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(54) Title: REDUCED EGR TRANSPORT DELAY VIA VARIABLE SPEED SUPERCHARGER

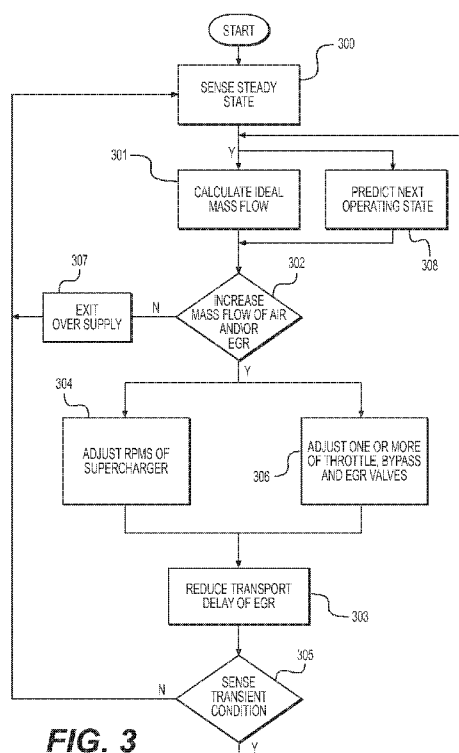


FIG. 3

(57) Abstract: A method of reducing transport delay in a combustion system comprises sensing and processing current operating conditions of a combustion system. An ideal mass-flow of recirculated exhaust gas for operating a combustion engine is calculated based on the sensed and processed current operating conditions. A next operating condition is predicted and an next-ideal mass-flow of recirculated exhaust gas is calculated for operating the combustion engine based on the predicted next operating condition. Transport delay reducing settings are determined and implemented for supplying recirculated exhaust gas according to the calculated next-ideal mass-flow. One or more of an exhaust gas recirculation valve and a throttle valve are controlled to maintain an ideal air to fuel ratio in the combustion engine for the current operating conditions. A supercharger can be driven for supplying recirculated exhaust gas. The supercharger is connected to transfer recirculated exhaust gas to the combustion engine.



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REDUCED EGR TRANSPORT DELAY VIA VARIABLE SPEED SUPERCHARGER

Field

[001] This application provides a system and method for tailoring the timing of the ratio of air to exhaust gas recirculation (EGR) provided to an engine.

Background

[002] Utilizing EGR (Exhaust Gas Recirculation) is a method for improving efficiency of the internal combustion engine. However, one of the key challenges is achieving the proper ratio of air and EGR going into the engine. At a continuous operating point (steady state) the ratio can be more easily controlled. But, during a transient condition (a change in engine speed or load), maintaining the ratio of air and EGR is difficult throughout the transient condition.

SUMMARY

[003] The disclosure overcomes the above disadvantages and improves the art by way of a method of operating a combustion system, comprising over-driving a supercharger during a steady state or transient operating condition to oversupply recirculated exhaust gas to the intake manifold. The supercharger is connected to transfer air and recirculated exhaust gas to an intake manifold of a combustion engine. Controlling one or more of a bypass valve, an exhaust gas recirculation valve, and a throttle valve maintains a predetermined air to fuel ratio in the combustion engine.

[004] A method of reducing transport delay in a combustion system comprises sensing and processing current operating conditions of a combustion system. An ideal mass-flow of recirculated exhaust gas for operating a combustion engine is calculated based on the sensed and processed current operating conditions. A next operating condition is predicted and an next-ideal mass-flow of recirculated exhaust gas is calculated for operating the combustion engine based on the predicted next operating condition. Transport delay reducing settings are determined and implemented for supplying recirculated exhaust gas according to the calculated next-ideal mass-flow. One or more of an exhaust gas recirculation valve and a throttle valve are controlled to maintain an ideal air to fuel ratio in the

combustion engine for the current operating conditions. A supercharger can be driven for supplying recirculated exhaust gas, the supercharger connected to transfer recirculated exhaust gas to the combustion engine.

[005] A method of operating a combustion system can comprise calculating an ideal mass-flow of intake air and recirculated exhaust gas for operating a combustion engine based on sensed and processed current operating conditions. Over-supply settings can be determined and implemented for over-supplying recirculated exhaust gas in excess of the calculated ideal mass-flow of intake air and recirculated exhaust gas. One or more of a bypass valve, an exhaust gas recirculation valve, and a throttle valve can be controlled to maintain an ideal air to fuel ratio in the combustion engine. A supercharger is over-driven to over-supply recirculated exhaust gas. The supercharger is connected to transfer recirculated exhaust gas to the combustion engine.

[006] A computer program product can comprise inputs, outputs, a storage device, algorithms stored on the storage device, and a processor for executing the algorithms stored on the storage device. The algorithms can comprise instructions for executing a method. The method can comprise receiving sensed current operating conditions of a combustion system and processing the received sensed current operating conditions. An ideal mass-flow of intake air and recirculated exhaust gas can be calculated for operating a combustion engine based on the current operating conditions. Over-supply settings can be determined for over-supplying recirculated exhaust gas in excess of the calculated ideal mass-flow of intake air and recirculated exhaust gas. An ideal air to fuel ratio for a combustion process in the combustion engine can be calculated. Adjustments to one or more of a bypass valve, an exhaust gas recirculation valve, and a throttle valve can be commanded to maintain the ideal air to fuel ratio in the combustion engine. An over-drive speed of a supercharger can be commanded to over-supply recirculated exhaust gas for a supercharger connected to transfer recirculated exhaust gas to the combustion engine.

[007] The computer program product can further comprise algorithms for calculating whether the current operating conditions indicate a transient operating condition or a steady state operating condition. The algorithms can result in issuing commands to over-supply recirculated exhaust gas in excess of the calculated ideal

mass-flow of intake air and recirculated exhaust gas to reduce a transport delay of recirculated exhaust gas when the combustion system transitions to new operating conditions.

[008] Additional objects and advantages will be set forth in part in the description which follows, and in part will be obvious from the description, or may be learned by practice of the disclosure. The objects and advantages will also be realized and attained by means of the elements and combinations particularly pointed out in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[009] Figures 1A & 1B are schematics of a variable drive supercharger in a combustion system.

[010] Figure 2 is a schematic for a computer program product linked to the combustion system.

[011] Figures 3 & 4 are flow diagrams for methods of reducing an EGR transport delay.

DETAILED DESCRIPTION

[012] Reference will now be made in detail to the examples 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. Directional references such as “left” and “right” are for ease of reference to the figures. Also, various fluids are present in combustion systems. Intake air can comprise air external to the combustion system, such as fresh air naturally aspirated or pumped in to the combustion system. Exhaust gas can comprise a variety of substances, including unburnt fuel, particulates, unused oxygen, among others. Exhaust gas is meant to comprise the matter exiting the combustion engine after the combustion process. “Air” in an air to fuel ratio (AFR) can comprise a combination of fluids, including recirculated exhaust gas and intake air. The “air” of the AFR controls the availability of matter, such as oxygen and nitrogen, for the combustion process. Fuel is mixed with the air for a stoichiometric or non-stoichiometric combustion process based on fuel type and operating conditions. For example, a gasoline combustion engine utilizes a stoichiometric AFR, and cannot deviate much from the stoichiometric amount. The gasoline combustion engine increases fuel and

air at factorials within a narrow range of the stoichiometric ratio in order to change torque output. A diesel combustion engine can also increase and decrease the mass flow at factorials, as done in the gasoline engine. However, the diesel engine can adjust the AFR for desired torque output within a larger range, capable of greater variations in the ratio of air to fuel. The diesel combustion engine can adjust air and fuel to select a torque output based on operating conditions, with an ideal ratio selected for optimal fuel use, optimal torque output, or minimal pollution, among other reasons.

[013] Exhaust gas recirculation (EGR) provides a way to ensure fuel is spent prior to releasing exhaust gases to the environment. A remainder of fuel can be present in exhaust gas. By recirculating the fuel remainder in to the combustion engine, the fuel remainder can be consumed. Or, certain particulates can be combusted via recirculation. Other reasons exist for utilizing EGR. So, it is beneficial to maximize recirculated exhaust gas to minimize negative environmental impacts of combustion.

[014] A transport delay can exist when the operating conditions change and the combustion system is not near the target combustion air to fuel ratio. So, a transport delay can be defined as a time to reach a target air to fuel ratio for combustion. The target can comprise an ideal quantity of recirculated exhaust gas for use in the combustion process. The target can also comprise an ideal quantity of fresh intake air mixed with the recirculated exhaust gas for use in the combustion process.

[015] Some combustion systems are optimized for in-the-moment operating conditions. The mass flow is tailored for the current condition. Then, when the conditions change, the mass flow is inappropriate for the next condition until the system can catch up to the next condition. In this disclosure, the next condition is predicted, and the mass flow is adjusted prior to reaching that next condition, so there is little or no transport delay to have the proper air to fuel ratio for the next condition. This can be accomplished by over-supplying or under-supplying the recirculated exhaust gas.

[016] Turning to Figure 1A, a variable drive supercharger can reduce the transport delay of recirculated exhaust gas by controlling a variable drive device 203 to adjust the speed of a supercharger 201 to over-supply recirculated exhaust gas

during steady state or transient operating conditions. Affiliated control mechanisms, such as actuators 62, 66, 67 can control positions of a bypass valve 35, EGR valve 45, and, when included, a throttle valve 55. The intent is to flow more intake air and recirculated exhaust gas through the supercharger 201 to reduce the time it takes to get the desired percentage of recirculated exhaust gas in the intake manifold 103 of the combustion engine 101.

[017] In order to increase the mass flow of intake air and recirculated exhaust gas during a steady state condition, where the proper ratio of intake air and exhaust gas going into the engine is easier to control, the supercharger 201 is driven at a higher speed than is required for maintaining an ideal ratio. That is, the supercharger is over-driven. The over-driving can be done during steady state operating conditions, such as a cruise mode where engine speed and load is not fluctuating significantly. Increasing recirculated exhaust gas during steady state lessens the transport delay during a transient condition. And, the over-driving can be done during transient operating conditions, such as when the engine load is changing or such as when the engine speed is changing.

[018] As shown in Figure 1A, a combustion system can comprise an engine 101. Four cylinders 1-4 are shown, though other numbers of cylinders, such as 3, 6, or 8, can be used. Cam or camless valve actuation, fuel injection, and piston reciprocation are omitted from the Figure, but are examples of customary mechanisms for implementing the combustion process. One or more engine sensors 68 can be included to sense engine operating conditions, such as torque output, crankshaft speed in rotations per minute (RPM), temperature, among others. A load sensor 69 can be affiliated with the engine 101, in this example linked to the crankshaft 107 and hub 109, to sense conditions such as low load, high load, idle, loaded idle, among others. The load sensor can be linked to an auxiliary switch such as a lifter, an acceleration pedal, steering inputs, traction sensors, wheel slip sensors, a grade sensor, a GPS or other terrain sensor, among others, to further indicate present or anticipated load.

[019] An intake manifold 103 is connected to an intake side of the engine, and an exhaust manifold 105 is connected to the exhaust side of the engine 101. One or more sensors 64, 65 can be included in the manifolds 103, 105 to sense one or more of mass flow, AFR, temperature, pollution, among others. Intake manifold

103 is a compartment for collecting air for the cylinders 1-4 for combustion. When intake valves of the cylinders 1-4 are open, air from the intake manifold 103 is drawn or boosted in to the cylinders. Exhaust manifold 105 can connect to exhaust ducting 43. Downstream devices such as catalysts, mufflers, and fuel dosers, among others, can be connected to exhaust ducting 43. An exhaust gas recirculation passage 40 is connected to the exhaust ducting 43. An optional cooler 41 is included in the EGR passage 40. An EGR valve 45, such as a butterfly valve or one-way valve, can be controlled by an actuator 66 to control the open or close percentage (0%-100%) of the EGR valve 45. The EGR valve 45 is connected between the intake passage 70 and the exhaust passage 40 to regulate flow of recirculated exhaust gas in to the intake passage 70.

[020] The intake passage 70 can comprise an air conditioner 80, such as a filter or cooler. One or more sensor 61 can be included to sense oxygen content, flow rate, pressure, or temperature, among other aspects, of the intake air. The intake passage can also comprise a throttle valve 55, sometimes called a throttle body. An actuator 62 can control the open or close percentage (0%-100%) of the throttle valve 55. The throttle valve can be used in the intake passage 70 to regulate intake air flow in to the intake passage.

[021] A bypass passage 30 can be connected to the intake manifold 103 and to the intake passage 70. A bypass valve 35 can be connected to an actuator 67 to control the bypass of fluids around the supercharger 201. When too much mass flow is supplied to the intake manifold 103, the bypass valve 35 can be opened to release intake air and recirculated exhaust gas back to the intake passage 70. So, excess recirculated exhaust gas can be supplied to the engine 101 via the intake manifold. The recirculated exhaust gas can be supplied with intake air. The mixture forms the "air" portion of the air to fuel ratio. The mass flow can be higher than ideal, presenting too much intake air and recirculated exhaust gas to the cylinders 1-4. By controlling the bypass valve 35, the mass flow can be reduced to bring the quantity of intake air and recirculated exhaust gas down to the appropriate amount to satisfy the air to fuel ratio for the operating conditions. Or, the bypass valve 35 can be shut to permit intake air and recirculated exhaust gas to compress or otherwise be isolated for use by engine 101. The actuator 67 can control the open or close percentage (0-100%) of the bypass valve 35.

[022] The variable drive device 203 of Figure 1A powers the supercharger 201 to boost recirculated exhaust gas and intake air to the engine 101. The variable drive device is shown with a drive shaft 207 coupled to the engine crankshaft 107 via a pulley mechanism 90 linked to hubs 109, 209, but other variable drive mechanisms, such as electric motor, mechanical type toroid, belt, chain, planetary, or cone transmissions can be used as the variable drive mechanism 203. The variable drive device 203 is linked to an input shaft 205 of the supercharger 201. The variable drive device can comprise a computer-controlled actuator 63 for precise control. The actuator 63 can comprise a sensor for feedback or feedforward processing.

[023] Supercharger 201 can be a positive displacement pump and can comprise any one of a variety of boosting devices, such as blowers and compressors. Supercharger 201 can be any one of a Roots-type blower, a twin-screw device, a twin-vortices system (TVS superchargers for internal combustion engines, namely, vehicle superchargers, roots-type blower superchargers, lobed rotor blower superchargers; vehicle parts, namely, positive displacement pumps manufactured by Eaton Corporation of Cleveland Ohio), among others. Other superchargers can comprise turbine-powered turbochargers such as scroll or nautilus compressors.

[024] The over-drive condition can be used to supply more recirculated exhaust gas than is necessary for the operating conditions during steady state. This can result in the correct amount of recirculated exhaust gas being available during a transient state for preferential use of exhaust gas for re-combustion. The over-supply of recirculated exhaust gas during one operating condition means that there is less or no transport delay during another operating condition. So, if too much recirculated exhaust gas is in the intake manifold 103 during one operating condition, then when the engine transitions to another operating condition that can consume more exhaust gas, the recirculated exhaust gas is ready to be used. As another example, the combustion system can iteratively over-supply recirculated exhaust gas during an acceleration, which is a transient condition, so that when a cruise mode is entered, there is no delay in using recirculated exhaust gas optimally. And, the recirculated exhaust gas is used throughout the transient mode. Excess recirculated exhaust gas is bypassed.

[025] Put another way, a current operating condition could benefit from using a current quantity of recirculated exhaust gas Q_R . The next operating condition could benefit from using a predicted quantity of recirculated exhaust gas Q_P . The predicted quantity is greater than the current quantity in this example, so

$$Q_P > Q_R \quad \text{equation 1.}$$

The variable speed supercharger is driven to oversupply exhaust gas and supplies a mass flow of fluid to the engine 101 by way of the intake manifold 103 according to the predicted quantity of recirculated exhaust gas Q_P . Then, the bypass valve 35 is controlled to reduce the mass flow down to the current quantity of recirculated exhaust gas Q_R . An amount of bypass recirculated exhaust gas Q_B is bypassed via the bypass valve 35.

$$Q_P - Q_R = Q_B \quad \text{equation 2.}$$

When the next operating condition is experienced, the bypass valve 35 can be adjusted, and the correct quantity of recirculated exhaust gas is readily available in the intake manifold 103. The engine 101 receives the correct amount of recirculated exhaust gas for the operating conditions.

[026] Controlling the EGR valve 45, throttle body or throttle valve 55, and bypass valve 35 adjusts the intake air-to-recirculated exhaust gas ratio for the operating conditions so that the air to fuel ratio is maintained for proper combustion. By drawing more recirculated exhaust gas during one operating condition, there is a reduced transport delay of recirculated exhaust gas fluid during another operating condition. The over-driving of the supercharger leads to less time to get the desired recirculated exhaust gas to air ratio in to the intake manifold 103 during transient operating conditions. The engine 101 can combust fuel efficiently while the combustion system benefits from recirculated exhaust gas.

[027] The EGR valve, throttle body or throttle valve, and bypass valve can be adjusted during the transient state operating conditions to adjust the intake air to recirculated exhaust gas ratio so that the air to fuel ratio is maintained for proper combustion. The overdriving during steady state leads to a faster response time during transient state to bring the intake air to recirculated exhaust gas ratio to the ideal ratio. That is, with the recirculated exhaust gas already flowing at a high rate during one operating condition, it is readily available for another operating condition. There is less or no delay waiting for the recirculated exhaust gas to be ready for

use. The valves 35, 45, 55 can be adjusted to the new operating condition, new mass flow, or new air to fuel ratio, without waiting for the EGR technique to initialize. In the prior art, the EGR technique is not used until the moment it can be used, resulting in a transport delay, where no recirculated exhaust gas is available until the system initializes. In the present application, the recirculated exhaust gas is readily available with less or no wait for the exhaust gas recirculation aspect of the combustion system to initialize.

[028] In Figure 1B, an alternative combustion system 400 places a reversible supercharger 204 in exhaust passage 40. A cooler can be placed before or after the supercharger 204. In this layout, the supercharger 204 can be run in an oversupply mode to supply the predicted quantity of recirculated exhaust gas Q_P instead of the current quantity of recirculated exhaust gas Q_R . Throttle valve 55 can be adjusted to mix intake air for formulating the desired air to fuel ratio. The engine 101 can naturally aspirate the intake air or a mixture of intake air and recirculated exhaust gas, or there can be other boosting devices present. For example, a turbocharger or other supercharger can be present to boost the intake air.

[029] In oversupply mode, supercharger 204 runs similarly to the above examples set forth in equations 1 & 2. The variable speed supercharger is driven to oversupply exhaust gas and supplies a mass flow of fluid to the engine 101 by way of the intake manifold 103 according to the predicted quantity of recirculated exhaust gas Q_P . The bypass passage 30 is moved to bypass the excess recirculated exhaust gas around the supercharger 204. The bypass valve 35 is controlled to reduce the mass flow down to the current quantity of recirculated exhaust gas Q_R . An amount of bypass recirculated exhaust gas Q_B is bypassed via the bypass valve 35 according to equation 2. When the next operating condition is experienced, the bypass valve 35 can be adjusted, and the correct quantity of recirculated exhaust gas is readily available for use in the combustion engine. By driving the supercharger 204 in oversupply mode, the recirculated exhaust gas is flowing at the correct rate for the next condition. But, the engine 101 receives the correct amount of recirculated exhaust gas for the operating conditions.

[030] The bypass passage 30 is optional.

[031] The supercharger 204 is reversible and controlled by variable speed device 203. The speed of the variable speed device 203 can be controlled to

increase or decrease the speed of the driveshaft 205. When the current quantity of recirculated exhaust gas Q_R is greater than needed for the next operating condition, the supercharger 204 can be slowed or reversed to under-supply recirculated exhaust gas.

$$Q_P < Q_R \quad \text{equation 3.}$$

[032] The variable speed supercharger is driven to undersupply exhaust gas, but can still supply a mass flow of fluid to the engine 101 by way of the intake manifold 103. The supercharger 204 can be slowed or reversed to bring the amount of recirculated exhaust gas down to the predicted quantity of recirculated exhaust gas Q_P . There is little, preferably no, transport delay when the next operating condition is experienced because the predicted target air to fuel ratio is already present.

[033] Using the optional bypass passage 30, the bypass valve 35 can be controlled to permit leakage of exhaust gas back to the manifold 103 during the current operating conditions, yet the bypass valve 35 can be quickly closed, or reduced in opening percentage when the predicted next operating condition is reached. The variable drive supercharger is driven at the ideal rate for the predicted next operating condition, so the target air to fuel ratio is reached with less delay. The leakage scenario can result in an amount of bypass recirculated exhaust gas Q_B being bypassed via the bypass valve 35.

$$Q_R - Q_P = Q_B \quad \text{equation 4.}$$

[034] Sensors 61, 63, 64, 65, 68, 69 are distributed in the system to sense such conditions as flow rate, temperature, oxygen content, fuel content, exhaust waste content, engine speed, variable drive speed, boost pressure, etc. Actuators 62, 63, 66, 67 can be affiliated with the sensors to adjust conditions, such as variable drive speed, valve open or close percentage (0-100%), flow rate, boost pressure, etc. Other actuators can also be included, such as fuel injectors, intake and exhaust valve actuators, auxiliary device actuators, among others.

[035] Computer control, such as an electronic control unit (ECU) 1000 can control the actuators based on sensed conditions to maintain predetermined combustion conditions. The computer control (ECU 1000) can include at a minimum a CAN (control area network), a processor 3000, memory device 2000, and

calculation algorithms 2020 stored in the memory device. The algorithms can, when executed by the processor, implement the methods disclosed herein.

[036] A signal circuit BUS can collect data signals from the sensors and actuators 61-69 to collect real-time operating conditions for the combustion system. Additional equipment, such as a global positioning satellite (GPS) transceiver can transmit grade, terrain, acceleration or other such information. The collected data can be stored in a sensor data storage location 2010 of the memory 2000. Additional predetermined data, such as look-up tables (LUTs) can be stored in the memory 2000 for correlating sensed data to factors or further algorithms. The further algorithms can be stored in a calculation algorithms storage location 2020. The stored data and algorithms can be accessed by the processor 3000. The processor 3000 can process the collected and predetermined data together with the stored algorithms. For example, a condition calculator 3010 can determine if the combustion system is in a steady state or transient operating condition, and can further determine if the engine is in a loaded or unloaded operating condition.

[037] The determined condition can be forwarded to an ideal AFR and mass flow calculator 3020. Based on the determined condition, the engine 101 can optimally combust fuel at a particular air to fuel ratio, as discussed above. The ideal AFR can be determined for the operating condition. And, the ideal, non-bypassed mass flow can also be determined for the operating condition. The ideal AFR results in the desired torque output. The ideal mass flow supplies that AFR without bypass valve use.

[038] However, the instant disclosure seeks to over-supply or under-supply recirculated exhaust gas to optimize its use. So, a transport delay prediction calculator 3030 is implemented to determine how much additional recirculated exhaust gas can be supplied during the present operating condition, or how much recirculated exhaust gas can be removed, so that adequate recirculated exhaust gas is available for use based on the next operating condition. So, the transport delay prediction calculator 3030 knows the presently desired amount of recirculated exhaust gas from the ideal AFR and mass flow calculator 3020. The transport delay prediction calculator 3030 calculates how much additional recirculated exhaust gas can be added or how much can be removed to meet a next operating condition so that enough exhaust gas is ready for the next operating condition. However, the

present situation still requires the correct air to fuel ratio, so the transport delay prediction calculator also calculates how much intake air to add or remove, and how much faster or slower to drive the supercharger 201 or 204 via variable drive device 203 so that the air to fuel ratio is correct for the current operating condition.

Increasing the mass flow too much dilutes the fuel too much, so the bypass valve 35 of Figure 1A can be opened to drain excess mass flow and bring the quantity of air down. So, a bypass valve 35 setting is selected to release the excess mass flow so that ultimately, the cylinders 1-4 receive the correct air for the fuel. Or, another boosting device can be added, as described in Figure 1B, to bring the quantity of intake air up.

[039] The transport delay prediction calculator 3030 determines how much intake air and recirculated exhaust gas can be increased or decreased to meet an anticipated next operating condition.

[040] A controller area network (CAN) can interface with actuators 35, 45, 55, 203, among others, to implement the settings calculated by the processor 3000.

[041] A single processor 3000 is shown with three calculators 3010, 3020, 3030. However, distributed processing is possible with more or fewer subroutines. Likewise, the memory device 2000 can comprise additional hardware or data compartments. Memory device 2000 can comprise RAM, ROM, ePROM, among other hardware. Like the processor 3000, the memory device can be centralized as shown in electronic control unit 1000. Or, the processor and memory can be distributed around the combustion system so that storage and processing is networked. For example, data and algorithm storage can be at each actuatable device (bypass valve 35, variable drive device 203, EGR valve 45, actuators 62, 66, 67, etc.), so that processing for that device is done at that device, with processing results shared among the networked components.

[042] A computer program product can comprise the ECU 1000, thereby having inputs for receiving data via a BUS or CAN or other connector, outputs such as CAN connectors or other transmitters, a storage device such as memory 2000, algorithms stored on the storage device, and a processor such as processor 3000 for executing the algorithms stored on the storage device. The algorithms can comprise instructions for executing one or more methods. The methods can comprise receiving sensed current operating conditions of a combustion system and

processing the received sensed current operating conditions. An ideal mass-flow of intake air and recirculated exhaust gas can be calculated for operating a combustion engine based on the current operating conditions. Over-supply settings can be determined for over-supplying recirculated exhaust gas in excess of the calculated ideal mass-flow of intake air and recirculated exhaust gas. An ideal air to fuel ratio for a combustion process in the combustion engine can be calculated. Adjustments to one or more of a bypass valve, an exhaust gas recirculation valve, and a throttle valve can be commanded to maintain the ideal air to fuel ratio in the combustion engine. An over-drive speed of a supercharger can be commanded to over-supply recirculated exhaust gas for a supercharger connected to transfer recirculated exhaust gas to the combustion engine.

[043] The computer program product can further comprise algorithms for calculating whether the current operating conditions indicate a transient operating condition or a steady state operating condition. The algorithms can result in issuing commands to over-supply recirculated exhaust gas in excess of the calculated ideal mass-flow of intake air and recirculated exhaust gas to reduce a transport delay of recirculated exhaust gas when the combustion system transitions to new operating conditions.

[044] Figure 3 outlines a processor-executable method that can be stored on a computer program product. Step 300 comprises sensing a steady state. This can comprise sensing other aspects, such as load on the engine or engine speed. Step 301 calculates an ideal mass flow for the current operating conditions. In parallel, a next operating state is predicted in step 308. The next operating condition can be predicted based on a variety of inputs, as above, to include one or more of a grade sensor, wheel slip sensor, terrain sensor, traction sensor, steering wheel input, accelerator pedal position, among others. For example, a grade sensor or GPS device can indicate that a hill climb is imminent, so it can be predicted that the load on the engine will increase to ascent the imminent hill. As another example, a terrain sensor can be coupled with a traction sensor to determine that a wheel slip due to sand has occurred, and the engine speed should be adjusted for the wheel slip.

[045] A determination step 302 determines whether or how much to increase the mass flow of intake air and/or recirculated exhaust gas. If steady state

is to be maintained, as by a sensed cruise mode, then there is no need to oversupply recirculated exhaust gas. The method can loop back to step 300 by way of step 307.

[046] If changes to the mass flow are needed, because a grade change or other terrain change is imminent, the method progresses to step 304 to adjust the rotations per minute (RPMs) of the supercharger, as by controlling the variable drive device 203. Also, in step 306, one or more of the throttle valve 55, bypass valve 35 and EGR valve 45 are adjusted. The result is a reduced transport delay of recirculated exhaust gas in step 303.

[047] A decision step 305 determines if a transient condition is sensed, such as continued grade or terrain changes, accelerator pedal depression, auxiliary switch activation, among others. The transient condition can result in a change in engine speed or engine load or both. If a transient condition is sensed, the method loops back to step 301 to determine how much recirculated exhaust gas can be stacked on top of the ideal quantity of recirculated exhaust gas in anticipation of increased recirculated exhaust gas use. If a transient condition is not sensed, the current settings can be maintained by looping back to step 300. Or, the over-supply condition can be exited by proceeding to step 307, as by discontinuing over-supplying recirculated exhaust gas and as by driving the supercharger 201 at an ideal speed instead of in an over-drive speed.

[048] Figure 4 outlines an alternative processor-executable method that can be stored on a computer program product. This method is similar to the method of Figure 3, and redundancies are not repeated. The method of Figure 4 decreases the mass flow of recirculated exhaust gas in step 402 after the ideal mass flow is calculated in step 301 and after a next operating state is predicted in step 308. With the bypass valve 35 omitted in this example, the throttle valve 55 and the EGR valve 45 can be adjusted in step 406 in parallel with adjusting the RPMs of the supercharger in step 304. If a transient condition is not sensed and the steady state is determined to benefit from optimal direct supply of recirculated exhaust gas, then the undersupply condition can be exited, as in step 407.

[049] Other implementations will be apparent to those skilled in the art from consideration of the specification and practice of the examples disclosed herein.

WHAT IS CLAIMED IS:

1. A method of reducing transport delay in a combustion system, comprising:
sensing and processing current operating conditions of a combustion system;
calculating an ideal mass-flow of recirculated exhaust gas for operating a
combustion engine based on the sensed and processed current operating
conditions;
predicting a next operating condition and calculating an next-ideal mass-flow
of recirculated exhaust gas for operating the combustion engine based on
the predicted next operating condition;
determining and implementing transport delay reducing settings for supplying
recirculated exhaust gas according to the calculated next-ideal mass-flow;
and
controlling one or more of an exhaust gas recirculation valve and a throttle
valve to maintain an ideal air to fuel ratio in the combustion engine for the
current operating conditions,
wherein the implementing comprises driving a supercharger for supplying
recirculated exhaust gas, the supercharger connected to transfer
recirculated exhaust gas to the combustion engine.
2. The method of claim 1, further comprising calculating an ideal mass-flow of
intake air for operating a combustion engine based on the sensed and processed
current operating conditions; and determining and implementing transport delay
reducing settings for supplying the intake air according to the calculated next-ideal
mass-flow, wherein the implementing comprises driving a supercharger for
supplying the intake air, the supercharger connected to transfer the intake air to the
combustion engine.
3. The method of claim 1 or 2, further comprising controlling a bypass valve to
maintain an ideal air to fuel ratio in the combustion engine.
4. The method of claim 3, wherein the bypass valve is connected between an
intake passage and an intake manifold to bypass the fluids around the
supercharger.
5. The method of claim 4, wherein the exhaust gas recirculation valve is
connected to regulate flow of recirculated exhaust gas in to the intake passage, and

the exhaust valve is connected in an exhaust passage between the intake passage and exhaust ducting connected to the combustion engine.

6. The method of claim 5, wherein the throttle valve is in the intake passage to regulate intake air flow in to the intake passage.

7. The method of claim 1, wherein the current operating conditions comprise one of a steady state operating condition or a transient operating condition.

8. The method of claim 1, wherein the implementing further comprises over-driving the supercharger to supply excess intake air to the combustion engine.

9. The method of claim 1, wherein the current operating conditions comprise a transition from a steady state operating condition to a transient state operating condition.

10. The method of claim 1 or 8, wherein over-driving the supercharger comprises increasing the rotations per minute of a drive shaft of the supercharger.

11. The method of claim 10, wherein increasing the rotations per minute of a drive shaft of the supercharger comprises controlling a variable drive device.

12. The method of claim 11, wherein the variable drive device is connected to a crankshaft of the combustion engine to couple torque output from the combustion engine to the drive shaft of the supercharger.

13. The method of claim 7 or 8, wherein the transient state operating condition is a condition wherein one of an engine operation speed of the combustion engine changes or a load on the combustion engine changes.

14. The method of claim 1, wherein determining and implementing transport delay reducing settings for supplying recirculated exhaust gas according to the calculated next-ideal mass-flow comprises determining and implementing over-supply settings for over-supplying recirculated exhaust gas in excess of the calculated ideal mass-flow of recirculated exhaust gas.

15. The method of claim 1, wherein determining and implementing transport delay reducing settings for supplying recirculated exhaust gas according to the calculated next-ideal mass-flow comprises determining and implementing under-supply settings for under-supplying recirculated exhaust gas for the current operating conditions.

16. The method of claim 15, wherein implementing the driving of a supercharger for supplying recirculated exhaust gas comprises driving a supercharger that is

further connected to transfer recirculated exhaust gas from an intake manifold of the combustion engine to an exhaust passage of the combustion system.

17. The method of claim 1, wherein the supercharger is further connected to run in reverse to transfer recirculated exhaust gas from an intake manifold of the combustion engine to an exhaust passage of the combustion system, and wherein determining and implementing transport delay reducing settings for supplying recirculated exhaust gas according to the calculated next-ideal mass-flow comprises selecting between driving the supercharger to over-supply recirculated exhaust gas to the intake manifold and driving the supercharger in reverse to under-supply recirculated exhaust gas to the intake manifold.

18. A computer program product comprising inputs, outputs, a storage device, algorithms stored on the storage device, and a processor for executing the algorithms stored on the storage device, the algorithms comprising instructions for executing a method comprising the steps of:

- receiving sensed current operating conditions of a combustion system;
- processing the received sensed current operating conditions;
- calculating an ideal mass-flow of intake air and recirculated exhaust gas for operating a combustion engine based on the current operating conditions;
- determining over-supply settings for over-supplying recirculated exhaust gas in excess of the calculated ideal mass-flow of intake air and recirculated exhaust gas;
- calculating an ideal air to fuel ratio for a combustion process in the combustion engine;
- commanding adjustments to one or more of a bypass valve, an exhaust gas recirculation valve, and a throttle valve to maintain the ideal air to fuel ratio in the combustion engine; and
- commanding an over-drive speed of a supercharger to over-supply recirculated exhaust gas for a supercharger connected to transfer recirculated exhaust gas to the combustion engine.

19. The computer program product of claim 18, wherein the algorithms further comprise instructions for executing a method comprising the steps of:

- calculating whether the current operating conditions indicate a transient operating condition or a steady state operating condition; and

issuing commands to over-supply recirculated exhaust gas in excess of the calculated ideal mass-flow of intake air and recirculated exhaust gas to reduce a transport delay of recirculated exhaust gas when the combustion system transitions to new operating conditions.

20. A method of operating a combustion system, comprising:
sensing and processing current operating conditions of a combustion system;
calculating an ideal mass-flow of intake air and recirculated exhaust gas for operating a combustion engine based on the sensed and processed current operating conditions;
determining and implementing over-supply settings for over-supplying recirculated exhaust gas in excess of the calculated ideal mass-flow of intake air and recirculated exhaust gas; and
controlling one or more of a bypass valve, an exhaust gas recirculation valve, and a throttle valve to maintain an ideal air to fuel ratio in the combustion engine,
wherein the implementing comprises over-driving a supercharger to over-supply recirculated exhaust gas, the supercharger connected to transfer recirculated exhaust gas to the combustion engine.
21. The method of claim 20, wherein the current operating conditions comprise one of a steady state operating condition or a transient operating condition.
22. The method of claim 20, wherein the implementing further comprises over-driving the supercharger to supply excess intake air to the combustion engine.
23. The method of claim 20, wherein the bypass valve is connected between an intake passage and an intake manifold to bypass the fluids around the supercharger.
24. The method of claim 23, wherein the exhaust gas recirculation valve is connected between the intake passage and an exhaust passage connected to the combustion engine to regulate flow of recirculated exhaust gas in to the intake passage.
25. The method of claim 23 or 24, wherein the throttle valve is in the intake passage to regulate air flow in to the intake passage.

26. The method of claim 20, wherein the current operating conditions comprise a transition from a steady state operating condition to a transient state operating condition.
27. The method of claim 20 or 26, wherein over-driving the supercharger comprises increasing the rotations per minute of a drive shaft of the supercharger.
28. The method of claim 27, wherein increasing the rotations per minute of a drive shaft of the supercharger comprises controlling a variable drive device.
29. The method of claim 28, wherein the variable drive device is connected to a crankshaft of the combustion engine to couple torque output from the combustion engine to the drive shaft of the supercharger.
30. The method of claim 21 or 26, wherein the transient state operating condition is a condition wherein one of an engine operation speed of the combustion engine changes or a load on the combustion engine changes.
31. The method of claim 20, wherein determining and implementing over-supply settings for over-supplying recirculated exhaust gas in excess of the calculated ideal mass-flow of intake air and recirculated exhaust gas comprises anticipating a next ideal mass-flow of intake air and recirculated exhaust gas for operating a combustion engine based on predicted operating conditions.
32. The method of claim 20, wherein determining and implementing over-supply settings for over-supplying recirculated exhaust gas in excess of the calculated ideal mass-flow of intake air and recirculated exhaust gas reduces a transport delay of recirculated exhaust gas when the combustion system transitions to new operating conditions.
33. A computer program product comprising inputs, outputs, a storage device, algorithms stored on the storage device, and a processor for executing the algorithms stored on the storage device, the algorithms comprising instructions for executing a method comprising the steps of:
- receiving sensed current operating conditions of a combustion system;
 - processing the received sensed current operating conditions;
 - calculating an ideal mass-flow of intake air and recirculated exhaust gas for operating a combustion engine based on the current operating conditions;

- predicting a next operating condition and calculating an next-ideal mass-flow of recirculated exhaust gas for operating the combustion engine based on the predicted next operating condition;
- determining and implementing transport delay reducing settings for supplying recirculated exhaust gas according to the calculated next-ideal mass-flow;
- calculating an ideal air to fuel ratio for a combustion process in the combustion engine;
- commanding adjustments to one or more of an exhaust gas recirculation valve and a throttle valve to maintain the ideal air to fuel ratio in the combustion engine; and
- commanding a forward or reverse drive speed of a supercharger to supply the next-ideal mass-flow of recirculated exhaust gas, the supercharger connected to transfer recirculated exhaust gas between the combustion engine and exhaust ducting.
34. The computer program product of claim 33, wherein the algorithms further comprise instructions for executing a method comprising the steps of:
- calculating whether the current operating conditions indicate a transient operating condition or a steady state operating condition; and
- issuing commands to over-supply recirculated exhaust gas in excess of the calculated ideal mass-flow of intake air and recirculated exhaust gas to reduce a transport delay of recirculated exhaust gas when the combustion system transitions to new operating conditions.
35. The computer program product of claim 33, wherein the algorithms further comprise instructions for executing a method comprising the steps of:
- calculating whether the current operating conditions indicate a transient operating condition or a steady state operating condition; and
- issuing commands to under-supply recirculated exhaust gas in in a quantity that is less than the calculated ideal mass-flow of intake air and recirculated exhaust gas to reduce a transport delay of recirculated exhaust gas when the combustion system transitions to new operating conditions.

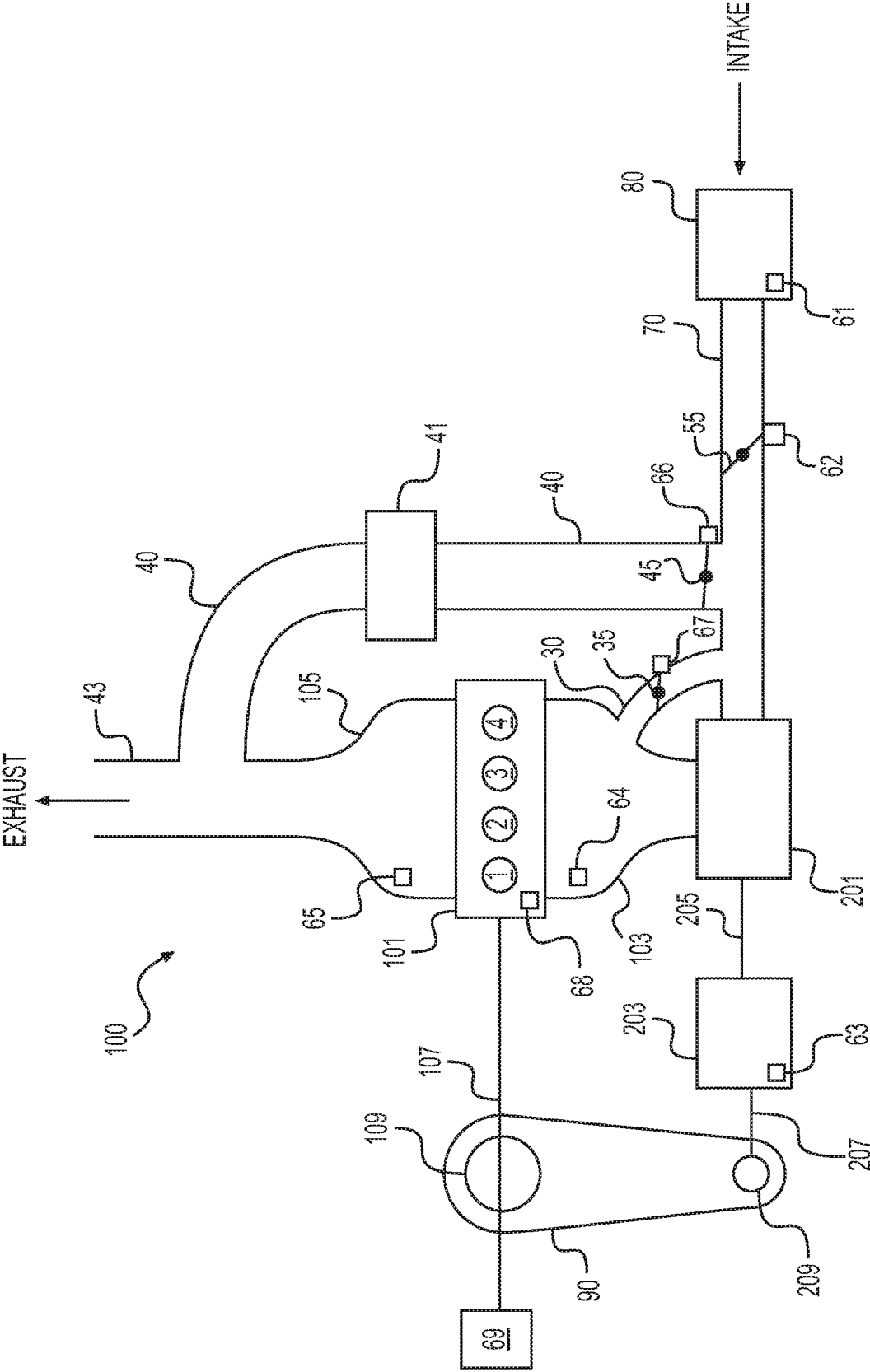


FIG. 1A

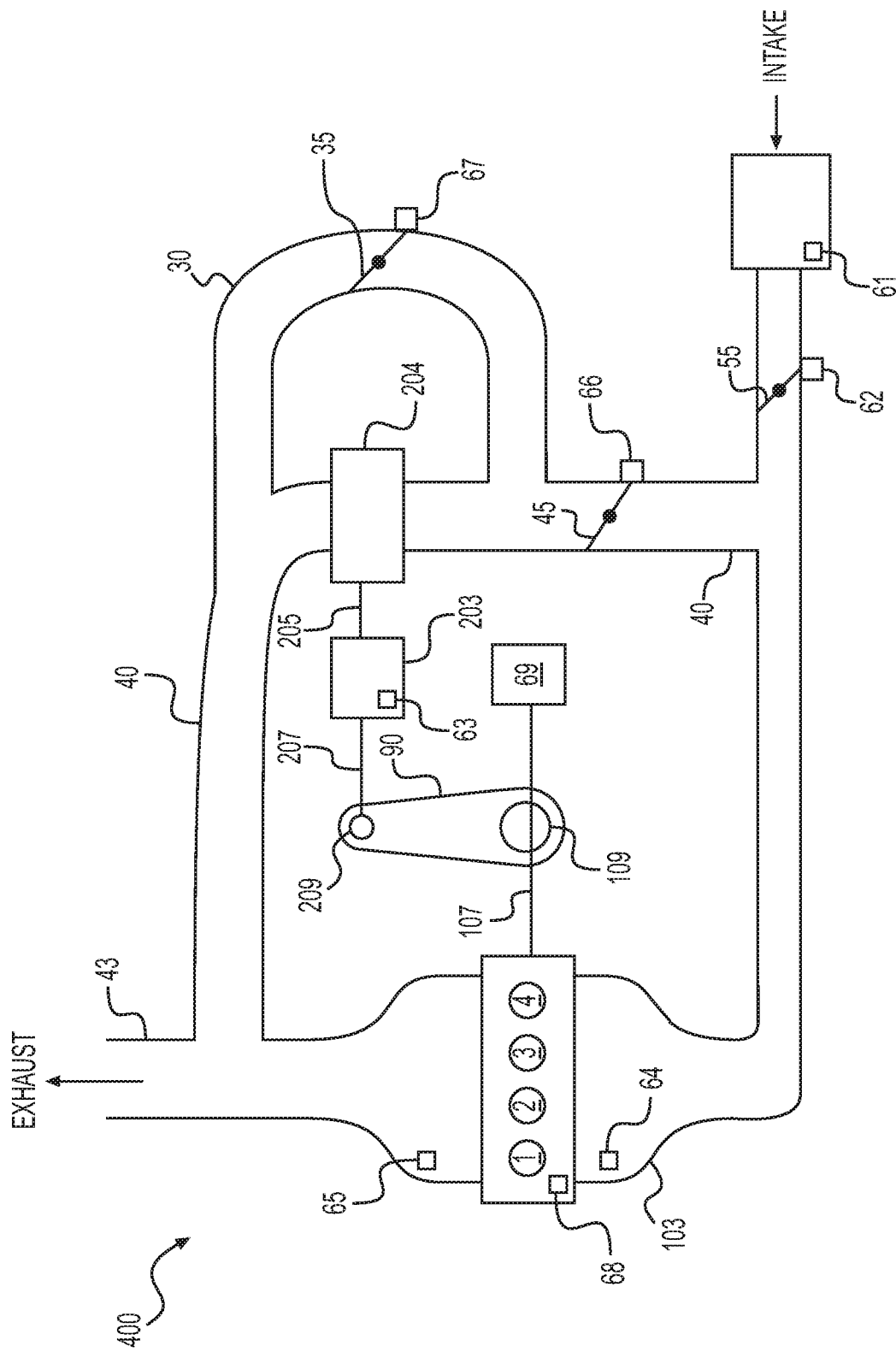


FIG. 1B

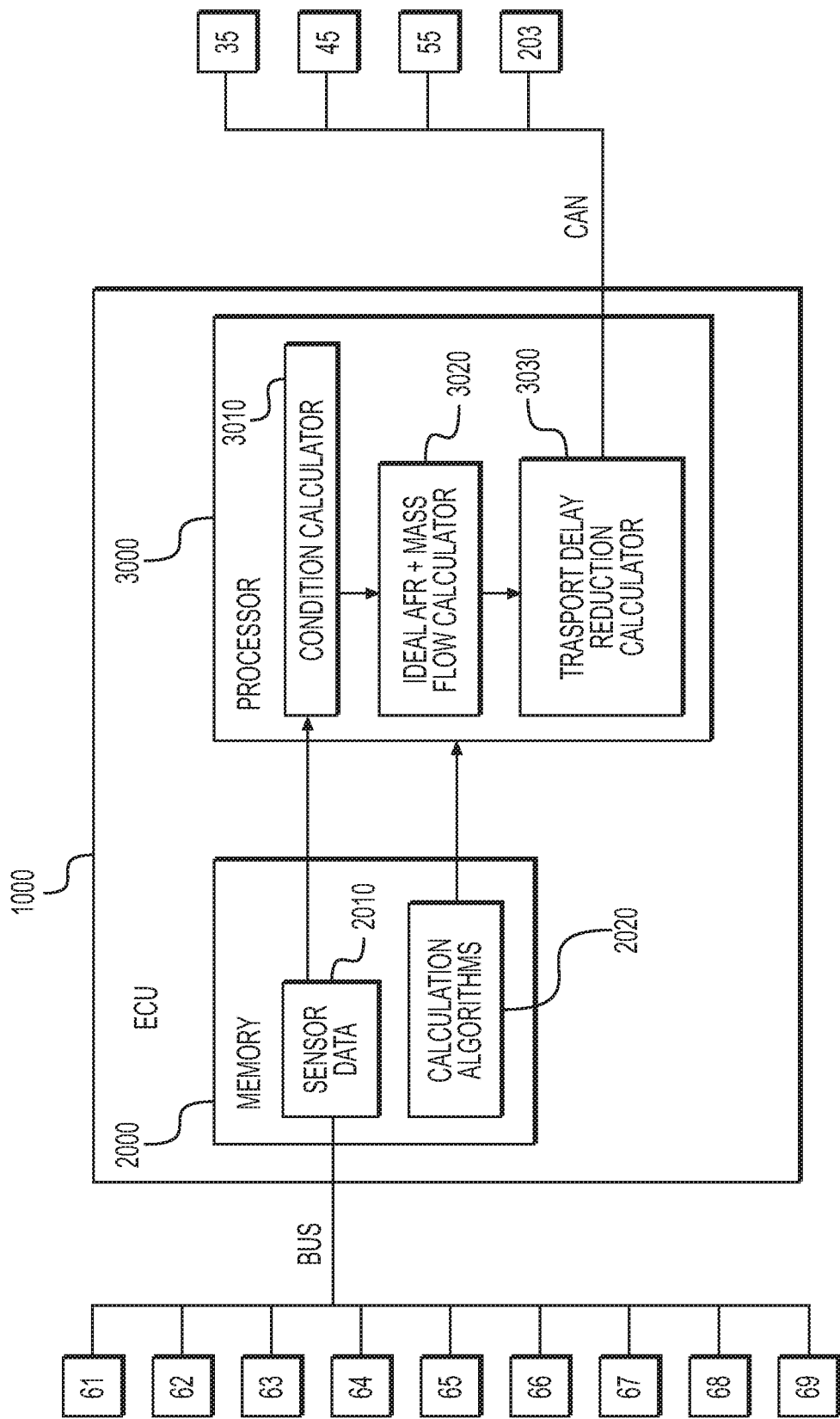
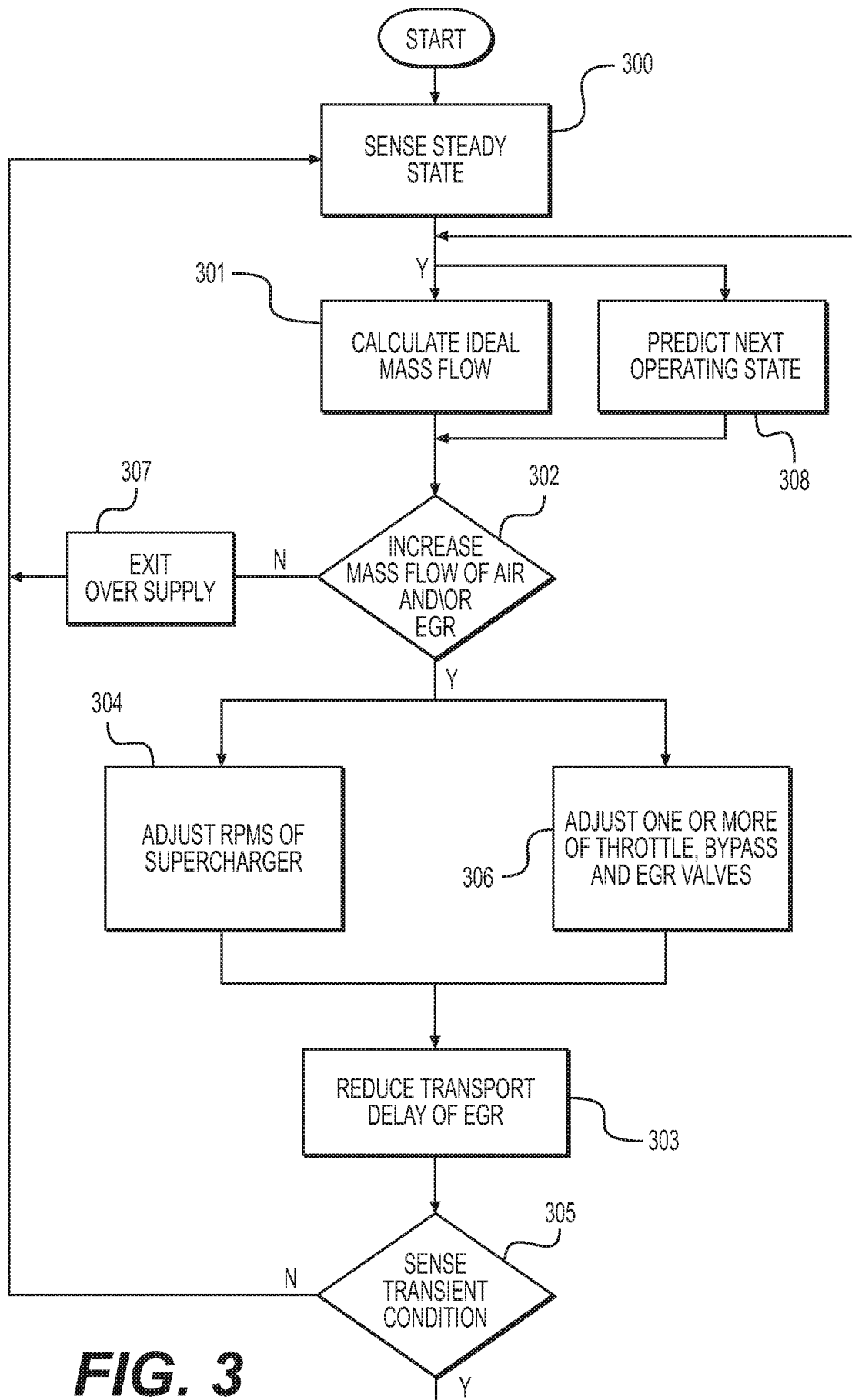
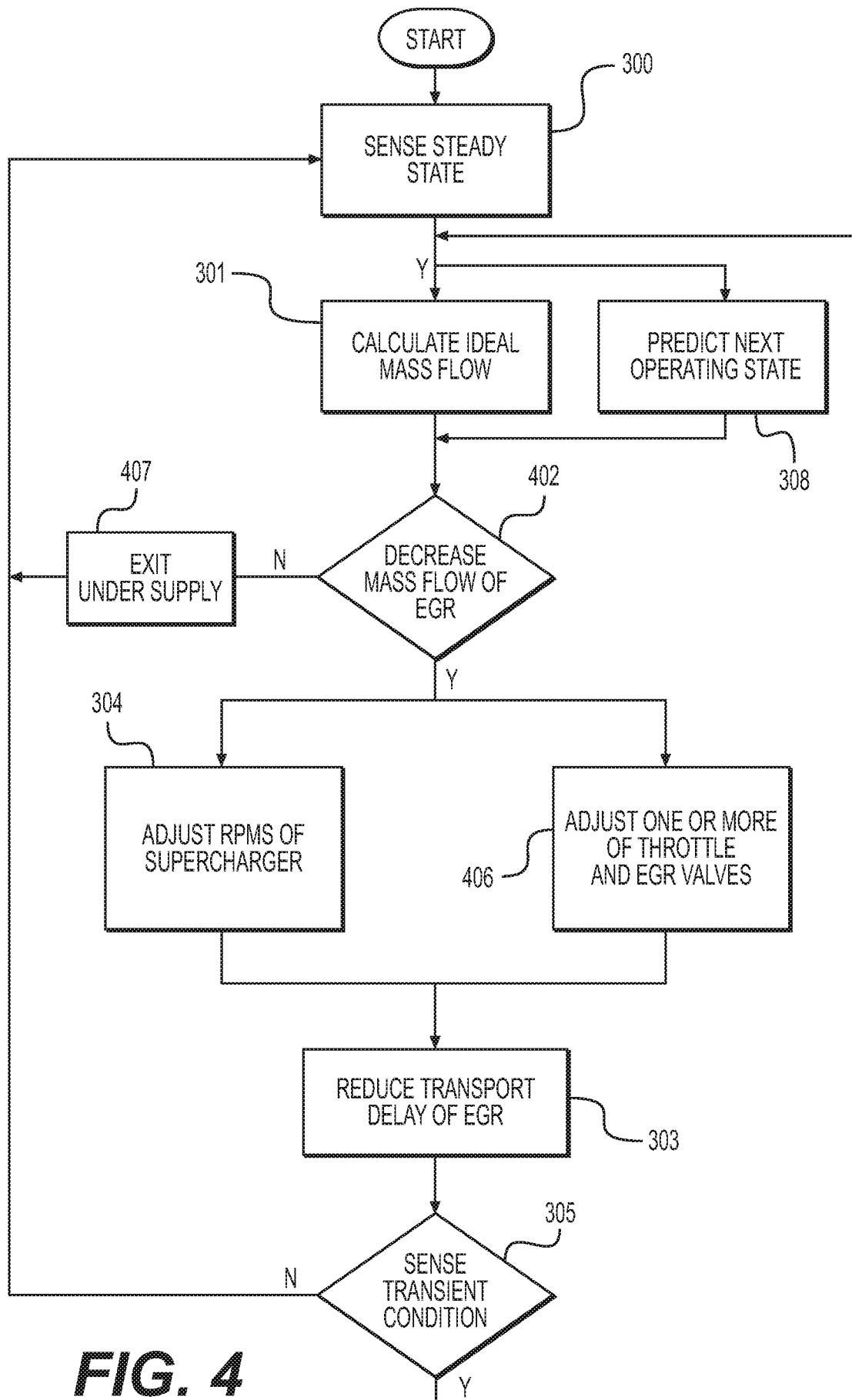


FIG. 2





A. CLASSIFICATION OF SUBJECT MATTER**F02D 41/00(2006.01)i, F02M 26/02(2016.01)i, F02M 26/52(2016.01)i, F02B 37/18(2006.01)i, F02D 41/26(2006.01)i**

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

F02D 41/00; F02B 47/08; F02B 37/24; F02B 33/00; F02D 41/38; F02M 25/07; F02B 47/02; F02B 3/00; F02M 26/02; F02M 26/52; F02B 37/18; F02D 41/26

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

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) & Keywords:

combustion, reduce, delay, current, next, exhaust gas recirculation, predict, valve, supercharger

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 1077320 A2 (NISSAN MOTOR CO., LTD.) 21 February 2001 See paragraphs [0007], [0012], [0022]; claim 1; and figure 1.	1-35
A	US 2009-0260603 A1 (BUCKNELL, JOHN R.) 22 October 2009 See paragraphs [0017]-[0025]; and figure 1.	1-35
A	US 2013-0118165 A1 (LEONE et al.) 16 May 2013 See paragraphs [0002]-[0015], [0028]-[0045]; and figure 1.	1-35
A	US 2014-0224231 A1 (WOODWARD, INC.) 14 August 2014 See paragraphs [0014]-[0042]; and figures 1-4.	1-35
A	US 2003-0145836 A1 (LINNA et al.) 07 August 2003 See paragraphs [0027]-[0040], [0051]-[0058]; and figures 1-2.	1-35



Further documents are listed in the continuation of Box C.



See patent family annex.

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2017/018927

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