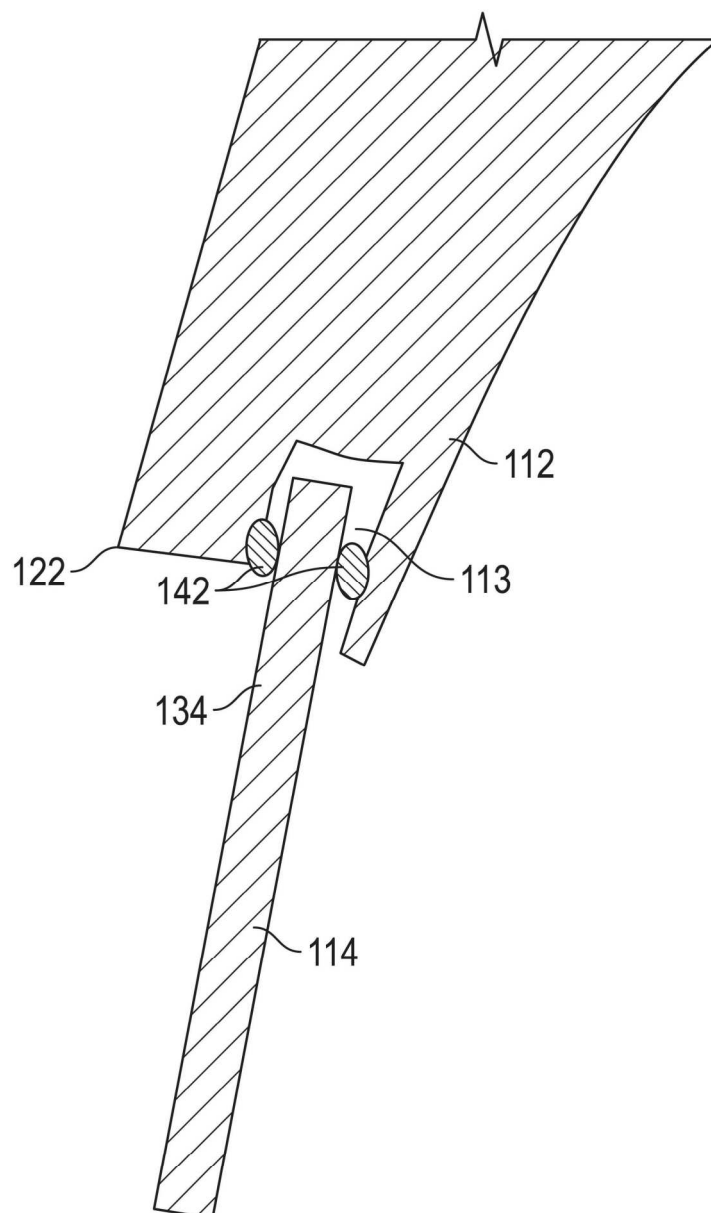


FIG. 5

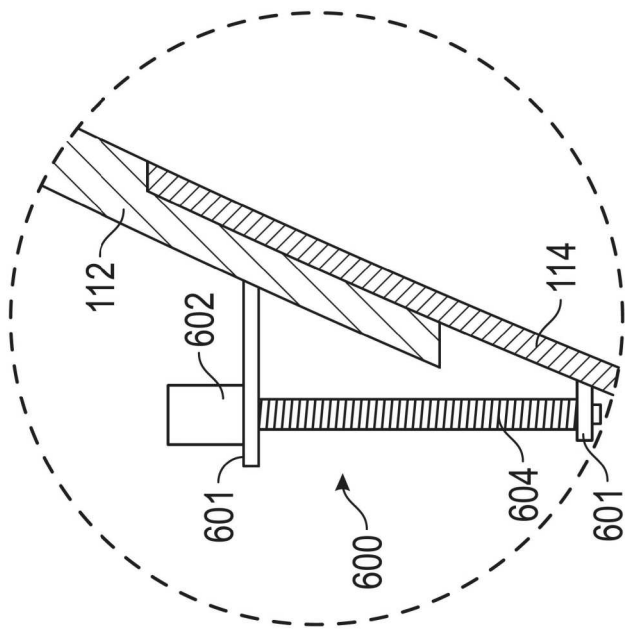


FIG. 6B

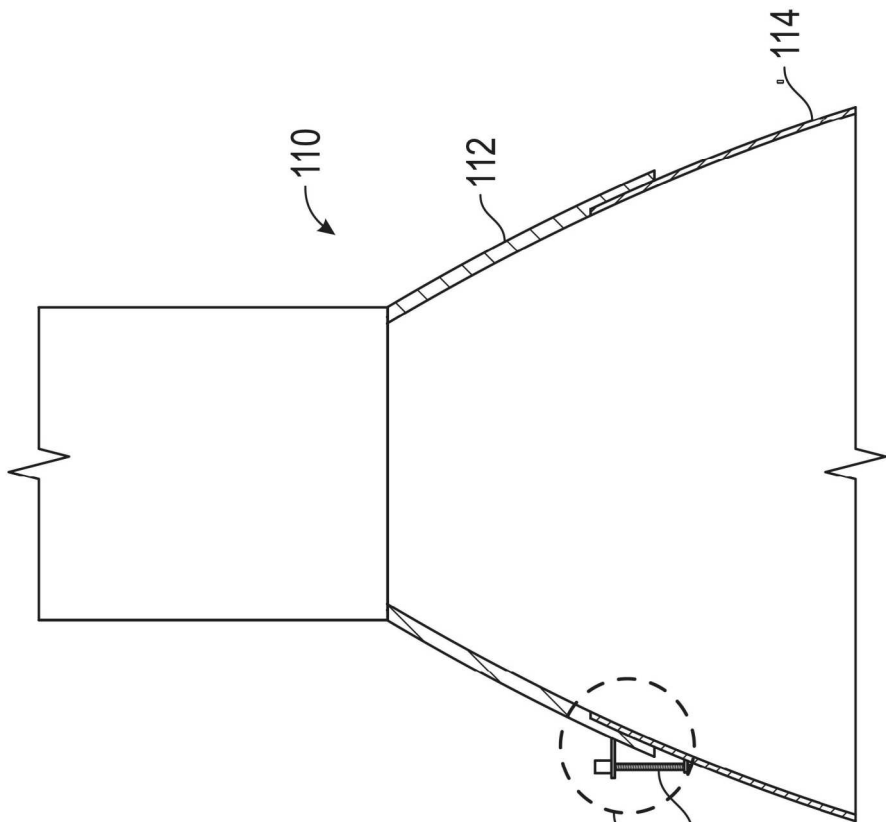


FIG. 6A

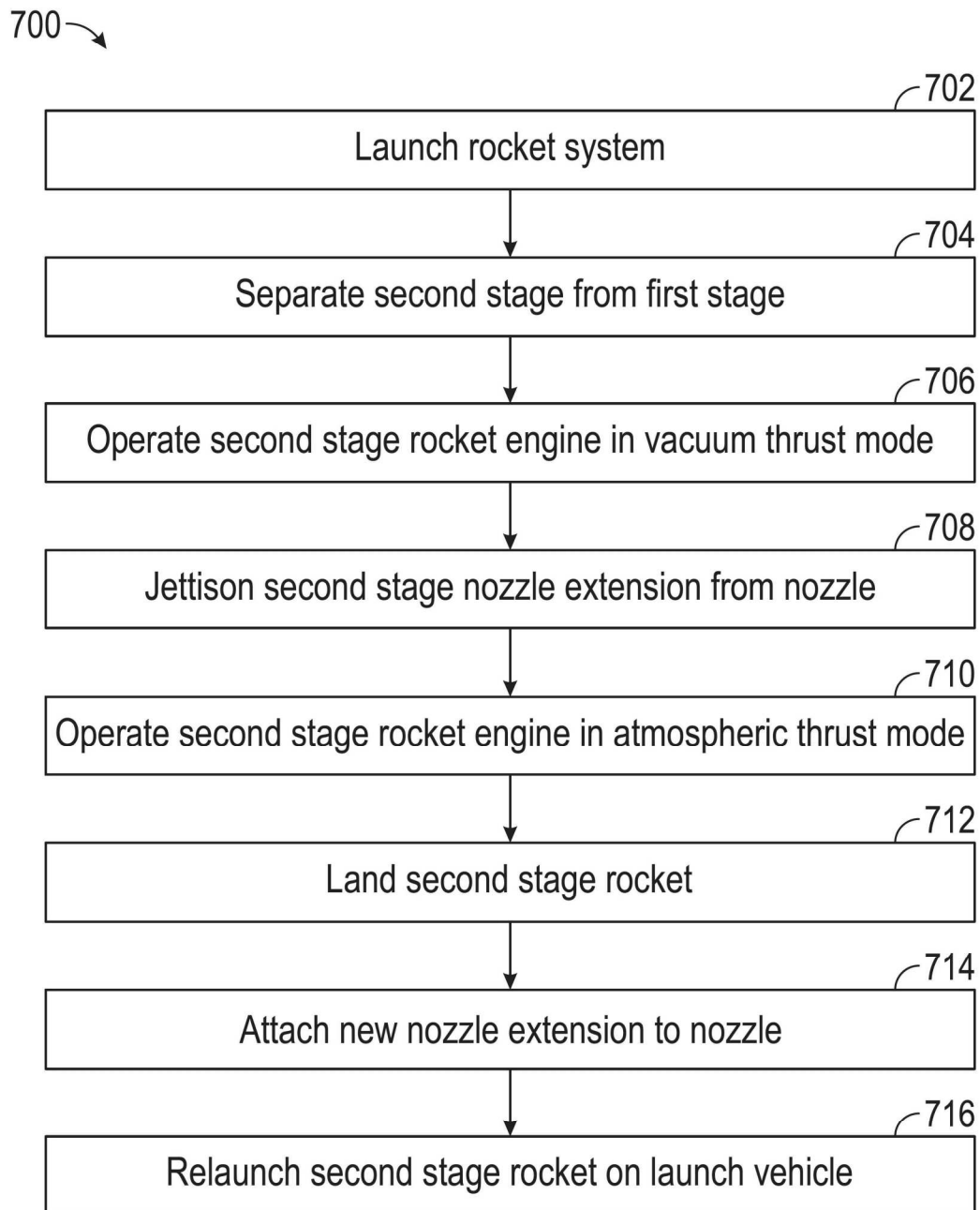


FIG. 7

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**ROCKET NOZZLE ASSEMBLY WITH
SEPARABLE NOZZLE EXTENSION****BACKGROUND****Field**

The technology relates generally to rocket engine nozzles, more specifically to variable length rocket nozzle assemblies that can jettison a nozzle portion.

Description of Related Art

Traditionally, orbital launch vehicles may use multiple stages, such as a first stage rocket and a second stage rocket. For example, an orbital launch vehicle may use a first stage rocket for launch from the earth's surface to a separation altitude. The orbital launch vehicle may then separate the first stage rocket from the second stage rocket and fire the second stage rocket to further ascend to a desired distance from earth in orbit (e.g., an orbiting distance). As such, the second stage rocket is typically used for further ascent after the rocket leaves the atmosphere and is not traditionally operated in dense atmosphere such as at sea level. The second stage rocket traditionally completes its mission (e.g., delivering a payload) in space. After the mission of the second stage rocket is complete, it is typically decommissioned and/or discarded. As such, second stage rockets are traditionally not reusable. There is therefore a need for a reusable second stage, which would decrease costs of subsequent launches. Further, because a reusable second stage may operate first in a vacuum and later in dense atmospheric air, there is a need for a rocket engine having components optimized for use in both environments. Traditional nozzles of second stages are optimized for vacuum environments, but such nozzles are either unusable in the atmosphere or result in suboptimal performance. There is therefore a need for second stage rocket engine nozzles that overcome these and other drawbacks.

SUMMARY

The examples disclosed herein, each have several aspects no single one of which is solely responsible for the disclosure's desirable attributes. Without limiting the scope of this disclosure, its more prominent features will now be briefly discussed. After considering this discussion, and particularly after reading the section entitled "Detailed Description" one will understand how the features of the examples described herein provide advantages over existing approaches to nozzle assemblies for second stage rockets.

The following disclosure describes non-limiting examples of some examples. For instance, other examples of the disclosed systems and methods may or may not include the features described herein. Moreover, disclosed advantages and benefits may apply only to certain examples of the disclosure and should not be used to limit the disclosure.

Systems, devices, and methods are described for a rocket nozzle assembly. In one aspect, the rocket nozzle assembly includes a nozzle having a frustoconical nozzle body that extends axially between an inboard nozzle end and an outboard nozzle end and defines a nozzle channel. The nozzle assembly further includes a nozzle extension having a frustoconical extension body that extends axially from an inboard extension end to an outboard extension end, where the inboard extension end is removably coupled to the outboard nozzle end at an interface via a connector extend-

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ing annularly about the interface. The frustoconical extension body defines an extension channel that is axially aligned with the nozzle channel. The nozzle assembly further includes an actuator in physical communication with the connector and configured to cause the nozzle extension to detach from the nozzle.

In some examples, the connector comprises a V-band clamp.

In some examples, the connector comprises one or more fasteners.

In some examples, the nozzle channel and the extension channel form a substantially continuous channel when the nozzle extension is coupled to the nozzle.

In some examples, the continuous channel is configured to form a first exhaust plume having a first exit diameter.

In some examples, the nozzle channel, after the extension has separated from the nozzle, is configured to form an exhaust plume having a second exit diameter that is smaller than the first exit diameter.

In some examples, the nozzle and the nozzle extension form a divergent section of the nozzle assembly configured for an initial burn of a second stage rocket engine.

In some examples, the second stage rocket engine is a vacuum optimized rocket engine.

In some examples, the nozzle, after the extension has separated from the nozzle, forms a divergent section of the nozzle assembly configured for a vertical landing burn of a second stage rocket engine in an atmosphere.

In some examples, the actuator comprises a pyrotechnic device.

In some examples, the actuator comprises an explosive shaped charge.

In some examples, the actuator comprises a hydraulic actuator.

In some examples, the actuator comprises an electromechanical actuator.

In some examples, the nozzle comprises a removable portion configured to be replaced on the ground during refurbishment of the nozzle.

In some examples, the outboard nozzle end comprises a nozzle flange that extends radially outward, and wherein the inboard extension end comprises an extension flange that extends radially outward, the nozzle assembly further comprising at least one clamp coupling the nozzle flange and the extension flange together.

In another aspect, a method of operating a rocket includes operating a rocket engine of the rocket in a vacuum thrust mode. The rocket engine includes at least one nozzle assembly having a nozzle removably attached to a nozzle extension. The method includes operating an actuator to release a connector extending annularly about the nozzle assembly to cause the nozzle extension to detach from the nozzle. The method includes operating the rocket engine in an atmospheric thrust mode using the nozzle without the nozzle extension.

In some examples, the vacuum thrust mode comprises fuel burn parameters that cause the rocket engine to expand an exhaust plume to a first diameter at an exit of the nozzle extension, and wherein the atmospheric thrust mode comprises fuel burn parameters that cause the rocket engine to expand the exhaust plume to a second diameter at an exit of the nozzle, and wherein the second diameter is smaller than the first diameter.

In some examples, operating the actuator includes operating a pyrotechnic device to detach an annular clamp.

In some examples, operating the actuator includes operating a shaped explosive charge.

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In some examples, the rocket is a second stage rocket. The method further includes launching a first stage rocket that is coupled to the second stage rocket. The method includes separating the first stage rocket from the second stage rocket. The method includes initiating the operating of the rocket engine of the second stage rocket in the vacuum thrust mode.

In some examples, the method further includes landing the second stage rocket. The method includes attaching a new nozzle extension to the nozzle. The method includes re-launching the second stage rocket on a launch vehicle.

In another aspect, a rocket system includes a second stage rocket including one or more second stage rocket engines having a nozzle assembly configured to transform from a vacuum-optimized configuration to an atmospheric-optimized configuration. The nozzle assembly includes a nozzle having a frustoconical nozzle body that extends axially between an inboard nozzle end and an outboard nozzle end and defines a nozzle channel. The nozzle includes a nozzle extension having a frustoconical extension body that extends axially from an inboard extension end to an outboard extension end. The inboard extension end is removably coupled to the outboard nozzle end at an interface via a connector extending annularly about the interface. The extension body defines an extension channel that is axially aligned with the nozzle channel. The system includes an actuator in physical communication with the connector and configured to cause the nozzle extension to detach from the nozzle.

In some examples, the system includes a first stage rocket having one or more first stage rocket engines and configured to be coupled with the second stage rocket to launch the rocket system from within an atmosphere.

In one aspect of the systems and methods disclosed herein, a rocket nozzle assembly is described having a nozzle, a nozzle extension, and an actuator. The nozzle has a frustoconical nozzle body that extends axially between an inboard nozzle end and an outboard nozzle end and defines a nozzle channel. The nozzle extension has a frustoconical extension body that extends axially from an inboard extension end to an outboard extension end. The inboard extension end is removably coupled to the outboard nozzle end at an interface via a connector extending annularly about the interface, and wherein the frustoconical extension body defines an extension channel that is axially aligned with the nozzle channel. The actuator is in physical communication with the connector and configured to cause the nozzle extension to detach from the nozzle. The connector includes a V-band clamp. The nozzle and the nozzle extension are configured for an initial burn of a vacuum-optimized, second stage rocket engine. The nozzle, after the nozzle extension has separated from the nozzle, is configured for a vertical landing burn of the second stage rocket engine in an atmosphere. The actuator includes a pyrotechnic device, an explosive shaped charge, a hydraulic actuator, or an electromechanical actuator. The nozzle includes a removable portion configured to be replaced on a landing surface during refurbishment of the nozzle. The outboard nozzle end includes a nozzle flange that extends radially outward, and wherein the inboard extension end includes an extension flange that extends radially outward, the rocket nozzle assembly further including at least one clamp coupling the nozzle flange and the extension flange together. The connector includes one or more wedge rings. The connector includes one or more clamps and a strap extending circumferentially around at least a portion of the nozzle and the nozzle extension. The actuator includes an explosive bolt, a non-explosive bolt, a clasp, or a reverse pliers mechanism.

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In one aspect of the system and methods disclosed herein, a method of operating a rocket is described. The method includes operating a rocket engine of the rocket in a vacuum thrust mode wherein the rocket engine includes at least one nozzle assembly having a nozzle extension removably attached to a nozzle, operating an actuator to release a connector extending annularly about the at least one nozzle assembly to cause the nozzle extension to detach from the nozzle, and operating the rocket engine in an atmospheric thrust mode using the nozzle without the nozzle extension. The vacuum thrust mode includes expanding an exhaust plume to a first diameter at an exit of the nozzle extension, and wherein the atmospheric thrust mode includes expanding the exhaust plume to a second diameter at an exit of the nozzle, and wherein the second diameter is smaller than the first diameter. In some examples, operating the actuator includes operating a pyrotechnic device to detach an annular clamp. In some examples, operating the actuator includes operating an explosive shaped charge. The rocket is a second stage rocket, the method further includes launching a first stage rocket that is coupled to the second stage rocket, separating the first stage rocket from the second stage rocket, and initiating operation of the rocket engine of the second stage rocket in the vacuum thrust mode. The method further includes landing the second stage rocket, attaching a new nozzle extension to the nozzle, and re-launching the second stage rocket on a launch vehicle.

In one aspect of the system and methods disclosed herein, a rocket system is described. The rocket system includes a second stage rocket comprising one or more second stage rocket engines having a nozzle assembly configured to transform from a vacuum-optimized configuration to an atmospheric-optimized configuration. The nozzle assembly includes a nozzle having a frustoconical nozzle body that extends axially between an inboard nozzle end and an outboard nozzle end and defines a nozzle channel, a nozzle extension having a frustoconical extension body that extends axially from an inboard extension end to an outboard extension end, wherein the inboard extension end is removably coupled to the outboard nozzle end at an interface via a connector extending annularly about the interface, and wherein the frustoconical extension body defines an extension channel that is axially aligned with the nozzle channel, and an actuator in physical communication with the connector and configured to cause the nozzle extension to detach from the nozzle. The rocket system further includes a first stage rocket having one or more first stage rocket engines and configured to be coupled with the second stage rocket to launch the rocket system from within an atmosphere. The actuator includes a pyrotechnic device, an explosive shaped charge, a hydraulic actuator, or an electromechanical actuator. The connector includes one or more clamps and a strap extending circumferentially around at least a portion of the nozzle and the nozzle extension.

In one aspect of the systems and methods disclosed herein, a rocket nozzle assembly is described including a nozzle having a frustoconical nozzle body that extends axially between a first inboard end and a first outboard end and defines a nozzle channel; a nozzle extension having a frustoconical extension body that extends axially from a second inboard end to a second outboard end, wherein the second inboard end is releasably coupled to the nozzle assembly at an outboard interface via a frangible connector extending annularly about the outboard interface, and wherein the frustoconical extension body defines an extension channel that is axially aligned with the nozzle channel; and an actuator in physical communication with the con-

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nector and configured to cause the nozzle extension to detach from the nozzle assembly.

In some examples, the actuator causes the connector to break. In some examples, the connector includes a plurality of detachable fasteners. In some examples, the plurality of detachable fasteners are rivets. In some examples, the actuator is configured to cause the nozzle extension to detach from the nozzle assembly during flight. In some examples, the rocket nozzle assembly further includes an intermediate nozzle extension having a second frustoconical extension body that extends axially between a third inboard end and a third outboard end and defines a second extension channel that is axially aligned with the nozzle channel, wherein the third inboard end is removably coupled to the first outboard end at an inboard interface via a second connector extending annularly about the inboard interface and the second inboard end is releasably coupled to the third outboard end via the frangible connector. In some examples, the intermediate nozzle is configured to remain attached to the nozzle along the inboard interface during flight. In some examples, the intermediate nozzle is configured to be removed from the nozzle along the inboard interface after landing.

In one aspect of the systems and methods disclosed herein, a rocket system is described including a second stage rocket including one or more second stage rocket engines having a nozzle assembly configured to transform from a vacuum-optimized configuration to an atmospheric-optimized configuration, wherein the nozzle assembly includes: a nozzle having a frustoconical nozzle body that extends axially between a first inboard end and a first outboard end and defines a nozzle channel; a nozzle extension having a frustoconical extension body that extends axially from a second inboard end to a second outboard end, wherein the second inboard end is releasably coupled to the nozzle assembly at an outboard interface via a frangible connector extending annularly about the outboard interface, and wherein the frustoconical extension body defines an extension channel that is axially aligned with the nozzle channel; and an actuator in physical communication with the connector and configured to cause the nozzle extension to detach from the nozzle assembly.

In some examples, the actuator causes the connector to break. In some examples, the connector includes a plurality of detachable fasteners. In some examples, the plurality of detachable fasteners are rivets. In some examples, the actuator is configured to cause the nozzle extension to detach from the nozzle assembly during flight. In some examples, the rocket system further includes an intermediate nozzle extension having a second frustoconical extension body that extends axially between a third inboard end and a third outboard end and defines a second extension channel that is axially aligned with the nozzle channel, wherein the third inboard end is removably coupled to the first outboard end at an inboard interface via a second connector extending annularly about the inboard interface and the second inboard end is releasably coupled to the third outboard end via the frangible connector. In some examples, the intermediate nozzle is configured to remain attached to the nozzle along the inboard interface during flight. In some examples, the intermediate nozzle is configured to be removed from the nozzle along the inboard interface after landing.

In one aspect of the systems and methods disclosed herein, a method is described including operating a rocket engine of a rocket in a vacuum thrust mode, wherein the rocket engine includes at least one nozzle assembly having a nozzle extension releasably attached to the nozzle assembly via a frangible connector along an outboard interface;

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breaking the frangible connector to cause the nozzle extension to release from the nozzle assembly; and operating the rocket engine in an atmospheric thrust mode using the nozzle assembly without the nozzle extension. In some examples, breaking the frangible connector includes activating an actuator to break a plurality of frangible components. In some examples, the method further includes removing an intermediate nozzle extension from the nozzle assembly after landing, wherein the intermediate nozzle extension remains attached to the nozzle assembly during flight. In some examples, breaking the frangible connector causes the nozzle extension to release from the intermediate nozzle extension.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other features of the present disclosure will become more fully apparent from the following description and appended claims, taken in conjunction with the accompanying drawings. Understanding that these drawings depict only several examples in accordance with the disclosure and are not to be considered limiting of its scope, the disclosure will be described with additional specificity and detail through use of the accompanying drawings. In the following detailed description, reference is made to the accompanying drawings, which form a part hereof. In the drawings, similar symbols typically identify similar components, unless context dictates otherwise. Other examples may be utilized, and other changes may be made without departing from the spirit or scope of the subject matter presented here. It will be readily understood that the aspects of the present disclosure, as generally described herein, and illustrated in the drawings, may be arranged, substituted, combined, and designed in a wide variety of different configurations, all of which are explicitly contemplated and make part of this disclosure.

FIG. 1 is a side view of an example of a rocket system that includes a first stage rocket and a second stage rocket having a nozzle assembly with a separable nozzle extension.

FIGS. 2A and 2B are respectively a side view of the second stage rocket and a closeup side view of examples of nozzle assemblies with separable nozzle extensions and that may be used with the second stage rocket.

FIGS. 2C and 2D are side views respectively of the nozzle assembly of FIG. 2B with and without the nozzle extensions with corresponding relatively wider and narrower exit diameters and exhaust plumes.

FIGS. 3A and 3B are respectively a detail partial view of a first and second example of a portion of a nozzle assembly having a separable nozzle extension that may be used with the second stage rockets of FIGS. 1, 2A and 2B.

FIG. 3C is a partial cross-section side view of an example of a portion of a nozzle assembly having a separable nozzle extension releasably secured to an inboard nozzle by a connector and jettison actuator that may be used with the second stage rockets herein.

FIGS. 4A and 4B are respectively a partial exploded view and an assembled view of an example of an interface of the flanges of the nozzle and the nozzle extension having two wedge rings and that may be used with the second stage rockets of FIGS. 1, 2A, and 2B.

FIGS. 4C and 4D are respectively a side view and a bottom view of the wedge ring of the interface of FIGS. 4A and 4B.

FIGS. 4E and 4F are a top view (with detail) and cross-sectional view respectively of an example of a clamp,

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having a release mechanism using explosive bolts, and that may be used with the interface of FIGS. 4A and 4B.

FIGS. 4G and 4H are respectively a partial top view and a partial side view of another example of a clamp, having a release mechanism using a clasp, and that may be used with the interface of FIGS. 4A and 4B.

FIG. 4I is a partial top view of another example of a clamp, having a release mechanism using bow opening pliers, and that may be used with the interface of FIGS. 4A and 4B.

FIG. 5 is a detail partial cross-sectional side view of an example of an interface between a nozzle and a separable nozzle extension having a seal.

FIGS. 6A and 6B are respectively a cross-section side view of an example of a nozzle assembly with separable extension via a jackscrew jettison actuator, and a detail view of the interface of the nozzle and extension with the actuator.

FIG. 7 is a flow chart showing an example of a process for launch and reuse of a launch vehicle having a second stage with separable and replaceable nozzle extension.

DETAILED DESCRIPTION

The following detailed description is directed to certain specific examples for devices, systems, and methods related to rocket nozzle systems having separable nozzle extensions. In this description, reference is made to the drawings wherein like parts or steps may be designated with like numerals throughout for clarity. Reference in this specification to "one example," "an example," or "in some example" means that a particular feature, structure, or characteristic described in connection with the example is included in at least one example of the disclosure. The appearances of the phrases "one example," "an example," or "in some examples" in various places in the specification are not necessarily all referring to the same example, nor are separate or alternative examples necessarily mutually exclusive of other examples. Moreover, various features are described which may be exhibited by some examples and not by others. Similarly, various requirements are described which may be requirements for some examples but may not be requirements for other examples. Reference will now be made in detail to examples of the disclosure, examples of which are illustrated in the accompanying drawings. Wherever possible, the same reference numbers will be used throughout the drawings to refer to the same or like parts.

It is desirable to operate reusable rockets for multiple launches and missions. As such, it is further desirable to reuse as many portions of a rocket as possible to minimize cost of missions and promote efficiency. Because rocket assemblies are often operated in multiple stages, it may be desirable to reuse as many of the rocket stages as possible for multiple missions. For example, a rocket may include a first stage with a fuel supply and engine assembly for an initial launch burn and/or other functions, and a second stage with a separate fuel supply and engine assembly for a continued ascent burn and/or other functions. It may be desirable to retain both the first stage and the second stage for multiple missions. While some rockets have disposable first stages and second stages, some rockets instead have reusable first stages that may be landed on earth after a mission which allows the first stage to be reusable. It is desirable to also have a reusable second stage that may be landed on earth after a mission as well.

To promote reusability, rockets may use propulsion for ascent and controlled landing. Rockets used for ascent have different operational requirements from rockets used for

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landing. It is however desirable to use the same second stage rocket engine(s) for the ascent burn and for deceleration and landing in order to maintain feasible weight and volumetric constraints for some rocket designs. This dual use of the second stage rocket engine(s) may make the second stage reusable such that the second stage may complete a mission and land back on a surface such as earth and be used again for subsequent launches without requiring a dedicated landing engine, (e.g., an engine that is separate from the ascent burn engine). However, it is desirable for the rocket to be optimized differently for ascent burn conditions, and for deceleration and landing conditions. The main ascent burn of the second stage rocket occurs mostly or entirely in vacuum, where to maximize performance, the engines may highly expand an exhaust plume using a relatively long and wide nozzle. But using such a long and wide nozzle in the atmosphere during landing would result in a plume that would be overexpanded for atmospheric conditions. The overexpanded plume could lead to catastrophic damage to the engine and/or vehicle. As such, it is desirable to adjust the nozzle configuration, such as changing the length and/or exit diameter of the nozzle, to alternately optimize for space flight in mostly vacuum and landing in an atmosphere.

To address these problems, the present disclosure relates to a second stage rocket that includes a nozzle extension configured to be jettisoned from the inboard integral nozzle portion optimized for landing in a non-vacuum environment. The extension may be installed on the second stage rocket prior to launch and used during ascent. The extension may then be jettisoned before landing burn using an actuator. A connector may releasably secure the extension to the nozzle. The actuator may cause the connector to release the extension.

Example Launch Vehicle

A rocket launch vehicle system having a nozzle assembly that includes an extension that may be jettisoned is described. The rocket system is provided to optimize the flow characteristics of the second stage rocket engine used for main ascent (e.g., in vacuum). The system is additionally provided to optimize the flow characteristics of that same second stage rocket engine for use during landing (e.g., in atmosphere). As mentioned above, launch engines with fixed nozzles have different exhaust plume characteristics for vacuum ascent and atmospheric landing. By providing for different physical nozzle characteristics of the same nozzle assembly, the exhaust may be optimally expanded in both environments. The nozzle without the extension provides a relatively shorter nozzle with an outlet having relatively smaller area for a controlled burn in the atmosphere, whereas the extension provides a relatively longer nozzle with an outlet having a relatively larger area for ascent and propulsion outside the atmosphere. The system also provides a lightweight jettison mechanism to remove the extension from the nozzle, thereby adjusting the nozzle parameters.

FIG. 1 shows an example of a rocket system **100** having a first stage rocket **104** and a second stage rocket **102**. A payload **101** may be carried by the second stage rocket **102**. The first stage rocket **104** may launch the rocket system **100** from ground to a first altitude. The first stage rocket **104** may then separate from the second stage rocket **102**. The first stage rocket **104** may then land back on earth for reuse. The second stage rocket **102** may then propel the payload **101** to a second, higher altitude, which may be along an orbital path. The second stage rocket **102** may then separate from the payload and land back on earth for reuse. The payload may continue its path and/or propel itself to a higher, third

altitude and/or different orbit. The rocket system **100** is provided to complete multiple extraplanetary missions. As such, the first stage rocket **104** and the second stage rocket **102** are reusable rockets that may be utilized for multiple missions.

Example First Stage Rocket

The first stage rocket **104** may provide the initial ascent from a planetary surface such as the earth's surface. The first stage rocket **104** shown in FIG. **1** includes propellant tanks therein and one or more first stage rocket engines **106**. The first stage rocket engines **106** may be configured for atmospheric launch operation. The first stage rocket **104** may have any number of rocket engines suitable for the application, size of the rocket system **100**, and payload of a mission. For example, the first stage rocket **104** may have one, two, three, four, five, six, seven, eight or more rocket engines. In some examples, the first stage rocket **104** includes a forward nose portion configured to receive an aft portion of the second stage rocket **102** to transport the second stage rocket **102** through at least a portion of a main ascent to the separation altitude where the second stage rocket **102** separates from the first stage rocket **104**. The first stage rocket **104** then lands back on earth and may be reused for subsequent launches. The second stage rocket **102**, after separation from the first stage rocket **104**, further propels the payload **101**.

Example Second Stage Rocket

FIG. **2A** shows a side view of an example of the second stage rocket **102**, and FIG. **2B** shows a closeup side view of the aft end of the second stage rocket **102** showing a plurality of nozzle assemblies **110**. In some examples, the plurality of nozzle assemblies **110** can be a rocket nozzle assembly. In some examples, there may be one, two, three, four, five, six, seven, eight, or more rocket engines **108** and/or nozzle assemblies **110**. The second stage rocket **102** shown in FIGS. **1** and **2A** includes therein four second stage rocket engines **108** (as also shown individually and schematically in FIGS. **3A** and **3B**), each including the nozzle assembly **110**. As shown in FIG. **2B**, each nozzle assembly **110** may have a nozzle **112** with an integral nozzle body **116** and a separable nozzle extension **114**, as further described. In some examples, the integral nozzle body **116** is disposed inboard of the nozzle extension **114** such that the nozzle body **116** is axially disposed between the second stage rocket engine **108** and the nozzle extension **114**. Further, the nozzle extension **114** is disposed outboard of the nozzle body **116**, such that the nozzle extension **114** is disposed axially farther from the engine than the nozzle body **116**. As shown, there may be four nozzle assemblies **110** (three of the nozzle assemblies **110** are visible).

The nozzle assemblies **110** may be used with the second stage rocket **102**. As described above, the second stage rocket **102** is provided to propel itself through at least a portion of a main ascent after the second stage rocket **102** is separated from the first stage rocket **104**. The second stage rocket **102** may then propel into orbit, e.g., for releasing a payload into orbit, using the nozzle assembly **110** having the nozzle body **116** and nozzle extension **114**. The second stage rocket **102** may propel the payload **101**, for example into a transfer orbit for travel of the payload **101** to another orbit and/or toward another planetary body.

The second stage rocket **102** may then separate from the payload **101** and release the nozzle extension **114** from the nozzle body **116** for a reentry and landing configuration. The second stage rocket **102** may decelerate during planetary reentry and safely land on earth during a landing sequence using the shortened nozzle assembly **110** without the nozzle

extension **114**. In some examples, the second stage rocket **102** prior to jettisoning the nozzle extension **114** may continue to another planetary body, such as the moon, and land on the other planetary body. In such case, the second stage rocket **102** may re-launch from the planetary body, return to earth, and jettison the nozzle extension **114** upon reaching a particular density of air within the earth's atmosphere.

The second stage rocket engines **108** may be vacuum-optimized rocket engines. The rocket engines **108** may be configured to provide thrust outside of an atmosphere such as the earth's outer atmosphere and/or in vacuum surrounding earth. In some examples, the rocket engines **108** are configured to utilize one or more of liquid hydrogen or liquid oxygen for propellant. The nozzle assemblies **110** of the second stage rocket engines **108** have first configurations that include the nozzle extension **114**. This first configuration may be configured to have an optimally expanded exhaust plume **115** for operation in such environments. The nozzle assemblies **110** may have second configurations without the nozzle extension **114**. The second configuration may be configured to produce exhaust plumes **115'** that are atmosphere-optimized. Each of the second stage rocket engines **108** shown in FIG. **2B** may include a substantially identical nozzle assembly **110** with similar performance characteristics, sizes, thrust, etc. For example, although FIGS. **2C-2D** illustrate a single expanded exhaust plume **115** and a single exhaust plume **115'**, respectively, each nozzle **112** can include a respective exhaust plume **115**. In some examples the second stage rocket engines **108** may have different kinds of nozzle assemblies, e.g., with different performance characteristics, sizes, thrust, etc., suitable for the application, size of the rocket, and payload of a mission.

The nozzle extension **114** may detach from the nozzle assembly **110** at a particular location along the length of the nozzle **112**. Different examples may include the extension detaching at different locations and/or using different detachment mechanisms, as further described.

Example Nozzle Assembly

FIGS. **3A-3C** show examples of one of the nozzle assemblies **110** and the second stage rocket engine **108** (shown schematically) in isolation from the rest of the second stage rocket **102**. FIGS. **3A** and **3B** show two different examples of nozzle assemblies **110** having detachable nozzle extensions **114**, where the nozzle extensions **114** detach from different locations of the nozzle assembly **110**, as further described. As shown in FIG. **3A**, the nozzle extension **114** may detach at a relatively forward interface such as an inboard interface **131**. As shown in FIG. **3B**, the nozzle extension **114** may detach at a relatively aft interface such as an outboard interface **133**. The various examples of the nozzle extensions **114** may detach using similar or different detachment mechanisms, as further described. FIG. **3C** is a partial cross-section view of an example of the nozzle assembly **110** of FIG. **3A**.

The nozzle assembly **110** is configured to direct exhaust gasses from the second stage rocket **102** to propel the second stage rocket **102** in a direction opposite the exhaust gasses during various operational stages. The nozzle assembly **110** is configured to direct exhaust gasses in a vacuum thrust mode during ascent and thereby propel the second stage rocket **102** through space and/or low-density atmosphere during a mission. The nozzle assembly **110** may be further configured to direct exhaust gasses to decelerate and/or stabilize the second stage rocket **102** in an atmospheric thrust mode during reentry and/or landing, which allows reuse of the second stage rocket **102**.

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The nozzle assembly **110** expels the exhaust gasses at various optimal nozzle configurations depending on whether the second stage rocket **102** is being operated in the vacuum thrust mode or the atmospheric thrust mode. As such, the nozzle assembly **110** is adjustable to form desired configurations, such as different nozzle exit diameters and nozzle lengths, for when the second stage rocket **102** transitions between operating within a vacuum and/or upper atmosphere, and during reentry and/or within denser portions of the atmosphere. For example, as shown in FIG. 2C, the nozzle assembly **110** may have a first configuration that includes the nozzle extension **114**, having a first exit diameter **D1**. The first exit diameter **D1** can be a larger nozzle exit diameter. The nozzle extension **114** can increase the overall nozzle length. The larger nozzle exit diameter and increased overall nozzle length can produce a desired exhaust plume **115** size for operation within the upper atmosphere and/or in vacuum. This may produce an expanded exhaust plume **115** optimized for low density or vacuum environments. The nozzle assembly **110** may have a second configuration, as shown in FIG. 2D, that does not include the nozzle extension **114**, having a second exit diameter **D2**. The second exit diameter **D2** can be a smaller nozzle exit diameter and overall nozzle length, to produce a desired exhaust plume **115'** size for operation within denser atmosphere, for instance during reentry and landing on earth. The desired exhaust plume **115'** size can prevent nozzle flow separation which could result in an unsuccessful burn or engine damage.

As shown in FIGS. 3A-3C, the nozzle assembly **110** includes a nozzle **112** having an integral nozzle body **116** releasably attached to a separable nozzle extension **114**. The nozzle **112** may be a divergent section of the nozzle assembly **110**. The nozzle assembly **110** may include a convergent section inboard or upstream of the nozzle **112**.

The nozzle extension **114** may be joined with and detach from the nozzle body **116** at the inboard interface **131** (FIG. 3A) or at the outboard interface **133** (FIG. 3B). The nozzle body **116** may be frustoconical. Accordingly, the nozzle body **116** can be referred to as a frustoconical nozzle body. The nozzle body **116** may define a divergent nozzle channel **118** (see FIG. 3C) therein and extend from an inboard nozzle end **120** to an outboard nozzle end **122**. The outboard nozzle end **122** may be at the different locations shown in FIGS. 3A and 3B depending on the location of the respective detachment interface **131**, **133**. The nozzle extension **114** may extend from an inboard extension end **134** to an outboard extension end **136**. The inboard extension end **134** may releasably attach to the outboard nozzle end **122** at the respective interface such as the inboard interface **131** (FIG. 3A) or the outboard interface **133** (FIG. 3B). The inboard extension end **134** may be at the different locations shown in FIGS. 3A and 3B depending on the location of the respective detachment interface **131**, **133**. The nozzle assembly **110** may release the nozzle extension **114** from the nozzle body **116** to be configured for reentry and/or landing burns of the second stage rocket engine **108** in an atmosphere such as the earth's atmosphere.

The nozzle **112** may include a nozzle flange **126**. The nozzle flange **126** may be configured for coupling with a corresponding extension flange **130** of the nozzle extension **114**. The nozzle flange **126** may extend annularly about and radially outwardly from the nozzle **112** at or near the outboard nozzle end **122**. The extension flange **130** may extend annularly about and radially outwardly from the nozzle extension **114** at or near the inboard extension end **134**. In some examples, the nozzle flange **126** and/or extension

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flange **130** may include one or more holes to receive a fastener (e.g., screw or bolt) to connect the flanges **126**, **130** together. In some examples, such as the example shown in FIG. 3B, the nozzle **112** includes a divergent section outboard of the nozzle flange **126**, such that the outboard nozzle end **122** is spaced apart in an inboard direction from the outboard extension end **136**. In some examples, the nozzle assembly **110** does not include a nozzle flange **126** and other suitable attachments may be used to connect the nozzle **112** to the nozzle extension **114**.

The nozzle **112** may be formed from materials such as copper; steel; metallic alloys comprised of nickel, chromium, tungsten, or other metals; refractory metals and alloys, carbon composites, or other high-temperature materials. In some examples, the nozzle **112** may be regeneratively cooled, cooled by a coolant film, and/or absorb and/or re-radiate heat during operations. The inboard nozzle end **120** has a diameter suitable to receive exhaust gas from an engine into the nozzle channel **118**, and the outboard nozzle end **122** has a diameter suitable to expel exhaust from the rocket engine into an atmosphere. For example, the diameter of the integral nozzle end **122** may be sized such that the nozzle exit pressure when configured for landing is near the ambient atmospheric pressure (e.g., 14.7 psi on Earth at sea-level). The diameter of the inboard extension end **134** may be sized to match the area of integral nozzle end **122** when coupled together with the integral nozzle end **122**. For example, the outboard nozzle end **122** diameter may be from 30 to 50 inches, from 35 to 45 inches, about 42 inches, or 42 inches.

Example Separable Nozzle Extension

The nozzle extension **114** provides a removable portion of the nozzle assembly **110**. As further shown in FIGS. 3A-3C, the nozzle extension **114** includes a frustoconical extension body **132**. The extension body **132** may define an extension channel **119** therein (see FIG. 3C). The extension channel **119** may diverge and continue the diverging contour of the inboard nozzle channel **118**. The extension body **132** may extend between the inboard extension end **134** and the outboard extension end **136**. Prior to removal of the nozzle extension **114**, the size of the nozzle assembly **110** is optimized for operation in an outer atmosphere and/or a vacuum. The nozzle extension **114** may then be discarded for operation of a relatively smaller nozzle assembly **110** inside of an atmosphere or denser atmosphere, such as earth's lower atmosphere.

In some examples, as shown in FIG. 3A, the nozzle extension **114** may include the extension flange **130** that extends annularly around the nozzle extension **114** and radially outwardly from or near the inboard extension end **134**. The extension flange **130** may be secured with the nozzle flange **126** via a connector **138**, such as a V-band clamp as shown, or other clamps or mechanisms as further described. In some examples, the extension flange **130** may include at least one hole to receive a releasable fastener (e.g., separation nut device) to releasably couple the extension flange **130** to the nozzle flange **126**. In other examples, the nozzle extension **114** may not include an extension flange **130**, and the nozzle **112** and the nozzle extension **114** may be releasably attached using other mechanisms. The nozzle extension **114** may be formed from materials such as inexpensive sheet metal, steel; metallic alloys comprised of metals such as nickel, chromium, tungsten; refractory metals and refractory metal alloys, carbon composites, or other high-temperature materials. In some examples, the nozzle extension **114** may be a film cooled nozzle extension that

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includes a coolant film to cool the nozzle assembly **110** during operation and/or absorb and/or re-radiate heat during operations.

The inboard extension end **134** has a diameter suitable to receive exhaust gas from the nozzle **112** into the extension channel **119**, and the outboard extension end **136** has a diameter suitable to expel exhaust gas for propulsion in an outer atmosphere or a vacuum for ascent. For example, the outboard extension end **136** diameter may be from 80 to 120 inches, from 90 to 110 inches, from 95 to 105 inches, about 99 inches, or 99 inches. In some examples, the nozzle extension **114** may provide an exit pressure of between 0.3 atmospheres (Atm) to 0.4 Atm, or no greater than 0.37 Atm. Example Connectors

As shown in FIG. 3A, the nozzle assembly **110** may include at least one connector **138**. The connector **138** may extend annularly around the inboard interface **131**. The connector **138** may be a structural securement component or components. The connector **138** may be configured to secure the nozzle extension **114** to the nozzle **112** during initial operation of the second stage rocket **102** in the upper atmosphere and/or in vacuum. As such, the connector **138** may couple the nozzle extension **114** to the nozzle **112** during at least some stages of a mission. As shown in FIG. 3A, the connector **138** may be a V-band clamp.

The connector **138** may be disposed about at least a portion of the nozzle flange **126** at the outboard nozzle end **122** and about the extension flange **130** about the inboard extension end **134**. For example, the connector **138** may be annularly disposed around the outboard nozzle end **122** and the inboard extension end **134** coupling the nozzle **112** and the nozzle extension **114** together. The two flanges **126**, **130** may include two opposing flat surfaces that abut each other and are held together via the connector **138**. The connector **138** may be a pipe clamp, a ring clamp, a band clamp, a Marman clamp, or other suitable connector. The connector **138** may be disposed around additional releasable fasteners such as releasable bolts that further releasably couple the nozzle extension **114** to the nozzle **112**. The connector **138** may be released via an actuator, such as a separation nut or other device, as further described.

In the example shown in FIG. 3B, a plurality of connectors **139** are shown as a plurality of detachable fasteners, such as rivets (for clarity, only some of the connectors **139** are labelled in the figure). The connectors **139** may include the fasteners disposed around at least a portion of the outboard nozzle end **122**. The connectors **139** may be frangible components. An actuator, such as a linear shape charge, may cause the connectors **139** to break to allow separation of the nozzle extension **114**, as further described. In some examples, the actuator can be an explosive shaped charge.

The nozzle assembly **110** may include either the connector **138** as shown in FIG. 3A or the connectors **139** as shown in FIG. 3B. In some examples, the nozzle assembly **110** may include both the connectors **138** and **139**. In some examples, the connectors **138** and **139** may be located at the same detachable interface, or at different interfaces. Multiple connectors may provide reliability and robustness to the design.

As shown in FIG. 3B, in some examples the nozzle extension **114** may include an outboard interface **133** that is separated during flight and another inboard interface **131** for replacing the outboard, partially detached extension. For instance, the nozzle extension **114** may be released along the outboard interface **133** during flight, such as via the actuator **141**, and a remaining removable portion such as an inter-

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mediate nozzle extension **128** may be replaced after landing. The intermediate nozzle extension **128** may thus be retained on the nozzle assembly **110** during missions after separation of the nozzle extension **114**. The intermediate nozzle extension **128** may then be removed from the nozzle **112** along the inboard interface **131**, for example via the detachable flanges **126**, **130**, and disposed of on the ground between missions during refurbishment. As such, the intermediate nozzle extension **128** may withstand forces such as detonation of shaped charges, without damaging portions of the second stage rocket **102** that are intended for continued use on multiple missions. The intermediate nozzle extension **128** may extend from the nozzle flange **126** of the nozzle **112** to a nozzle location inboard of the outboard extension end **136**. The intermediate nozzle extension **128** may include the extension flange **130** for coupling the intermediate nozzle extension **128** to the nozzle flange **126** of the nozzle **112**.

In some examples, the actuator **141** in FIG. 3B may be an explosive shaped charge. The actuator **141** may be directed to the outboard nozzle end **122**. The actuator **141** may be a C-4 shaped charge that includes a housing band with a V-shaped cross section configured to direct explosive force to a desired point or points on the nozzle assembly **110**. The actuator **141** may be coupled to an electronic ignition, which may detonate the explosive charge at a desired time of separation. The actuator **141** may include the charge disposed about the outboard interface **133**. The actuator **141** may extend along the outboard nozzle end **122**, the inboard extension end **134**, and the connectors **139** such that the nozzle extension **114** is disconnected when the force from the actuator **141** impacts the nozzle extension **114** and/or the connectors **139**.

Example Actuators

As shown in FIG. 3A, the nozzle assembly **110** may include an actuator **140**. The actuator **140** may be in physical communication with one or more separable components of the nozzle assembly **110**. The actuator **140** provides a separation force against the nozzle **112**, and/or the nozzle extension **114**, and/or the connector **138**, **139**. As such, the actuator **140** may cause the nozzle extension **114** to jettison from the nozzle **112** when the second stage rocket engine **108** is to enter atmospheric thrust mode.

The actuator **140** as shown in FIG. 3A may include a pyrotechnic device such as a separation nut. For instance, the connector **138** may be held together via one or more separation bolts/nuts, and the actuator **140** may be a pyrotechnic device that causes the connector **138** to separate, thereby allowing the nozzle extension **114** to separate from the nozzle **112**. The connector **138** may be a clamp that is released due to the operation of the actuator **140**. In some examples, the actuator **140** may include pyrotechnics, pneumatics, hydraulics (e.g., a hydraulic actuator), electromechanical components (e.g., an electromechanical actuator), an actuated pin puller, actuation with electricity or gas, other suitable mechanisms, or combinations thereof. Actuators such as electrical motors or pneumatic actuators may be provided to separate the nozzle extension **114** from the nozzle **112**. For example, the actuator **140** may be a pneumatic actuator (e.g., solenoid actuator) that is configured to release the first connector **138**. In some examples, the actuator **140** may relieve pressure that secures the V-band clamp to either side of the flanges **126**, **130**. As such, the actuator **140** may decouple the nozzle **112** from the nozzle extension **114**. In some examples, the actuator **140** may translate a release mechanism on the V-band clamp that pushes open a lock on the V-band clamp, thereby releasing

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the portions of the V-band clamp that are annularly disposed about either side of the flanges **126**, **130** of the nozzle assembly **110**.

FIGS. **4A-4D** illustrate one or more components of a nozzle assembly **110**. In some examples, as shown in FIGS. **4A** and **4B**, the nozzle assembly **110** may include a nozzle flange **126**, an extension flange **130**, a connector **138** and a plurality of wedge rings **160**. FIG. **4A** is a partial exploded side view of the nozzle assembly **110** in an unassembled state and FIG. **4B** is a side view of the nozzle assembly **110** in an assembled state. FIGS. **4C** and **4D** are side and bottom views, respectively, of the wedge ring **160** shown in isolation.

The nozzle assembly **110** can include two of the wedge rings **160**. Each wedge ring **160** is a circular member that extends annularly in a ring-like shape (see, e.g., the bottom view of the wedge ring **160** in FIG. **4D**). One of the wedge rings **160** can be secured on the top of the nozzle flange **126** and the other wedge ring **160** can be secured on the bottom of the extension flange **130**. Accordingly, the nozzle flange **126** and the extension flange **130** can be positioned between the two wedge rings **160**. For example, the nozzle flange **126** and/or the extension flange **130** can be sandwiched between the two wedge rings **160**. The wedge rings **160** can be secured in place onto the respective flanges **126**, **130** by the connector **138** to thereby sandwich and hold the flanges **126**, **130** together along an interface **135** in the assembled state. The interface **135** may correspond to the inboard interface **131** of FIG. **3A**.

As shown in FIGS. **4A-4D**, the wedge rings **160** may have a wedge-shaped cross-sectional shape. The wedge-shaped body may include a thick radially inner end and a thinner radially outer end. The wedge-shaped body may taper from the thick end to the thin end. The wedge rings **160** may each include a sloped surface **161**, a securing surface **162**, and a cylindrical inner wall **166** (see FIG. **4D**). The sloped surface **161**, the securing surface **162**, and the cylindrical inner wall **166** may form three sides of the cross-section of the wedge ring **160**. In some examples, a cross-section of the wedge rings **160** can be a triangle. For example, the securing surface **162** may define a first side of the wedge rings **160**, the cylindrical inner wall **166** may define a second side of the wedge rings **160**, and the sloped surface **161** may define a third side of the wedge rings **160**. In some examples, the securing surface **162** may be a planar surface extending radially outward from the cylindrical inner wall **166** to a radially outer edge **170** along a first plane. The cylindrical inner wall **166** can extend orthogonally from the securing surface **162** to the sloped surface **161**. The sloped surface **161** may extend between the radially outer edge **170** to the cylindrical inner wall **166**.

In some examples, the wedge rings **160** may also include one or more holes **164**. The one or more holes **164** may extend through the wedge rings **160** from the sloped surface **161** to the securing surface **162**. In some examples, the holes **164** may be equally spaced along the annular length of the wedge rings **160**. For example, as shown in FIG. **4D**, a plurality of the holes **164** may be positioned along the annular length of the wedge rings **160**. In some examples, the one or more holes **164** can be a bolt hole. In some examples, the nozzle flange **126** and the extension flange **130** can also include one or more bolt holes. Accordingly, a bolt may be configured to pass through the nozzle flange **126**, the extension flange **130**, and the wedge rings **160** in an assembled state when the bolt holes of the respective parts are axially aligned.

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The securing surface **162** can further include a plurality of protrusions **163** (for clarity, only some of the protrusions **163** are labelled in FIG. **4A**). The plurality of protrusions **163** may extend orthogonally from a respective securing surface **162** toward the flanges **126**, **130**. The plurality of protrusions **163** may be radially positioned between the inner wall **166** and outer edge **170** of the wedge ring **160**. In some examples, the plurality of protrusions **163** may be positioned along the annular length of the wedge rings **160**. For example, as shown in FIG. **4D**, the plurality of protrusions **163** can include **112** protrusions equally spaced along the annular length of the wedge rings **160**. In some examples, a subset of the plurality of protrusions **163** may be positioned between two of the one or more holes **164**. For example, as shown in FIG. **4D**, fourteen of the plurality of protrusions **163** (for clarity, only some of the protrusions **163** are labelled in the figure) may be positioned between two holes **164** positioned at either end of the fourteen protrusions **163**. In some examples, the plurality of protrusions **163** may be equally spaced from their respective adjacent protrusions **163** and/or hole **164** along the annular length of the wedge rings **160**. For example, the plurality of protrusions **163** and the one or more holes **164** may be uniformly spaced along the annular length of the wedge rings **160** such that a common gap size extends between each of the plurality of protrusions **163** and their respective adjacent protrusions **163** and/or hole **164**.

As shown in the bottom view of the wedge ring **160** of FIG. **4D**, the wedge rings **160** can be formed from one or more portions or segments **121A** and **121B**. For example, the wedge rings **160** may include the two separable segments **121A**, **121B** forming equal halves of the body of the wedge rings **160**. In some examples, the wedge rings **160** may be assembled with the one or more segments **121A**, **121B** placed around the nozzle and extension interface. The segments **121A**, **121B** may be welded together. In some examples, the connector **138** may be configured to clamp the segments **121A**, **121B** together.

The nozzle flange **126** and the extension flange **130** may have the same features as the nozzle flange **126** and extension flange **130** described above. As shown in FIG. **4A**, in some examples, the nozzle flange **126** may further include an engagement surface **176**. In some examples, the extension flange **130** may further include an engagement surface **177**. The engagement surfaces **176**, **177** may be configured to engage (e.g., contact) with the securement surface **162** of the respective wedge rings **160**. For example, the engagement surfaces **176**, **177** may each further include one or more recesses **180**, for example openings or blind holes in the surfaces, each configured to receive a corresponding one of the plurality of protrusions **163**. The recesses **180** within the respective flanges are shown in dashed line and for clarity only some of the recesses **180** are labelled in FIG. **4A**.

In the assembled state, as shown in FIG. **4B**, the nozzle flange **126** can abut the extension flange **130**. The respective wedge rings **160** can be positioned on the abutting nozzle flange **126** and extension flange **130**. The securing surface **162** of each of the wedge rings **160** can contact respective opposing surfaces of the nozzle flange **126** and the extension flange **130**. The protrusions **163** of the wedge rings **160** may operatively couple with the corresponding recesses **180** in the engagement surfaces **176**, **177** of the nozzle flange **126** and extension flange **130**, respectively. The engagement of the protrusions **163** with the recesses **180** of the engagement surfaces **176**, **177** of the nozzle flange **126** and the extension flange **130** may prevent lateral movement between the two flanges **126**, **130**.

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The connector **138** can be a mechanism configured for securing the wedge rings **160** to the nozzle flange **126** and/or the extension flange **130**. For example, as further shown in FIG. **4B**, the connector **138** can retain the nozzle flange **126** and the extension flange **130** between the two wedge rings **160** by providing a clamping force onto the wedge rings **160**. The connector **138** may be positioned around at least a portion of the wedge rings **160** to secure the nozzle assembly **110** together and prevent the wedge rings **160** from axially separating from the nozzle flange **126** and/or extension flange **130**.

The connector **138** may be one or more of a plurality of different mechanisms. For example, the connector **138** may include a Marman clamp mechanism, an explosive bolt, a bolt cutter (e.g., a hydraulic bolt cutter), a clasp, and/or reverse pliers, as described in greater detail below. FIGS. **4A** and **4B** illustrate an example of the connector **138** in the form of a Marman clamp mechanism. FIGS. **4E** and **4F** illustrate an example of the connector **138** in the form of an explosive bolt. FIGS. **4G** and **4H** illustrate an example of the connector **138** in the form of a clasp. FIG. **4I** illustrates an example of the connector **138** in the form of reverse pliers. As shown in FIGS. **4A** and **4B**, the connector **138** can include a strap **143** with a clamp body **144**. In some examples, the connector **138** may be a Marman clamp mechanism.

The clamp body **144** can be configured to fit around the outer sides or perimeter of the nozzle assembly **110** and secure the nozzle assembly **110** together. In some examples, the clamp body **144** can have an interior groove **181** configured to receive a portion of the wedge rings **160** therein. In some examples, the clamp body **144** may be a semi-circular body with the interior groove **181**. In some examples, the clamp body **144** may be a Marman clamp shoe. The interior groove **181** can include one or more mating surfaces **182** configured to abut the nozzle assembly **110**. In some examples, a profile of the interior groove **181** can correspond to the profile of the nozzle assembly **110**. For example, the interior groove **181** can be a substantially arched, C-shaped, or V-shaped cross-section, or other open profile. In such examples, the interior surface(s) of the interior groove **181** can abut the sloped surfaces **161** of the respective wedge rings **160** as shown in FIG. **4B**. Accordingly, the clamp body **144** can retain the nozzle flange **126** and the extension flange **130** between the two wedge rings **160** by providing an axial inward clamping force via the interior groove **181**. The clamp body **144** can extend around the entire perimeter of the nozzle assembly, or partially around the perimeter and with one or more clamp bodies **144**.

As further shown in FIG. **4B**, the strap **143** can be configured to secure the clamp body **144** to the nozzle assembly **110**. The strap **143** may extend around the perimeter of the clamp body **144** to secure the clamp body **144** to the nozzle assembly **110**. In some examples, the strap **143** can extend around a radially outer surface **183** of the clamp body **144**. The strap **143** can provide a radially inward force to secure the clamp body **144** to the nozzle assembly **110**.

The strap **143** may have a rectangular cross-sectional shape, like a belt. In some examples, the strap **143** can extend along a circular path around the nozzle assembly **110**. The strap **143** can extend along a path with a radius greater than the outer radius of the nozzle assembly **110**. In some examples, the strap **143** can extend along a path having a radius corresponding to the outer dimension of the clamp

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body **144**. The strap **143** can extend around the entire perimeter of the nozzle assembly **110**, or partially around the perimeter.

In some examples, the strap **143** may extend from a first end to a second end. The two ends may be positioned adjacently and/or configured to abut each other forming a circular or other closed shape. In some examples, the strap **143** may be a Marman clamp strap.

The strap **143** may have its two ends releasably connected together. In some examples, a mechanism may be used to releasably secure the two ends of the strap **143** together, such as an actuator having an explosive bolt as described with respect to FIGS. **4E** and **4F**, a bolt cutter, a clasp as described with respect to FIGS. **4G-4H**, or reverse pliers as described with respect to FIG. **4I**. FIGS. **4E** and **4F** illustrate an example of an actuator **141A** including an explosive bolt **145** releasably securing a nozzle assembly **110A** in an assembled state. FIG. **4E** illustrates a top view of the nozzle assembly **110A** having two actuators **141A** that each use an explosive bolt **145**. The nozzle assembly **110A** includes a nozzle flange **126** and an extension flange **130** releasably secured together by the two actuators **141A**. FIG. **4F** illustrates a cross-section view of the nozzle assembly **110A**, as taken along line **4F-4F** of FIG. **4E**, showing the nozzle flange **126** secured with the extension flange **130** by a connector **138A** that includes a split clamp body **144A** and a split strap **143A**. “Split” means there are multiple pieces that form the entire component, such as the strap described above having two ends, and as further described.

As shown in FIG. **4E**, the split clamp body **144A** can include a first segment **125A** and a second segment **125B**. The first segment **125A** and the second segment **125B** may each have a semi-circular shape and extent. Similarly, the split strap **143A** may include two segments each extending about half the circumference of the nozzle assembly **110A**. When the first and second segments **125A**, **125B** of the split clamp body **144A** are released, the split clamp body **144A** is thereby released and can allow for separation of the extension flange **130** from the nozzle flange **126**. For example, after the connectors **138A** release the split strap **143A**, the first segment **125A** can separate from the second segment **125B**, thereby allowing the extension flange **130** and the nozzle flange **126** to separate from each other. In some examples, there may be a single clamp body **144A** or more than two segments of the split clamp body **144A**. Similarly, there may be a single strap **143A**, or more than two segments of the split strap **143A**.

The actuators **141A** can releasably secure adjacent ends of the split strap **143A**, for example adjacent ends of the two segments of the split strap **143A** as shown. As shown in the detail view of FIG. **4E**, the actuators **141A** can each include a first portion **123A**, a second portion **123B**, and an explosive bolt **145** extending therebetween. The first portion **123A** of the actuator **141A** can be a mount. The second portion **123B** of the actuator **141A** can be a mount. The first portion **123A** can further include a cavity for receiving a first end of the explosive bolt **145**, a spherical washer **152**, and a nut **159**. The second portion **123B** can further include a cavity for receiving a second opposite end of the explosive bolt **145**. In some examples, the first portion **123A** can be configured to secure to a first end of the split strap **143A**, and the second portion **123B** can be configured to secure to an opposing end of the split strap **143A**. The explosive bolt **145** can thus releasably secure the first portion **123A** and the second portion **123B** of the actuator **141A**. In some examples, the explosive bolt **145** may be coupled to the first portion **123A** via the spherical washer **152** and the nut **159**.

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The explosive bolt **145** can include a longitudinal shaft. In some examples, the explosive bolt **145** can be an explosive fastener, stud, or other elongated structure. A pyrotechnic charge can be configured to fracture and break the shaft. The pyrotechnic charge may be remotely initiated. For example, an electric charge may be remotely controlled to activate the explosive bolt **145**. The explosive bolt **145** may be configured to break into two or more parts after detonation. In some examples, the explosive bolt **145** can include a structurally weakened portion relative to other portions of the shaft. For example, the structurally weakened portion can include a thinner width relative to another portion of the explosive bolt. In some examples, the structurally weakened portion can be scored. For example, the weaker portion may be located where the explosive bolt **145** should fracture and split. The explosive fastener may incorporate an exploding bridge wire detonator, a slapper detonator, or a pulsed laser diode to activate the explosive bolt **145**.

In some examples, in the assembled state, the split clamp body **144A** extends annularly around the nozzle assembly **110A**, the split strap **143A** extends annularly around the split clamp body **144A**, the first portions **123A** of the two actuators **141A** are secured to respective first ends of the split strap **143A**, the second portions **123B** of the two actuators **141A** are secured to respective second ends of the split strap **143A**, and the explosive bolts **145** each extend between the first portions **123A** and the second portions **123B** of the two actuators **141A**. Accordingly, the explosive bolt **145** releasably couples the first segment **125A** of the split clamp body **144A** to the second segment **125B** of the split clamp body **144A**.

Actuating the explosive bolt **145** may cause the first portion **123A** of each actuator **141A** to separate from the corresponding second portion **123B** of the actuator **141A**, thus allowing opposing portions of the split strap **143A** to separate. With the radial inward force of the split strap **143A** removed, the split clamp body **144A** can separate, thereby allowing the extension flange **130** to separate from the nozzle flange **126**. The angled outer surfaces of the flanges **126**, **130** (see FIG. 4F) facilitate and bias separation of the split clamp body **144A** from the flanges **126**, **130**.

As shown in FIGS. 4E and 4F, the nozzle assembly **110A** may not include the wedge rings **160** described above. As further shown, the nozzle flange **126** and the extension flange **130** may each have angled or sloped outer surfaces that contact the split clamp body **144A**. Thus, the split clamp body **144A** may directly contact the angled outer surfaces of the nozzle flange **126** and the extension flange **130**. In some examples, the nozzle assembly **110A** may include one or both wedge rings **160**. In some examples, the explosive bolt **145** described with respect to the actuators **141A** of FIGS. 4E and 4F may be replaced with a non-explosive bolt and bolt cutter. The nozzle assembly **110A** described above may be used with the connector **138A** as described above. However, the actuator **141** may use a non-explosive bolt, such as a fastener or stud nut. The non-explosive bolt may be released by a bolt cutter that is disposed about the bolt. The bolt cutter may be an automatic bolt cutter having a cutting portion adjacent the bolt. For example, the bolt cutter may include bladed jaws, that are disposed on either side of a bolt, such that the bolt cutter may be actuated to close about and cut the bolt so that the bolt does not secure the connector **138A** in a closed position. Actuating the bolt cutter to break the non-explosive fastener into two or more parts may similarly release the nozzle assembly **110A** as described above. FIGS. 4G and 4H illustrate an example of an actuator **141B** including a clasp system **146** for releasably securing a

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nozzle assembly **110A** together in an assembled state. FIG. 4G illustrates a side view of the clasp system **146**. FIG. 4H illustrates a top view of the clasp system **146**. The actuator **141B** may be used on any of the nozzle assemblies described herein. The nozzle assembly **110A** may be the same or similar as described above.

As shown in FIGS. 4G and 4H, the actuator **141B** may have a clasp system **146**. The clasp system **146** may be configured as a snap latch system. The clasp system **146** may include a dynamic element **147**, a static element **148**, a rod **149**, and the strap **143**. The strap **143** may have the same or similar features as described above. Therefore, the strap **143** may be a semi-flexible band extending from a first end to a second end configured to wrap around an exterior surface of the nozzle assembly **110**, etc.

The dynamic element **147** can be a portion of the clasp system **146** configured to be actuated for transitioning the clasp system **146** between a secured position and an unsecured position. In some examples, the clasp system **146** can maintain tension within the connector **138A** in the secured position and the clasp system **146** may not maintain tension within the connector **138A** in the unsecured position. The dynamic element **147** can further include a base member **150** and a rotational member **151**. The base member **150** may include a contoured, e.g., rounded, inner surface that conforms to the outer contour of the strap **143**. The base member **150** may include a pivot point **165A**. In some examples, the pivot point **165A** may include a pin extending transversely from the base member **150**.

The rotational member **151** may be movable between a first position and a second position. In some examples, the first position may correspond to the secured position and the second position may correspond to the unsecured position. The rotational member **151** can be secured to the base member **150** via the pivot point **165A** such as with a pin or hinge. Accordingly, the rotational member **151** may rotate about the pivot point **165A** to transition between the first position and the second position.

The dynamic element **147** may further include a latch actuator **153**. The latch actuator **153** may be configured to move linearly. For example, as shown in FIG. 4G, the latch actuator **153** may extend from an end of the rotational member **151** opposite the pivot point **165A**. Accordingly, the latch actuator **153** can move linearly toward and away from the rotational member **151** to cause rotation of the rotational member **151** about the pivot point **165A** between the first position and the second position.

The static element **148** can be a stationary member securing the actuator **141B** to the nozzle assembly **110**. The static element **148** can be a straight inner surface as shown, or a contoured inner surface conforming to the sidewall of another end of the strap **143** (or to another segment of the strap **143**, in the case of a split strap **143**). In some examples, the contoured surface may be rounded. The static element **148** may further include a pivot point **165B**, such as a pin, extending transversely from the static element **148**. The static element **148** can include an actuation mechanism **167**. As shown, the actuation mechanism **167** can include a sliding latch **168** and a securing element **169**. The sliding latch **168** may be linearly movable within a slot defined by the static element **148**. The securing element **169** may be a magnet. In some examples, the actuation mechanism **167** may be a solenoid, spring, or an electric motor.

The rod **149** can be a substantially rigid member. The rod **149** can couple the dynamic element **147** with the static element **148**. The rod **149** can provide a force to pull the dynamic element **147** and the static element **148** together. In

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some examples, the rod **149** can be configured to move the dynamic element **147** relative to the static element **148**. A first end of the rod **149** may be rotatably coupled to the dynamic element **147** and a second opposite end of the static element **148** can be rotatably connected to the static element **148**. In some examples, the rod **149** can rotatably couple with the pivot point **165B**. Accordingly, in some examples, the rod **149** may rotate when the latch actuator **153** is actuated. The rod **149** can rotate with a portion of the dynamic element **147** relative to the static element **148** about respective pivot points **165A**, **165B**. In some examples, the latch actuator **153** may be coupled to the dynamic element **147** such that the latch actuator **153** can actuate (e.g., release spring tension, provide air pressure, etc.) to initiate rotation of the rotational member **151** and the rod **149** in a radially outward direction away from the strap **143**. As such, the latch actuator **153** may cause release of the strap **143**, to allow the extension flange **130** to separate from the nozzle flange **126**, as described.

Respective ends of the strap **143** may be coupled to the dynamic element **147** and the static element **148**. The actuator **141B** may transition between a secured position and an unsecured position. In some examples, the secured position may correspond to a state wherein the actuator **141B** maintains tension of the strap **143** about the nozzle assembly **110**, such as the configuration shown in FIG. **4G**. In some examples, the unsecured position may correspond to a state wherein the actuator **141B** does not maintain tension of the strap **143** about the nozzle assembly **110**, such as after rotation of the mechanism as described.

In the secured position, as shown in FIGS. **4G** and **4H**, the rotational member **151** may be aligned with the base member **150** such that a longitudinal axis of the rotational member **151** extends along a longitudinal axis of the base member **150**. In such examples, the rotational member **151** may abut the strap **143**. In the unsecured position, the rotational member **151** may be angularly displaced from the base member **150**. For example, the longitudinal axis of the rotational member **151** may be angularly displaced from the strap **143** at an angle of ten or more, 20 or more, or 30 or more, degrees. Angularly displacing the rotational member **151** from the base member **150** can reduce the tension in the strap **143**, thereby enabling the nozzle assembly **110** to release, as described.

In some examples, the second stage rocket **102** can be operated by operating the second stage rocket engine **108** in a vacuum thrust mode, wherein the second stage rocket engine **108** comprises at least one nozzle assembly **110** having a nozzle extension **114** releasably attached to a nozzle **112** along an interface **135**. The second stage rocket **102** can be further operated by operating a clasp system **146** to release a connector **138A** extending annularly about the interface **135**. The second stage rocket **102** can be further operated by releasing the nozzle extension **114** from the nozzle **112** and operating the second stage rocket engine **108** in an atmospheric thrust mode using the nozzle **112** without the nozzle extension **114**. In some examples, operating the clasp system **146** can include rotating the dynamic element **147** to release the connector **138A** from the interface **135**. In some examples, rotating the dynamic element **147** to release the connector **138A** from the interface **135** can include transitioning the dynamic element **147** from a secured position to an unsecured position. In some examples, operating the clasp system **146** to release the connector **138A** can include actuating the latch actuator **153** to transition the dynamic element **147** from the secured position to the unsecured position. In some examples, rotating the dynamic

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element **147** to release the connector **138A** from the interface **135** can include rotating the rotational member **151** away from the static element **148** to transition the dynamic element **147** to the secured position and/or rotating the rotational member **151** toward the static element **148** to transition the dynamic element **147** to the unsecured position. Accordingly, the second stage rocket can include a nozzle assembly configured to transform from a vacuum-optimized configuration to an atmospheric-optimized configuration.

FIG. **4I** is a top view of a schematic of another example of an actuator **141C** for releasably securing the nozzle assembly **110**. The actuator **141C** may be used with any of the nozzle assemblies described herein. The actuator **141C** may be configured to releasably secure the strap **143**. The strap **143** may be secured about the clamp body **144**, as described. In some examples, the actuator **141C** can include a reverse pliers mechanism **154** that couples to ends of the strap **143** (or to ends of segments of the strap **143**, as in a split strap, as described). The reverse pliers mechanism **154** may be used to secure and release the strap **143** from around the clamp body **144** for separation of the nozzle flange **126** from the extension flange **130**, as described. In FIG. **4I**, the reverse pliers mechanism **154** and strap **143** are shown in a secured configuration (represented by the solid lines) and an unsecured configuration (shown by the dashed lines).

The reverse pliers mechanism **154** can include a first extension **155** and a second extension **156** which may be substantially rigid, elongated bodies. Each of the first extension **155** and the second extension **156** can form a half of the reverse pliers mechanism **154**. The first and second extensions **155**, **156** rotate to move the mechanism between a secured and unsecured configuration. The reverse pliers mechanism **154** includes, as shown in their positions when the mechanism is in a secured configuration, first ends **157**, one or more second ends **158**, a first portion **171**, a second portion **172**, a third portion **173**, a first hinge point **174**, and one or more second hinge points **175**. The corresponding unsecured positions of these features are designated as the first end **157'**, the second end **158'**, the first portion **171'**, the second portion **172'**, the third portion **173'**, the first hinge point **174**, and the second hinge point **175'**. Thus, the first hinge point **174** may not move between the secured and unsecured configurations. The first hinge point **174** may be a hard point to support the mechanism.

The strap **143** may have the same features as described above, such as a semi-flexible band extending from a first end to a second end, etc. In the secured configuration, the first ends **157** may be attached to the opposing ends of the strap **143**. The first ends **157** may locate the ends of the strap **143** relatively closer together such that the strap **143** is tensioned around the exterior surface of the clamp body **144**. In the unsecured configuration, the first ends **157'** are located relatively farther apart, such that the strap **143** is not tensioned around the nozzle assembly **110** and allows the clamp body **144** to release. In some examples, the first extension **155** and the second extension **156** can apply opposing tangential forces respectively to a first end of the connector **138A** and a second opposing end of the connector **138A**. For example, the first extension **155** can apply a first tangential force to the first end of the connector **138A** (e.g., the first end of the strap **143**) and the second extension **156** can apply a second tangential force opposite the first tangential force to the second end of the connector **138A** (e.g., the second end of the strap **143**). The “tangential” force may refer to a force in a direction, or a force having a component

in a direction, along a circumference of the interface or a direction that is tangent to such circumference.

The first ends **157** may define an engagement end of each of the first extension **155** and the second extension **156** for engaging the strap **143** (or in some examples engaging the clamp body **144**). The first ends **157** may be configured to transition between a first position and a second position to translate the ends of the strap **143** between the secured and unsecured configurations. The first ends **157** can transition between the first position and the second position by rotating about the hinge point **174** via rotation of the first portions **171**. The first ends **157** may rotate in opposite directions. For example, one of the first ends **157** may transition from its first position to its second position by rotating counter-clockwise about the hinge point **174** while the other of the first ends **157** may transition from its first position to its second position by rotating clockwise about the hinge point **174**. In some examples, the first positions may correspond to the secured configuration and the second positions may correspond to the unsecured configuration.

The one or more second ends **158** may be at an opposite side of the actuator **141C** relative to the first ends **157**. The one or more second ends **158** may be configured to transition between a first position as shown by the location of the second end **158** to a second position as shown by the different, radially inward location of the second end **158'**. Transitioning the one or more second ends **158** may act to operatively move the first ends **157** between their respective first and second positions via rotation of the first portions **171**, second portions **172** and third portions **173** about the hinge point **174**, as further described. In some examples, the second ends **158** may translate along a linear path. For example, as shown in FIG. **4I**, the second ends **158** can translate radially between a radial outward position at the second end **158** and a radial inward position at the second end **158'**. In some examples, the radial outward position may correspond to the first position and the radial inward position may correspond to the second position. Accordingly, translating the one or more second ends **158** radially inward may cause the first ends **157** to move farther apart from each other. The first position of the one or more second ends **158** may correspond to when the reverse pliers mechanism **154** is in the secured configuration, and the second position of the second ends **158'** may correspond to when the reverse pliers mechanism **154** is in the unsecured configuration. In some examples, there may only be a single second end **158** that joins both of the third portions **173** together. The single second end **158** may operate as described above. Movement of the one or more second ends **158** can cause movement of the first ends **157** via rotation of one or more portions of the mechanism, as further described.

The first portions **171** can be rigid segments of fixed length. The first portions **171** can extend from proximal ends at the respective first ends **157** to distal ends at the first hinge point **174**. The first portions **171** can be non-linear. For example, as shown in FIG. **4I**, the first portions **171** may extend in a first circumferential direction from their proximal ends, and then extend radially outward and in a second opposite circumferential direction to the first hinge point **174**. The first portions **171** may therefore have a bent or arced shape.

The second portions **172** can be rigid segments of fixed length. In some examples, the second portions **172** can extend (for example, linearly) between a proximal end at the hinge point **174** to a distal end at the second hinge point **175**. The second portions **172** may extend radially outward in first circumferential directions to their respective second hinge

points **175**. In some examples, the angle between the first portion **171** and the adjacent second portion **172** may be fixed. This angle may be between 45 degrees and 90 degrees, between 65 degrees and 80 degrees, or between 70 degrees and 75 degrees. In some examples, the second portions **172** can be configured to rotate to cause the respective first portions **171** to rotate, as described. The second portions **172** may be rotated via the third portions **173** that connect to the second portions **172** at respective hinge points **175**. In some examples, the second portions **172** may be able to flex slightly in response to actuation forces in order to move between the configurations.

The third portions **173** can be rigid segments of fixed length. In some examples, the third portions **173** can extend between a proximal end at the second hinge point **175** to a distal end at the respective second ends **158**. The third portions **173** can extend in a second circumferential direction, that is opposite the first circumferential direction in which the corresponding second portions **172** extend. The third portions **173** can extend from their respective proximal ends at the respective second hinge points **175** to their respective distal ends at the one or more second ends **158**. The third portions **173** are configured to transition, relative to the nozzle assembly **110**, from a relatively more circumferential orientation in the secured state (e.g., in FIG. **4I**, see positions of the second hinge points **175** and the second ends **158**) to a relatively more radial orientation in the unsecured state (e.g., see positions of the second hinge points **175'** and the second ends **158'**). In some examples, the third portions **173** may be able to flex slightly in response to actuation forces in order to move between the configurations. In the secured state, as shown in FIG. **4I**, the angle between the third portions **173** and the respective adjacent second portions **172** can be greater than 20 degrees, greater than 30 degrees, or between 30 degrees and 60 degrees. In the unsecured configuration, as shown in FIG. **4I**, the angle between the third portions **173** and the corresponding second portions **172** can be less than 20 degrees. In some examples, the angle between the third portions **173** and the corresponding second portions **172** can be between 5 degrees and 15 degrees, in the unsecured configuration.

The first extension **155** and the second extension **156** may each include respective first, second, and third portions **171**, **172**, **173**. The first extension **155** and the second extension **156** may be coupled together at their respective second ends **158** and at the first hinge point **174**. The actuator **141C** may be actuated via an application of a force to the second ends **158**. In some examples, the second ends **158** may be configured to be linearly actuated by an applied force. In some examples, the linear actuation can be along a center line between the first extension **155** and the second extension **156**. For example, the center line may be in a radial direction relative to the nozzle assembly **110**. Transitioning the one or more second ends **158** from the first position to the second position may include moving the second ends **158** radially inward to a radially inward position located closer to the first hinge point **174** than a radially outward position as shown.

The first extension **155** and the second extension **156** may be configured to transition between the secured configuration and the unsecured configuration. As discussed above, in the secured configuration, the first ends **157** of the first extension **155** and the second extension **156** are in a closed configuration and act to secure the strap **143** and/or clamp body **144**. In the unsecured configuration, the first ends **157** of the first extension **155** and the second extension **156** move

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away from each other and are in an open configuration to release the strap **143** and clamp body **144**.

Changing the position of the second ends **158**, **158'** of the first extension **155** and the second extension **156** changes the configuration of the first extension **155** and the second extension **156** between the secured configuration and the unsecured configuration. In the secured configuration, the second ends **158** are in a first position (radially outward position) distal from the strap **143** and/or clamp body **144**. In this configuration, the third portions **173** extend substantially laterally (e.g. circumferentially) from the second end **158**. In the secured configuration, the third portions **173** act to prevent rotation of the second portions **172** thereby keeping the first ends **157** in a secured configuration. By comparison, in the unsecured configuration, the second ends **158'** of the first extension **155** and the second extension **156** are in a second position (radially inward position) closer to the strap **143** and/or clamp body **144**. In the second position, the third portions **173'** extend in a substantially radial direction. In the unsecured configuration, the third portions **173'** act to rotate the second portions **172'** such that the second hinge points **175'** are farther away from the strap **143** and clamp body **144**, thereby further separating the first ends **157'** via rotation about the first hinge point **174**. Accordingly, the reverse pliers mechanism **154** can include moving the first ends **157'** of the first extension **155** and the second extension **156** away from each other at least partially in a tangential direction.

Accordingly, the first extension **155** and the second extension **156** may be rotatably coupled to each other and configured to transition between the secured and unsecured configurations. In some examples, the first extension **155** and the second extension **156** may be rotatably coupled about the first hinge point **174** such that the respective first ends **157** of the first extension **155** and the second extension **156** advance toward each other when the respective second ends **158** are in a first position to achieve the secured configuration. Similarly, the respective first ends **157'** of the first extension **155** and the second extension **156** may advance away from each other when the respective second ends **158'** are in a second position to achieve the unsecured configuration. The first ends **157**, **157'** may be coupled to respective ends of the strap **143**. The second ends **158**, **158'** may be held in place at least in part by a connector coupled to an actuator **141**, such as a solenoid. The second ends **158**, **158'** may be actuated by a linear force actuator **141**. In some examples, the linear force actuator **141** may be a linear solenoid. In some examples, the linear force actuator **141** may be positioned external of the nozzle **112**. The actuator **141** may be activated to release the first extension **155** and the second extension **156** to rotate with respect to each other such that the first ends **157**, **157'** advance away from each other, which may allow the ends of the strap **143** to move away from each other releasing the Marman clamp mechanism.

FIG. **5** is a cross-section view of a sample interface of the nozzle **112** and the nozzle extension **114**. The outboard nozzle end **122** may interface with the inboard extension end **134**. The outboard nozzle end **122** may define a groove **113** that extends annularly within and around the outboard nozzle end **122**. The inboard extension end **134** may be received into the groove **113**. The assembly shown may be used at the inboard interface **131** or the outboard interface **133**, or in other examples of the nozzle assembly **110** having different interfaces.

There may be one or more seals **142** located at the interface. The seal **142** may extend annularly around the

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circumference of the interface. The seal **142** may be a deformable material that secures the nozzle **112** and nozzle extension **114** together while preventing loss of exhaust gas through the interface. As shown there may be two seals **142**, with one of the seals located on a radially outward side of the nozzle extension **114** and the other of the seals located on a radially inward side of the nozzle extension **114**.

FIG. **6A** is a side cross-sectional view of another example of the nozzle assembly **110** having an actuator **600**, and FIG. **6B** is a close-up detail view of the actuator **600**. The actuator **600** is shown as a jackscrew assembly that may jettison the nozzle extension **114** from the nozzle **112**. As shown in FIG. **6A**, the nozzle **112** can extend from an inboard end to an outboard end along an axis. Similarly, the nozzle extension **114** can extend from an inboard end to an outboard end along the axis. One or more flanges **601** may extend radially outwardly from the nozzle **112** and the nozzle extension **114**. For example, as shown in FIG. **6B**, the outboard end of the nozzle **112** can include a first flange **601** extending annularly about, and protruding radially outward from, the outboard end of the nozzle **112**. As further shown in FIG. **6B**, the inboard end of the nozzle extension **114** can include a second flange **601** extending annularly about, and protruding radially outward from, the inboard end of the nozzle extension **114**. The actuator **600** may include a threaded jackscrew **604** disposed through the flanges **601**, such as through an opening which may be a cylindrical, threaded channel in the flanges **601**. Accordingly, the jackscrew **604** may axially secure the nozzle **112** and nozzle extension **114** via attachment with the respective flanges **601**. The jackscrew **604** can releasably couple the first flange **601** and the second flange **601** together. In some examples, the jackscrew **604** can be configured to rotate to release the nozzle extension **114** from the nozzle **112**. For example, the actuator **600** may further include an electrical motor **602**, which may rotate the jackscrew **604** to translate the jackscrew **604** axially up or down. The jackscrew **604** may translate upward to detach from the second flange **601**, thereby releasing the nozzle extension **114**. In some examples, the jackscrew **604** may translate downward to axially press downward against the nozzle extension **114** to separate and jettison the nozzle extension **114** by applying pressure to at least a portion of a surface of the nozzle extension **114**. There may be multiple jackscrews **604** located at various circumferential locations along the interface.

Example Method of Jettisoning Nozzle Extension

In operation, at least one processor may be used to coordinate the functions of the first stage rocket **104** and/or the second stage rocket **102** during operation. The first stage rocket engine **106** may be activated to cause the rocket system **100** to expel propulsive exhaust gasses and complete an engine burn to propel the rocket system **100** to a desired altitude.

As described above, the second stage rocket engine **108** may be activated to propel the second stage rocket **102** during a launch mission and facilitate reentry and/or landing of the second stage rocket **102**. For example, the second stage rocket engine **108** may provide thrust to cause the second stage rocket **102** to ascend in the earth's atmosphere to a desired distance. During the time that the second stage rocket **102** ascends in or away from the earth's atmosphere, the second stage rocket **102** may be operated in the vacuum thrust mode for optimized operation outside an atmosphere. The second stage rocket **102** may further be operated to facilitate controlled landing of the second stage rocket **102** within the atmosphere. During the time the second stage rocket **102** approaches landing, the second stage rocket **102**

may be operated in the atmospheric thrust mode for operation inside an atmosphere such as the earth's atmosphere during landing.

FIG. 7 is a flow diagram illustrating an example method 700 that may be used with the rocket system 100, for example for extraplanetary propulsion and reentry of the rocket system 100. Each of the following steps may be executed by one or more processors. At block 702, the rocket system 100 launches, for example via one or more processors. As described above, the rocket system 100 may be launched by initiating the first stage rocket engines 106 for an initial ascent launch.

The method 700 continues with step 704, where the second stage rocket 102 separates from the first stage rocket 104, for example via control signals from the one or more processors. The second stage rocket 102 may be jettisoned by releasing connectors coupling the second stage rocket 102 to the first stage rocket 104. For example, the first stage rocket 104 may release clamps, open portions of the first stage rocket 104 containing portions of the second stage rocket 102, and/or detonate explosives to separate portions of the second stage rocket 102 from the first stage rocket 104.

The method 700 then moves to step 706, where the second stage rocket engine 108 is operated in the vacuum thrust mode, for example via control signals from the one or more processors. When in the vacuum thrust mode, the second stage rocket engine 108 may operate while retaining the nozzle extension 114 attached to the nozzle 112. For example, the processor may specify fuel burn parameters optimized for producing thrust in a vacuum that cause the rocket engine to expand the exhaust plume to a desired diameter at the outboard extension end 136. As the processor operates the second stage rocket engine 108, the outlet diameter is the diameter of the outboard extension end 136 which provides nozzle dimensions to operate the second stage rocket 102 in the vacuum thrust mode. In some examples, the vacuum thrust mode is initiated based on a time from initiation of ascent and/or jettison. In other examples, the vacuum thrust mode is initiated based on a sensed distance traveled. In some examples, the vacuum thrust mode is initiated by a user interfacing with the processor.

The method 700 then moves to step 708, where the nozzle extension 114 is jettisoned from the nozzle 112. The one or more processors may provide control signals that cause the actuator 140 to detach the nozzle extension 114 from the nozzle 112. Any of the actuators and associated mechanisms, devices and methods described herein may be used to separate the nozzle extension, for example those shown in and described with respect to FIGS. 3A-4I. For example, the processor may initiate an electrical signal to activate the actuator 140 to release the connector 138. Alternatively or additionally, the processor may initiate an electrical signal sent to a detonator in the explosive charge that detonates the shaped charge of the actuator 141 against the connectors 139. As such, the actuator separates the nozzle extension 114 from the nozzle 112. In some examples, the nozzle extension 114 may be jettisoned in space during a mission, and in other examples, the nozzle extension 114 may be jettisoned in the atmosphere after a descent burn has begun, in further examples, the nozzle extension 114 may be jettisoned in space before the ascent burn has completed. In some examples, the actuator 140 is initiated based on a time from initiation of descent. In other examples, the actuator 140 is initiated based on a sensed altitude. In some examples, the actuator 140 is initiated by a user interfacing with the

processor. In some examples, the actuator 140 is initiated based on a time from the start of ascent.

The method 700 then moves to step 710, where the second stage rocket 102 is operated in the atmospheric thrust mode, for example via one or more processors providing control signals. For example, the processor may determine fuel burn parameters that cause the second stage rocket engine 108 to expand the exhaust plume to a second, different exit diameter that is optimized for atmospheric operation. As the processor operates the second stage rocket engine 108, the outlet diameter is the second diameter of the nozzle 112 which provides the nozzle dimensions to operate the second stage rocket 102 in the atmospheric thrust mode. In some examples, the atmospheric thrust mode is initiated based on a time from initiation of descent. In other examples, the atmospheric thrust mode is initiated based on a sensed altitude such as a minimum altitude to land (e.g., from 5000 ft.-10,000 from land surface). In some examples, the atmospheric thrust mode is initiated by a user interfacing with the processor.

The method 700 then moves to step 712, where the second stage rocket 102 lands. The processor may provide control signals to cause the second stage rocket 102 to operate in a landing thrust mode. The landing thrust mode may include fuel burn parameters configured to manage momentum of the second stage rocket 102 as the second stage rocket 102 approaches a surface such as a planetary surface. In some examples, the landing thrust mode is initiated based on a time from initiation of descent. In other examples, the landing thrust mode is initiated based on a sensed altitude. In some examples, the landing thrust mode is initiated by a user interfacing with the processor.

The method 700 then moves to step 714, where a new nozzle extension is attached to the nozzle 112. The nozzle extension 114 may be replaced with a new one by a human operator on a landing surface such as the ground. In some examples, the intermediate nozzle extension 128 is removed and replaced. In some examples, the processor may initiate an electrical connection with the actuator to secure the new nozzle extension with the nozzle 112. The processor may initiate the electrical connection upon final assembly of the new nozzle extension with the nozzle assembly 110.

The method 700 then moves to step 716, where the second stage rocket is relaunched on the launch vehicle. The processor may cause the first stage rocket 104 to re-launch with the second stage rocket 102 coupled thereto. For example, the second stage rocket 102 may be attached to a nose portion of the first stage rocket 104 which is used for the initial launch such as a launch out of an atmosphere such as earth's atmosphere. In some examples, the first stage rocket 104 may be the same first stage rocket 104 used for at least one previous launch with the second stage rocket 102. In other examples, the first stage rocket 104 may be a different first stage rocket that has not been used in a previous launch with the second stage rocket 102. The first stage rocket 104 may further be operated as described above.

EMBODIMENTS AND TERMINOLOGY

All of the methods and processes described above may be embodied in, and fully automated via, software code modules executed by one or more computers or processors. The code modules may be stored in any type of non-transitory computer-readable medium or other computer storage device. Some or all of the methods may alternatively be embodied in specialized computer hardware.

Various modifications to the implementations described in this disclosure will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other implementations without departing from the spirit or scope of this disclosure. Thus, the disclosure is not intended to be limited to the implementations shown herein but is to be accorded the widest scope consistent with the claims, the principles and the novel features disclosed herein. The word “example” is used exclusively herein to mean “serving as an example, instance, or illustration.” Any implementation described herein as “example” is not necessarily to be construed as preferred or advantageous over other implementations, unless otherwise stated.

Certain features that are described in this specification in the context of separate implementations also may be implemented in combination in a single implementation. Conversely, various features that are described in the context of a single implementation also may be implemented in multiple implementations separately or in any suitable sub-combination. Moreover, although features may be described above as acting in certain combinations and even initially claimed as such, one or more features from a claimed combination may in some cases be excised from the combination, and the claimed combination may be directed to a sub-combination or variation of a sub-combination.

Similarly, while operations are depicted in the drawings in a particular order, this should not be understood as requiring that such operations be performed in the particular order shown or in sequential order, or that all illustrated operations be performed, to achieve desirable results. Additionally, other implementations are within the scope of the following claims. In some cases, the actions recited in the claims may be performed in a different order and still achieve desirable results.

It will be understood by those within the art that, in general, terms used herein are generally intended as “open” terms (e.g., the term “including” should be interpreted as “including but not limited to,” the term “having” should be interpreted as “having at least,” the term “includes” should be interpreted as “includes but is not limited to,” etc.). It will be further understood by those within the art that if a specific number of an introduced claim recitation is intended, such an intent will be explicitly recited in the claim, and in the absence of such recitation no such intent is present. For example, as an aid to understanding, the following appended claims may contain usage of the introductory phrases “at least one” and “one or more” to introduce claim recitations. However, the use of such phrases should not be construed to imply that the introduction of a claim recitation by the indefinite articles “a” or “an” limits any particular claim containing such introduced claim recitation to examples containing only one such recitation, even when the same claim includes the introductory phrases “one or more” or “at least one” and indefinite articles such as “a” or “an” (e.g., “a” and/or “an” should typically be interpreted to mean “at least one” or “one or more”); the same holds true for the use of definite articles used to introduce claim recitations. In addition, even if a specific number of an introduced claim recitation is explicitly recited, those skilled in the art will recognize that such recitation should typically be interpreted to mean at least the recited number (e.g., the bare recitation of “two recitations,” without other modifiers, typically means at least two recitations, or two or more recitations). Furthermore, in those instances where a convention analogous to “at least one of A, B, and C, etc.” is used, in general such a construction is intended in the sense one having skill in the art would understand the convention (e.g., “a system

having at least one of A, B, and C” would include but not be limited to systems that have A alone, B alone, C alone, A and B together, A and C together, B and C together, and/or A, B, and C together, etc.). In those instances where a convention analogous to “at least one of A, B, or C, etc.” is used, in general such a construction is intended in the sense one having skill in the art would understand the convention (e.g., “a system having at least one of A, B, or C” would include but not be limited to systems that have A alone, B alone, C alone, A and B together, A and C together, B and C together, and/or A, B, and C together, etc.). It will be further understood by those within the art that virtually any disjunctive word and/or phrase presenting two or more alternative terms, whether in the description, claims, or drawings, should be understood to contemplate the possibilities of including one of the terms, either of the terms, or both terms. For example, the phrase “A or B” will be understood to include the possibilities of “A” or “B” or “A and B.”

What is claimed is:

1. A rocket nozzle assembly comprising:

a nozzle having a frustoconical nozzle body that extends axially between a first inboard end and a first outboard end and defines a nozzle channel;

a nozzle extension having a frustoconical extension body that extends axially from a second inboard end to a second outboard end, wherein the second inboard end is releasably coupled to the nozzle assembly at an outboard interface via a frangible connector extending annularly about the outboard interface, and wherein the frustoconical extension body defines an extension channel that is axially aligned with the nozzle channel;

an intermediate nozzle extension having a second frustoconical extension body that extends axially between a third inboard end and a third outboard end and defines a second extension channel that is axially aligned with the nozzle channel, wherein the third inboard end is removably coupled to the first outboard end at an inboard interface via a second connector extending annularly about the inboard interface and the second inboard end is releasably coupled to the third outboard end at the outboard interface via the frangible connector; and

an actuator in physical communication with the frangible connector and configured to cause the nozzle extension to detach from the nozzle assembly along the outboard interface.

2. The rocket nozzle assembly of claim 1, wherein the actuator causes the frangible connector to break.

3. The rocket nozzle assembly of claim 1, wherein the frangible connector comprises a plurality of detachable fasteners.

4. The rocket nozzle assembly of claim 3, wherein the plurality of detachable fasteners are rivets.

5. The rocket nozzle assembly of claim 1, wherein the actuator is configured to cause the nozzle extension to detach from the intermediate nozzle extension during flight.

6. The rocket nozzle assembly of claim 1, wherein the intermediate nozzle extension is configured to remain attached to the nozzle along the inboard interface during flight.

7. The rocket nozzle assembly of claim 1, wherein the intermediate nozzle extension is configured to be removed from the nozzle along the inboard interface after landing.

8. A rocket system comprising:

a second stage rocket comprising one or more second stage rocket engines having a nozzle assembly configured to transform from a vacuum-optimized configura-

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ration to an atmospheric-optimized configuration, wherein the nozzle assembly comprises:

a nozzle having a frustoconical nozzle body that extends axially between a first inboard end and a first outboard end and defines a nozzle channel;

a nozzle extension having a frustoconical extension body that extends axially from a second inboard end to a second outboard end, wherein the second inboard end is releasably coupled to the nozzle assembly at an outboard interface via a frangible connector extending annularly about the outboard interface, and wherein the frustoconical extension body defines an extension channel that is axially aligned with the nozzle channel;

an intermediate nozzle extension having a second frustoconical extension body that extends axially between a third inboard end and a third outboard end and defines a second extension channel that is axially aligned with the nozzle channel, wherein the third inboard end is removably coupled to the first outboard end at an inboard interface via a second connector extending annularly about the inboard interface and the second inboard end is releasably

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coupled to the third outboard end at the outboard interface via the frangible connector; and

an actuator in physical communication with the frangible connector and configured to cause the nozzle extension to detach from the nozzle assembly along the outboard interface.

9. The rocket system of claim 8, wherein the actuator causes the frangible connector to break.

10. The rocket system of claim 8, wherein the frangible connector comprises a plurality of detachable fasteners.

11. The rocket system of claim 10, wherein the plurality of detachable fasteners are rivets.

12. The rocket system of claim 8, wherein the actuator is configured to cause the nozzle extension to detach from the intermediate nozzle extension during flight.

13. The rocket system of claim 8, wherein the intermediate nozzle extension is configured to remain attached to the nozzle along the inboard interface during flight.

14. The rocket system of claim 2, wherein the intermediate nozzle extension is configured to be removed from the nozzle along the inboard interface after landing.

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