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MULTISTAGE TURBOCHARGING SYSTEM

TECHNOLOGICAL FIELD

The present disclosure is generally in the field of turbochargers for use with internal combustion engines. More particularly, the disclosure is concerned with multistage turbochargers for use with internal combustion engines.

5 BACKGROUND ART

References considered to be relevant as background to the presently disclosed subject matter are listed below:

- US 7,958,730
- GB2507061

10 Acknowledgement of the above references herein is not to be inferred as meaning that these are in any way relevant to the patentability of the presently disclosed subject matter.

US7,958,730 discloses multivariable dual stage series turbochargers having two degrees of freedom. A multistage series turbocharger apparatus has a low pressure
15 turbocharger comprising a low pressure compressor and a low pressure turbine; a high pressure turbocharger comprising a high pressure compressor and a high pressure turbine, and an exhaust gas recirculation device. A controller controls the operation of at least two of the low pressure compressor, high pressure compressor, low pressure turbine, high pressure turbine, and exhaust gas recirculation device such that at least one
20 operating parameter is maintained at about a selected value.

GB2507061 discloses a method of controlling an internal combustion engine, comprising a two-stage turbocharger, an exhaust gas recirculation (EGR) valve and a cylinder deactivation system, comprises setting a high pressure (HP) turbine, a HP
25 turbine controlled by-pass, a low pressure (LP) turbine controlled by-pass and the EGR valve to first or second values taking into account the exhaust flow in the HP and LP by-passes, the expansion ratio in the HP turbine and instantaneous engine speed and

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load. The HP turbine, the HP and LP by-passes and the EGR valve are also set according to preset values for boost and EGR targets ramp-in. The method may also comprise the step of realizing a cylinders activation or deactivation, as well as controlling the EGR and boost in closed loop. The method may be carried out using a
5 suitable internal combustion engine and control apparatus.

BACKGROUND

Turbocharged engines are well known in the art and have been utilized already at the beginning of the previous century and are nowadays used in a variety of engines, among others widely in aircraft engines.

10 As an aircraft climbs to higher altitudes ambient air density, and respectively air pressure, rapidly drop. Since the charge in the cylinders of the engine is pushed in by the ambient air pressure, the engine does not produce enough power and engine output drops substantially linearly to pressure drop. In order to enable aircrafts to fly at high altitudes and to take advantage of the low drag at high altitudes so as to fly faster, a
15 turbocharger is used to overcome the problem of thin air, by compressing the ambient air back to sea-level pressure.

The turbocharger uses waste energy discharged from the engine at exhaust, using a turbine, to drive a compressor and compresses the ambient air so that the engine is fed with higher pressure than ambient pressure, the object being to maintain the
20 engine input pressure at sea-level pressure.

The size of the turbocharger is chosen to produce a given amount of pressure at high altitude, and however since each turbocharger has efficiency limitations depending on the input/output ratio, depending on parameters such as weight, size, inertia, losses, etc. Alternatively, two or more superchargers are used in series, wherein the overall
25 compression ratio is a multiplication of the compression ratio of the superchargers.

The speed of the turbocharger is controlled by a wastegate (typically automatically adjustable). When the aircraft is at low altitude the wastegate is usually open, thus venting exhaust gases, and as the aircraft climbs and the air density drops, the wastegate gradually closes so as to maintain full power. The altitude at which the
30 wastegate fully closes and the engine still produces full power is referred to as the 'critical altitude'. When the aircraft continues its climb above the critical altitude, engine power output decreases as altitude increases, just as it would in a naturally aspirated

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engine. As a turbocharged aircraft climbs, however, the wastegate gradually closes, forcing more exhaust gas through the turbocharger turbine, thereby maintaining manifold pressure during the climb, at least until the critical pressure altitude is reached (when the wastegate is fully closed), after which manifold pressure falls.

- 5 A turbocharged aircraft engine which has been qualified for a particular flight envelope (flight performance envelope) receives a flight certification. Any alteration of an aircraft engine or engine associated systems requires issuance of a new flight certification, that being a complex and costly process.

GENERAL DESCRIPTION

- 10 It is an aim of the present disclosure to provide a turbocharged aircraft engine system configured with an increased critical altitude, however without actual changes made to the engine or turbocharger, and wherein a flight certificate still applies, and wherein only a supplemental supercharging assembly requires to be certified at a supplemental certification process.

- 15 According to the presently disclosed subject matter, there is provided an aircraft engine system configured with a high pressure stage turbocharger assembly and a supplemental stage turbocharger assembly disposed in series with respect to said high pressure stage turbocharger, wherein the supplemental stage turbocharger assembly provides a compressor unit of the high pressure stage turbocharger with substantially
20 constant critical altitude pressure input.

- The arrangement according to the present disclosure is such that the supplemental stage turbocharger assembly is configured to provide the high pressure stage turbocharger assembly, namely the compressor of said high pressure stage turbocharger assembly, with pressure resembling sea level conditions. Accordingly, the
25 critical altitude for the engine occurs at a higher altitude.

 Hereinafter in the specification and claims the term *supplemental stage turbocharger assembly* denotes a low pressure turbocharger assembly which is not in direct contact with the engine or a control unit associated with the engine or with the high pressure stage turbocharger assembly.

- 30 The supplemental stage turbocharger assembly of the present disclosure can be added as a retrofit assembly to an aircraft engine. In such a case an original turbocharger assembly (initially configured with the engine) of the engine will be

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considered as the high pressure stage turbocharger assembly, and the supplemental stage turbocharger assembly will be attached in series to said original turbocharger assembly. Likewise, the supplemental stage turbocharger assembly provides the compressor unit of the original turbocharger with substantially constant original
5 pressure input, up to the new critical altitude. Respectively the term *original critical altitude* denotes the critical altitude of the engine with the original turbocharger.

Accordingly, herein after in the specification and claims, the term *high pressure stage turbocharger assembly* denotes either an initially fitted turbocharger assembly (in the retrofit case) to which the supplemental stage turbocharger assembly as then
10 attached, or a high pressure stage of a multistage turbocharger assembly fitted to an engine and further including a supplemental stage turbocharger assembly.

Any one or more of the following features, configurations and designs can be implemented in a turbocharged airborne engine system according to the present disclosure, individually or in various combinations thereof:

- 15 • The supplemental stage turbocharger assembly can be a multistage supplemental turbocharger assembly and comprises two or more turbochargers, however disposed in series to one another;
- A control system is associated with the high pressure stage turbocharger assembly and is a closed-loop control system, i.e. substantially does not transfer or
20 receive control signals from the supplemental stage turbocharger assembly;
- The control system associated with the supplemental stage turbocharger assembly can be a closed-loop system, i.e. the supplemental stage turbocharger assembly substantially does not transfer or receive control signals from the high pressure stage turbocharger assembly;
- 25 • The engine system can further be configured with a TCU (Turbocharger Control Unit) configured for controlling pressure parameters of the high pressure stage turbocharger assembly, i.e. controlling the pressure inlet to the engine from the compressor of the high pressure stage turbocharger assembly;
- The TCU controls a wastegate associated with the high pressure stage
30 turbocharger assembly;
- As long as the engine assembly is exposed to pressure within the critical altitude, the TCU reads actual ambient pressure conditions, and however after said

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critical altitude the TCU reads pressure parameters generated by the supplemental stage turbocharger assembly;

- A supplemental wastegate is associated with the supplemental stage turbocharger assembly, said supplemental wastegate configured for assuring that a compressor of the supplemental stage turbocharger assembly generates pressure corresponding with that residing at the critical altitude;
- A supplemental TCU can be configured at the supplemental stage turbocharger assembly for monitoring pressure outlet at the compressor of the supplemental stage turbocharger assembly, so as to generate a control signal to the supplemental wastegate to close/open respectively;
- The engine and the high pressure stage turbocharger assembly, as well as the control unit associated therewith, remain substantially intact in-spite of the addition of the supplemental stage turbocharger assembly.

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BRIEF DESCRIPTION OF THE DRAWINGS

In order to better understand the subject matter that is disclosed herein and to exemplify how it may be carried out in practice, embodiments will now be described, by way of non-limiting example only, with reference to the accompanying drawings, in which:

Fig. 1 is a graph schematically representing performance of an airborne engine with and without a supplemental turbocharger assembly;

Fig. 2A is a block diagram of a prior art airborne engine configured with a high pressure stage turbocharger assembly and a supplemental stage turbocharger assembly disposed in parallel with respect to said high pressure stage turbocharger assembly;

Fig. 2B is a block diagram of a prior art airborne engine configured with a high pressure stage turbocharger assembly and a supplemental stage turbocharger assembly disposed in series with respect to said high pressure stage turbocharger assembly and with a control unit;

Fig. 3A is a block diagram of an airborne engine configured with a high pressure stage turbocharger assembly and a supplemental turbocharger assembly, according to an example of the present disclosure, illustrated without sensors;

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Fig. 3B is the same as Fig. 3A, however with sensors depicted;

Fig. 4A is the same as Fig. 3B, however with an oil system depicted;

Fig. 4B is a block diagram of an oil system associated with an isolated turbocharger system; and

5 **Fig. 5** is a block diagram of an airborne engine configured with a high pressure stage turbocharger assembly and a multistage supplemental turbocharger assembly, according to another example of the present disclosure.

DETAILED DESCRIPTION OF EMBODIMENTS

The graph illustrated in Fig. 1 of the drawings represents performance of an
10 airborne engine in terms of engine performance [HP %] vs. Altitude [meters]. The engine represented is configured with a high pressure stage turbocharger assembly and a supplemental stage turbocharger assembly disposed in series with respect to said high pressure stage turbocharger, wherein the supplemental stage turbocharger assembly provides a compressor unit of the high pressure stage turbocharger with substantially
15 constant critical altitude pressure input.

It is noted that as long as the aircraft (namely the engine thereof) flies with the critical elevation zone, i.e. within the aircraft elevation envelope (point **CR**), the engine output is maximal and substantially constant. However, as the aircraft continues to climb with air density, and respectively air pressure, rapidly dropping, the engine's
20 output would naturally drop (as represented by line segment 1-1'). However, this does not happen since the supplemental stage turbocharger assembly 'kicks in' namely provides the high pressure stage turbocharger assembly with a higher input pressure than ambient pressure (substantially constant pressure resembling ambient pressure at point **CR**), resulting in that the adjusted critical elevation zone (point **CR2**) is extended
25 and the engine output remains substantially constant (represented by dotted line extending between points 1-2).

Likewise, if the aircraft will continue climbing beyond the adjusted critical elevation zone (point **CR2**) the engine's output would naturally drop (as represented by line segment 2-2'). Then, if the supplemental stage turbocharger assembly is a multiple
30 stage turbocharger (i.e. an additional turbocharger is configured at the supplemental stage turbocharger assembly, in series with a high pressure stage turbocharger of the supplemental stage turbocharger assembly), the high pressure stage turbocharger

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assembly will then receive an 'amended' input pressure, i.e. corrected to substantially constant pressure resembling ambient pressure at point **CR**, resulting in that a new adjusted critical elevation zone (point **CR3**) is extended and the engine output remains substantially constant (represented by dotted line extending between points **2-3**).

5 In Fig. 2A of the drawings there is illustrated a block diagram representing a first example of a prior art two-stage turbocharged engine, generally designated **10**. The engine **E** is configured with a high pressure stage turbocharger assembly **12** and a low pressure stage turbocharger assembly **22**, each configured with a turbine **T₁₂**, **T₂₂** and a respective compressor **C₁₂** and **C₂₂**, and a respective wastegate **WG₁₂**, **WG₂₂**. The
10 system represented in this diagram is typically intended to increase the air flow to the engine. However, in the arrangement illustrated in Fig. 2A the first stage turbocharger assembly **12** and a second stage turbocharger assembly **22** are disposed parallel to one another, i.e. the output of each of the compressors **C₁₂** and **C₂₂** is directly connected to the input of the engine **E** and likewise, each of the turbines **T₁₂** and **T₂₂** is directly
15 coupled to the output of the engine **E**.

Fig. 2B is also directed to a prior art two-stage turbocharged engine, generally designated **30**, generally comprising an engine **E** configured with a high pressure stage turbocharger assembly **32** and a low pressure stage turbocharger assembly **34**, each configured with a turbine **T₃₂**, **T₃₄** and a respective compressor **C₃₂** and **C₃₄**, and a
20 respective wastegate **WG₃₂**, **WG₃₄**. However, in this example there is a control unit ECU (engine control unit), receiving/generating control signals from/to both the high pressure stage turbocharger assembly **32** and a low pressure stage turbocharger assembly **34** and the engine **E**.

Turning now to Fig. 3A of the drawings, there is illustrated a multi-stage
25 turbocharged engine assembly according to a first example of the disclosure, generally designated **50**, comprising an engine **E**, a high pressure stage turbocharger assembly generally designated **52**, and a supplemental stage turbocharger assembly generally designated **56**, disposed in series with respect to said high pressure stage turbocharger assembly **52**.

30 The high pressure stage turbocharger assembly **52** comprises a turbocharger **59** with a turbine **60** and an associated compressor **62**, wherein an inlet to the turbine **60** is coupled to an exhaust outlet port **64** of engine **E** through line **66**. A pressure outlet of

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the compressor **62** is in turn coupled to an inlet port **70** of the engine **E** through pressure line **72**.

A pressure sensor **78** generates a compressor output pressure signal, through line **79**, to a TCU (Turbocharger Control Unit) **80** associated with the pressure at pressure line **72**, said TCU **80** receiving also an intake pressure signal, via line **85**, associated with the compressor intake pressure through intake pressure sensor **84**. Responsive to said compressor output pressure signal at **78** and the intake pressure signal at **84** the TCU **80** generates a control signal through communication line **86** to a wastegate **88** disposed in communication between line **66** and an exhaust line **92** extending from the turbine **60**, said control signal controlling the extent to which the wastegate **88** opens/closes.

The supplemental stage turbocharger assembly **56** comprises a supplemental turbocharger **100** with a turbine **102** and an associated compressor **104**, wherein an inlet to the turbine **102** is coupled to exhaust line **92** extending from the high pressure stage turbine **60**, and a pressure outlet from the compressor **104** is in turn coupled, through a pressure-monitored line **108** to the inlet of compressor **62** of the of the high pressure stage turbocharger assembly **52**.

As can further be seen in Fig. 3A, the compressor **104** of the supplemental stage turbocharger assembly **56** has an ambient intake port **110** configured with an ambient pressure sensor **114**. A supplemental TCU (Turbocharger Control Unit) **120** receives the ambient pressure signal generated by pressure sensor **114** through line **116**, and further receives a pressure signal from pressure sensor **124** via control line **126**, representative of pressure generated to the high pressure stage compressor **62** via pressure-monitored line **108**. In turn, the TCU **120** generates control signal through communication line **128** to a wastegate **132** disposed in communication between line **92** (i.e. the exhaust line from the high pressure stage turbine **60**) and an exhaust line **134** extending from the supplemental turbine **102** to the atmosphere (or to an additional turbocharger stage as discussed hereinafter with reference to Fig. 5). The control signal generated to wastegate **132** controls the extent to which the wastegate **132** opens/closes.

In the block diagrams of the present description, a pressure inlet line is designated by a thick dashed line (such as pressure lines **72** and **108**), exhaust lines are designated by a solid thick line (such as lines **66** and **92**), and control lines are designated by thin dashed lines (such as lines **79**, **85**, **86**, **116**, **128**).

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It is appreciated that the engine **E** and the associated high pressure stage turbocharger assembly **52**, as well as the associated TCU **80**, remain intact with no changes thereto. In fact, the TCU **80** governs only parameters associated with the high pressure stage turbocharger assembly **52**, and respectively generates a control signal so
5 as to close/open the wastegate **88**, so as to determine if exhausted air from the engine **E** flows to the turbine **60** of the high pressure stage turbocharger assembly **52**, or is discharged into line **92** (and from there either to the atmosphere or to the turbine **102**).

Rather, the exhaust gases from the turbine **60** of the associated high pressure stage turbocharger assembly **52** are directed towards the turbine **102** of the
10 supplemental stage turbocharger assembly **56**, whilst the compressed air generated at the compressor **104** of the supplemental stage turbocharger assembly **56** is fed to the compressor **62** of the high pressure stage turbocharger assembly **52** (at need, i.e. when the aircraft climbs to an altitude above **CR**), whereby the compressor **62** is constantly exposed to pressure mimicking that residing at point **CR**, to thereby constantly provide
15 the engine **E** with sea level conditions. With reference to the graph of Fig. 1 it appears that the supplemental stage turbocharger assembly **56** extends the substantially flat power output line of the engine, from point **1** to point **2**.

From said point **1** to point **2** the pressure ratio read by the TCU **80** remains substantially constant and within that range wastegate **132** maintains predetermined
20 constant pressure generation by turbocharger **100**, to thereby maintain a constant pressure up to point **2**.

The pressure and command signals at the supplemental stage turbocharger assembly **56** take place a closed loop, i.e. the high pressure stage turbocharger assembly **52** does not receive or transmit any signals or indications to the supplemental stage
25 turbocharger assembly **56**, and vice-versa.

In operation, the supplemental TCU **120** monitors the pressure output at compressor **104** (pressure sensor **124**, via control line **126**) and respectively generates a control signal to wastegate **132** to close or open, so as to ensure that the compressor **104** generates pressure corresponding with the pressure required to maintain point **1**
30 (corresponding at elevation **CR**). Accordingly, when wastegate **132** closes gases received from the high pressure stage turbine (from line **92**) are directed towards the turbine **102**, and respectively, when the wastegate **132** is fully open gases are exhausted through exhaust line **134** to the atmosphere (or to another supplemental stage, if

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applicable; Fig. 5). The TCU **80** receives pressure parameters, (from sensor **84**) within a constant range, i.e. either ambient pressure signal extending within the altitude range up to **CR**, or pressure signal mimicking ambient pressure at point **CR**, as received at compressor **62** from compressor **104**, whilst sensor **78** generates a signal corresponding
5 with the engine inlet pressure.

The arrangement is such that up to the critical elevation at **CR**, the pressure sensor **124** senses high pressure and accordingly the supplemental TCU **120** generates a command signal to the wastegate **132** to remain open. However, when pressure sensed by the pressure sensor **124** drops (i.e. when the airplane has further climbed), the
10 supplemental TCU **120** generates a command signal to the wastegate **132** to gradually close, depending on the pressure output required. Other parameters are constantly collected and monitored by the supplemental TCU **120** such as temperature (sensor **143** in Fig. 3B) of the compressed air delivered to the compressor **62** of the high pressure stage turbocharger assembly **52**, etc, to thereby ensure ideal and proper performance of
15 the compressor **62**. Accordingly, up to point **1** corresponding with altitude **CR** (graph of Fig. 1) the TCU **80** actually receives pressure signals corresponding with actual ambient parameters, whilst beyond that point it reads 'processed' pressure signals, as received from the supplemental stage turbocharger assembly **56**, however mimicking ambient pressure at the altitude up to **CR**.

20 The TCU **80** ensures that the engine E continuously receives constant pressure (e.g. within the range 1-3 atm., depending on the engine) and thus the TCU **80** constantly compares the pressure signal received from pressure sensor **78** and that received from intake pressure sensor **84** to thereby generate a control signal to wastegate **88**.

25 At the event that the airplane continues to climb above the critical elevation **CR2**, the wastegate **132** will open, to discharge pressure from line **92** to the atmosphere in order to maintain the turbocharger within its speed limit.

With further reference to Fig. 3B, there is illustrated a block diagram of a system **150** substantially similar to that disclosed in Fig. 3A, however with some optional
30 features. The system **150** is principally similar to the previous example, and operates in a similar fashion, whereby like elements are designated with same reference numbers.

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An optional wastegate **137** is added to the supplemental stage turbocharger assembly **56**. Also, an additional bypass wastegate **139** can be provided, both of said wastegates **137** and **139** governed by the TCU **120**.

Also seen in Fig. 3B, the system can comprise a blow off protection valve **145** at the high pressure stage turbocharger assembly **52**, configured for discharging excessive pressure from the system prior to reaching the engine **E**.

In Fig. 4A of the drawings there is illustrated a block diagram of yet a modification of the disclosure of Figs. 3A and 3B, generally designated **180**. The system is principally similar to the previous examples, and operates in a similar fashion, whereby like elements are designated with same reference numbers. In addition to the components illustrated in Figs. 3A and 3B, Fig. 4A includes also an oil system **190**, associated with the supplemental stage turbocharger assembly **56**, seen isolated in Fig. 4B. The oil system **190** comprises an additional pressure sensor **192** and a temperature sensor **194** configured for measuring these parameters along oil system pressure line, and several other temperature sensors **196A**, **196B**, said parameters being transmitted to and processed at the TCU **120** which also constantly monitors and governs the oil system **190** and the oil pump **200** (Fig. 4B) in coordination with the other parameters as mentioned herein above in connection with the previous example.

Further attention is now directed to Fig. 5 of the drawings illustrating a multi-stage turbocharged engine assembly according to another example of the disclosure, generally designated **250** and comprising an engine **E** and a turbocharging system following the principals discussed herein above, and wherein like elements are designated with like reference numbers, however shifted by 200.

The multi-stage turbocharged engine assembly **250** comprises a high pressure stage turbocharger assembly generally designated **252**, and a multiple stage, supplemental stage turbocharger assembly generally designated **256**, disposed in series with respect to said high pressure stage turbocharger assembly **252**, wherein said supplemental stage turbocharger assembly **256** is a two stage turbocharger, comprising a first supplemental turbocharger assembly **257** (which acts within the supplemental stage turbocharger assembly **256** as a high pressure stage), and a second pressure supplemental turbocharger assembly **255** (which acts within the supplemental stage turbocharger assembly **256** as a low pressure stage).

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The high pressure stage turbocharger assembly **252** in the illustrated example of Fig. 5, is identical with the high pressure stage turbocharger assembly **52** of Figs. 3 and 4, and differences in the system **250** reside in the multiple stage, supplemental stage turbocharger assembly generally designated **256** and in the fashion it interacts with the
5 high pressure stage turbocharger assembly **252**, however following the principals of the previous examples, namely, that the engine **E** and the associated high pressure stage turbocharger assembly **252**, as well as the associated TCU **280**, remain intact with no changes thereto.

In fact, the TCU **280** governs only parameters associated with the high pressure
10 stage turbocharger assembly **252**, and respectively generates a control signal so as to close/open the wastegate **288**, so as to determine if exhausted air from the engine **E** flows to the turbine **260** of the high pressure stage turbocharger assembly **252**, or is discharged into line **292** (and from there either to the turbine **302** of the high pressure stage supplemental turbocharger assembly **257**, i.e. high pressure stage, or into line
15 **334**). Accordingly, signals at the multiple stage supplemental stage turbocharger assembly **256** take place a closed loop, i.e. the high pressure stage turbocharger assembly **252** does not receive or transmit any signals or indications to the supplemental stage turbocharger assembly **256**, and vice-versa.

The high pressure stage turbocharger assembly **252** comprises a turbocharger
20 **259** with a turbine **260** and an associated compressor **262**, wherein an inlet to the turbine **260** is coupled to an exhaust outlet port **264** of engine **E** through line **266**. A pressure outlet of the compressor **262** is in turn coupled to an inlet port **270** of the engine **E** through pressure line **272**.

A pressure sensor **278** generates a compressor output pressure signal, through
25 line **279**, to a TCU (Turbocharger Control Unit) **280** associated with the pressure at pressure line **272**, said TCU **280** receiving also an intake pressure signal, via line **285**, associated with the compressor inlet pressure through an intake pressure sensor **284**. Responsive to said compressor output pressure signal at **278** and the intake pressure signal at **284** the TCU **280** generates a control signal through communication line **286** to
30 a wastegate **288** disposed in communication between line **266** and an exhaust line **292** extending from the turbine **260**, said control signal controlling the extent to which the wastegate **288** opens/closes.

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The high pressure stage supplemental turbocharger assembly **257** comprises a high pressure stage supplemental turbocharger **300** with a turbine **302** and an associated compressor **304**, wherein an inlet to the turbine **302** is coupled to exhaust line **292** extending from the high pressure stage turbine **260**, and a pressure outlet from the compressor **304** is in turn coupled, through a pressure-monitored line **308** to the inlet of compressor **262** of the of the high pressure stage turbocharger assembly **252**. The compressor **304** of the high pressure stage supplemental turbocharger assembly **257** is configured with an intake port **311**, to be further discussed hereinafter.

A wastegate bypass **332** is disposed in communication between line **292** (i.e. the exhaust line from the high pressure stage turbine **260**) and an exhaust line **334** extending from the supplemental turbine **302** to a turbine **343** of turbocharger **341** of the low pressure supplemental turbocharger assembly **255**, i.e. low pressure stage supplemental turbocharger, said wastegate **332** governed by a supplemental TCU (Turbocharger Control Unit) **320**.

The turbocharger **341** further comprises a compressor **345** associated with the turbine **343**, said compressor **345** configured with an ambient air intake **347**. A wastegate **349** is disposed in communication between line **351** (i.e. an exhaust line from the turbine **343** of the low pressure supplemental turbocharger **341**, i.e. low pressure stage supplemental turbocharger) and an exhaust line **334** extending from the high pressure stage supplemental turbine **302**, (i.e. high pressure stage supplemental turbocharger) to the turbine **343**, with a control line **353** extending between the wastegate **349** and the supplemental TCU **320**, wherein a control signal generated to wastegate **349** controls the extent to which the wastegate opens/closes, as discussed herein before.

Compressor **345** of the low pressure stage supplemental turbocharger **341** is in pressure communication through pressure line **357** with the compressor **304** of the high pressure stage supplemental turbocharger **300**. Said pressure line configured with an additional bypass (optional) **361**, for selective inlet of ambient air through line **363**. Also disposed along pressure line **357** are a temperature sensor **365** and a pressure sensor **367**, wherein said temperature sensor **365** and pressure sensor **367** are monitored and said additional bypass **361** is also governed by the supplemental TCU **320**.

The supplemental TCU (Turbocharger Control Unit) **320**, common for the high pressure stage supplemental turbocharger assembly **257** and the low pressure stage

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supplemental turbocharger assembly **255**, further receives parameters associated with the monitored line **308**, namely a pressure signal generated by pressure sensor **224** and a temperature signal generated by thermo-sensor **243**. The supplemental TCU **320** also governs an additional wastegate **337** applied to pressure line **308** extending between
5 compressor **304** and compressor **262**.

Responsive to the monitored parameters, the supplemental TCU **320** generates control signals through communication line **353** to wastegate **349** and through communication line **373** to the additional bypass **361**.

The arrangement is such that as the aircraft continues climbing beyond the
10 adjusted critical elevation zone (point **CR2** in Fig. 1) the engine's output would naturally drop (as represented by line segment **2-2'**).

At this event the low pressure supplemental turbocharger assembly **255** will kick-in, and wastegate **349** closes (controlled by TCU **320**), such that exhaust gases from turbine **260** now flow through lines **292** towards turbine **302** and through line **334**
15 into turbine **343**. At this situation the turbine **343** drives the compressor **345** to compress ambient air (through inlet **347**) and apply the compressed air through line **357** to the compressor **304** of the high pressure stage supplemental turbocharger **300** where it is further compressed and then delivered to the compressor **262** of the high pressure stage turbocharger assembly **252**. Thus, the high pressure stage turbocharger assembly **259**
20 then receives a constant input pressure, resembling the ambient pressure at CR, resulting in that a new adjusted critical elevation zone (point **CR3** in Fig. 1) is extended and the engine output remains substantially constant (represented by dotted line extending between points **2-3**). The amount of exhaust gases flowing through turbine **343** is governed by wastegate **349**, determining the amount of gas discharged to the
25 atmosphere through line **351**.