United States Patent Application Publication	20250259557
Kind Code	A1
Publication Date	August 14, 2025
Inventor(s)	Olney; Lance

WAKE TURBULENCE ALERT SYSTEMS AND METHODS

Abstract

A system and a method include a control unit configured to monitor a first position of an ownship aircraft within an airspace, determine a projected path for the ownship aircraft within the airspace, monitor a second position of a target aircraft within an airspace, and determine a projected wake turbulence of the target aircraft within the airspace. The ownship aircraft is configured to be operated to avoid the projected wake turbulence.

Inventors: **Olney; Lance (Arlington, MA)**

Applicant: **THE BOEING COMPANY** (Arlington, VA)

Family ID: **1000007682782**

Assignee: **THE BOEING COMPANY (Arlington, VA)**

Appl. No.: **18/436296**

Filed: **February 08, 2024**

Publication Classification

Int. Cl.: **G08G5/00** (20250101)

U.S. Cl.:

CPC **G08G5/76** (20250101); **G08G5/21** (20250101); **G08G5/55** (20250101); **G08G5/59** (20250101);

Background/Summary

FIELD OF THE DISCLOSURE

[0001] Examples of the present disclosure generally relate to systems and methods for determining wake turbulence of an aircraft within an airspace, and alerting pilots of the wake turbulence.

BACKGROUND OF THE DISCLOSURE

[0002] Aircraft are used to transport passengers and cargo between various locations. Numerous aircraft depart from and arrive at a typical airport every day.

[0003] An aircraft in flight within an airspace generates wake turbulence, which forms counter-rotating vortices behind the aircraft. Wake turbulence from an aircraft can affect other aircraft within a defined range.

[0004] Typically, a pilot of an aircraft is alerted to wake turbulence from air traffic control. In general, air traffic personnel contact the pilot and verbally inform the pilot of potential wake turbulence within an airspace.

[0005] However, air traffic control may not always be able to promptly inform a pilot of wake turbulence. In such situations, air traffic control may forego verbally informing a pilot of wake turbulence, and instead instruct the pilot to maintain visual separation.

SUMMARY OF THE DISCLOSURE

[0006] A need exists for a system and a method for detecting wake turbulence of aircraft within an airspace. Further, a need exists for a system and a method for effectively and efficiently alerting an operator of an aircraft of wake turbulence that can potentially affect the aircraft.

[0007] With those needs in mind, certain examples of the present disclosure provide a system including a control unit configured to monitor a first position of an ownship aircraft within an airspace, determine a projected path for the ownship aircraft within the airspace, monitor a second position of a target aircraft within an airspace, and determine a projected wake turbulence of the target aircraft within the airspace. The ownship aircraft is configured to be operated to avoid the projected wake turbulence.

[0008] In at least one example, the control unit is further configured to output a wake turbulence alert to the ownship aircraft in response to detecting that the projected path of the ownship aircraft intersects one or more portions of the projected wake turbulence of the target aircraft. In at least one example, the ownship aircraft includes a user interface including one or both of a display or a speaker. The control unit is further configured to one or both of show the wake turbulence alert on the display or broadcast the wake turbulence alert through the speaker.

[0009] In at least one example, the control unit is configured to determine the projected wake turbulence based on the second position of the target aircraft, weather within the airspace, and one or both of a size or a shape of the target aircraft. The weather includes a wind speed and wind direction.

[0010] In at least one example, the control unit is further configured to filter out one or more other target aircraft that do not affect the ownship aircraft. For example, the control unit is configured to filter based on whether the one or more other target aircraft are (a) airborne, (b) within a predetermined zone of the ownship aircraft, (c) within a predetermined altitude of the ownship aircraft, and/or (d) large enough to affect the ownship aircraft.

[0011] In at least one example the ownship aircraft is configured to be automatically operated to avoid the projected wake turbulence. For example, the control unit is further configured to automatically operate one or more controls of the ownship aircraft to automatically operate the ownship aircraft to avoid the projected wake turbulence.

[0012] In at least one example, the control unit is an artificial intelligence or machine learning system.

[0013] Certain examples of the present disclosure provide a method including monitoring, by a control unit, a first position of an ownship aircraft within an airspace; determining, by the control unit, a projected path for the ownship aircraft within the airspace; monitoring, by the control unit, a second position of a target aircraft within an airspace; and determining, by the control unit, a projected wake turbulence of the target aircraft within the airspace, wherein the ownship aircraft is configured to be operated to avoid the projected wake turbulence.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] FIG. **1** illustrates a block diagram of a system, according to an example of the present disclosure.

[0015] FIG. **2** illustrates a front view of a display, according to an example of the present disclosure.

[0016] FIG. **3** illustrates a front view of a display, according to an example of the present disclosure.

[0017] FIG. **4** illustrates a front view of a display, according to an example of the present disclosure.

[0018] FIG. **5** illustrates a flow chart of a method, according to an example of the present disclosure.

[0019] FIG. **6** illustrates a schematic block diagram of a control unit, according to an example of the present disclosure.

[0020] FIG. **7** illustrates a perspective front view of an aircraft, according to an example of the present disclosure.

DETAILED DESCRIPTION OF THE DISCLOSURE

[0021] The foregoing summary, as well as the following detailed description of certain examples will be better understood when read in conjunction with the appended drawings. As used herein, an element or step recited in the singular and preceded by the word “a” or “an” should be understood as not necessarily excluding the plural of the elements or steps. Further, references to “one example” are not intended to be interpreted as excluding the existence of additional examples that also incorporate the recited features. Moreover, unless explicitly stated to the contrary, examples “comprising” or “having” an element or a plurality of elements having a particular condition can include additional elements not having that condition.

[0022] Examples of the present disclosure provide systems and methods including a control unit configured to detect wake turbulence of target aircraft within an airspace, and provide an alert to an operator of an aircraft (for example, an ownship aircraft) of the wake turbulence that can affect the aircraft. In at least one example, the control unit analyzes available traffic data and weather data, such as received by an automatic dependent surveillance-broadcast (ADS B) receiver during flight. The control unit further calculates wake turbulence behind the target aircraft that reacts to current winds, and follows a defined wake turbulence flight path. In at least one example, the control unit determines wake turbulence based on aircraft type, past position (including track, altitude, and airspeed), and current winds aloft data. The wake turbulence, as determined by the control unit, dynamically morphs as it descends and dissipates over time. In response to the control unit detecting that a projected path of the aircraft intersects a determined wake turbulence of the target aircraft, the control unit outputs an alert, such as a visual and/or aural caution message, which can be displayed and/or broadcast via a user interface of the aircraft.

[0023] FIG. **1** illustrates a block diagram of a system **100**, according to an example of the present disclosure. The system **100** includes a control unit **102** in communication with a plurality of flight information sources **104**, such as through one or more wired or wireless connections. For example, the control unit **102** can be coupled to a communication device **106** that receives data from the flight information sources **104**. The communication device **106** can be one or more of an antenna, a transceiver, an internet connection, a cloud-based connection, and/or the like.

[0024] The control unit **102** is also in communication with one or more aircraft **108** within an airspace **109**, such as via communication between the communication device **106** and a communication device **110** of the aircraft **108**. The communication device **110** can be an antenna, a transceiver, an internet connection, a cloud-based connection, and/or the like. In at least one example, the control unit **102** is separate and distinct from the aircraft **108**. For example, the control unit **102** can be located at a central monitoring location, which can be remote from, or optionally co-located with, one or more of the flight information sources **104**. As another example, the control unit **102** can be onboard the aircraft **108**, such as within a flight deck or cockpit. For example, the control unit **102** can be part of a flight computer of the aircraft **108**.

[0025] The aircraft **108** includes controls **112** configured to allow an operator, such as a pilot, to control operation of the aircraft **108**. For example, the controls **112** include one or more of a control handle, yoke, joystick, control surface controls, accelerators, decelerators, and/or the like.

[0026] The aircraft **108** also includes one or more user interfaces **114**. For example, a user interface **114** can be within a flight deck or cockpit of the aircraft **108**. In at least one example, a user interface **114** includes a display **116** and an input device **118**. In at least one example, the display **116** is an electronic device configured to electronically show images, videos, text, and/or the like. The display **116** can be a monitor, screen, television, touchscreen, and/or the like. The input device **118** can include a keyboard, mouse, stylus, touchscreen interface (that is, the input device **118** can be integral with the display **116**), and/or the like. The display **116** is configured to show visual graphics, videos, text, and/or the like. The user interface **114** can also include a speaker **119**, which is configured to broadcast audio messages. The user interface **114** can be, or part of, a computer workstation. For example, the user interface **114** can be part of the flight computer within the flight deck or cockpit of the aircraft **108**. As another example, the user interface **114** can be a handheld device, such as a smart phone, tablet, or the like.

[0027] In at least one example, the control unit **102** can be in communication with a user interface **114** that is not onboard an aircraft **108**, in addition to (or optionally instead of) the user interface **114** onboard one or more aircraft **108**. For example, the user interface **114** can be at a land-based monitoring location, such as with respect to air traffic control, a flight dispatcher, an airline operations center, and/or the like.

[0028] The control unit **102** receives data from the flight information sources **104**. The data includes vast amounts of information from numerous different flight information sources **104**. The flight information sources **104** include a tracking sub-system **120**, which is configured to track the various aircraft **108** on the ground and in the airspace **109**. In at least one example, the tracking sub-system **120** is configured to track positions of the aircraft **108** in real time. In at least one example, the tracking sub-system **120** is a radar sub-system. As another example, the tracking sub-system is an automatic dependent surveillance-broadcast (ADS-B) tracking sub-system. Real time positions of the aircraft **108** on the ground and within an airspace are detected by the tracking sub-system **120** that receives position signals output by position sensors of the aircraft **108**. For example, the tracking sub-system **120** receives ADS-B signals output by the position sensors of the aircraft **108**. As another example, the position sensors of the aircraft **108** can be global positioning system sensors. The position sensors output signals indicative of one or more of the position, altitude, heading, acceleration, velocity, and/or the like of the aircraft **108**. The signals are received by the tracking sub-system **120**.

[0029] The flight information sources **104** also include a weather sub-system **122**, which provides past, current, and predicted weather for locations of the aircraft **108**, airports, and the like. As an example, the weather sub-system **122** can include a weather station, channel, or the like. As another example, the weather sub-system **122** can include aeronautical weather services that provide weather notifications at various locations, such as airports. An example of data from a weather sub-system **122** includes a meteorological aerodrome report (METAR). The weather sub-system **122** detects current weather conditions within the airspace **109**, such as air temperatures, wind speeds and directions, air pressure, precipitation, and the like within the airspace **109**.

[0030] The flight information sources **104** also include aircraft data sources **124**, which provide information about the various aircraft. For example, the aircraft data sources **124** include information regarding a type, size, shape, and capabilities of the aircraft **108**. The aircraft data sources **124** can be information provided by a manufacturer, maintenance provider, operator, and/or the like of the aircraft **108**.

[0031] In at least one example, the aircraft data sources **124** can provide tail-specific information regarding the aircraft **108**. The tail-specific information for the aircraft **108** provides information regarding the performance of the specific, actual aircraft, in contrast to a different test aircraft, a general performance model, or the like. Optionally, the aircraft data sources **124** can provide general information regarding the type of aircraft **108**.

[0032] In operation, the control unit **102** determines a wake turbulence for one or more of the aircraft **108** within the airspace **109**. For example, the control unit **102** determines a wake turbulence generated by each aircraft **108** within the airspace **109**. The control unit **102** determines the wake turbulence for the aircraft **108** as function of a tracked position of the aircraft **108**, as received from the tracking sub-system **120**, weather within the airspace **109**, as received from the weather sub-system **122**, and the features of the aircraft **108**, such as received from the aircraft data sources **124**. The position of the aircraft **108** includes the location, airspeed, heading, altitude, and the like of the aircraft **108** within the airspace **109**. The weather includes wind direction and speed at various altitudes within the airspace **109**. The features of the aircraft **108** include the size and shape of the aircraft **108**.

[0033] In at least one example, the control unit **102** determines a position of a particular aircraft **108**, such as an ownship aircraft **108***a* within the airspace **109**, from data received from the tracking sub-system **120**. The control unit **102** outputs a signal showing the position of the ownship aircraft **108***a* on the display **116**. The control unit **102** further determines a projected path for the ownship aircraft **108**. The projected path for the ownship aircraft **108***a* can be a projected future path for the aircraft, such as a predetermined period of time into the future. The predetermined period of time can be 30 seconds, 1 minute, 2 minutes, or the like. The projected future path is determined by the control unit **102** from the current location, heading, airspeed, altitude, and the like of the aircraft **108**.

[0034] The control unit **102** further determines the positions of other aircraft **108**, such as target aircraft **108***b* that are different from the ownship aircraft **108***a*, within the airspace **109**. For the target aircraft **108***b*, the control unit **102** further determines a wake turbulence generated thereby. The control unit **102** determines the wake turbulence for the target aircraft **108***b* based on the position of the target aircraft **108***b* (including one or more of the location, heading, airspeed, altitude, and/or the like) received from the tracking sub-system **120**, the data regarding the target aircraft **108***b* (such as size, shape, and optionally a predetermined wake turbulence trailing the target aircraft) as received from the aircraft data sources **124**, and weather data including wind speed and direction as received from the weather sub-system **122**. Thus, the control unit **102** determines a wake turbulence for the target aircraft **108***b* as a function of tracked position of the target aircraft **108***b*, the size and/or shape of the target aircraft **108***b*, and the weather within the airspace **109** in which the target aircraft is flying.

[0035] The control unit **102** can further show the target aircraft **108***b* in relation to the ownship aircraft **108***a* on the display **116**. The control unit **102** further monitors the projected path for the ownship aircraft **108***a* in relation to the wake turbulence of the target aircraft **108***b*. If the projected path of the ownship aircraft **108***a* does not intersect the wake turbulence of the target aircraft **108***b*, the control unit **102** continues monitoring and does not output an alert. If, however, the projected path of the ownship aircraft **108***a* intersects the wake turbulence of the target aircraft **108***b*, the control unit **102** outputs a wake turbulence alert to the ownship aircraft **108***a*. For example, the control unit **102** operates the display **116** of the ownship aircraft **108***a* to show a wake turbulence alert message (such as a graphic and/or text) regarding wake turbulence. As another example, the control unit **102** can broadcast an audible wake turbulence alert message through the speaker **119**. In at least one example, the control unit **102** shows the wake turbulence alert on the display **116** and broadcasts the wake turbulence alert through the speaker **119**.

[0036] In at least one example, the control unit **102** filters traffic information for relevant wake turbulence information. That is, the control unit **102** can filter out one or more other target aircraft having wake turbulence that do not affect the ownship aircraft **102***a*. For example, the control unit **102** determines if a target aircraft **108***b* is airborne within the airspace **109**. If the target aircraft **108***b*, as tracked by the tracking sub-system **120**, is not airborne, the control unit **102** removes the target aircraft **108***b* from further analysis, as an aircraft **108** on the ground may not generate wake turbulence.
[0037] If, however, the control unit **102** determines that the target aircraft **108***b* is airborne, the control unit **102** then determines if the target aircraft **108***b* is within a predetermined zone of the ownship aircraft **108***a*. The predetermined zone a portion of the airspace **109** in front of the ownship aircraft **108***a*. For example, based on the current position of the ownship aircraft **108***a*, which is tracked by the tracking sub-system **120**, the predetermined zone can be five minutes laterally, and five minutes forward. Optionally, the predetermined zone can be less than five minutes (such as 2 or 3 minutes), or greater than five minutes (such as 10 or 15 minutes). If the target aircraft **108***b* is outside of the predetermined zone, the control unit **102** removes the target aircraft **108***b* from further analysis.
[0038] If, however, the target aircraft **108***b* is within the predetermined zone, the control unit **102** then determines if the target aircraft **108***b* is within a predetermined altitude of the ownship aircraft **108***a*. For example, the predetermined altitude can be 3000 feet or less above or below the ownship aircraft **108***a*. Optionally, the predetermined altitude can be less than 3000 feet (such as 2000 or 2500 feet) or greater than 3000 feet (such as 4000 or 5000 feet). If the target aircraft **108***b* is outside of the predetermined altitude, the control unit **102** removes the target aircraft **108***b* from further analysis.
[0039] If, however, the target aircraft **108***b* is within the predetermined altitude, the control unit **102** determines if the target aircraft **108***b* is large enough (such as within a particular wake category) to affect the ownship aircraft **108***a*. The control unit **102** receives data regarding the size, shape, weight, and the like of the aircraft **108** from the aircraft data sources **124**. Predetermined comparative data between different sizes of aircraft can be used to determine whether the target aircraft **108***b* is large enough to generate sufficient wake so as to affect the ownship aircraft **108***a*. As an example, the wake turbulence of a small, single propeller aircraft may not affect a large jet aircraft, such as a Boeing 747. If the control unit **102** determines that the target aircraft **108***b* is too small to affect the ownship aircraft **108***a*, the control unit **102** discards the target aircraft **108***b* from further analysis.
[0040] As described, the control unit **102** continues to analyze the target aircraft **108***b* based on the target aircraft **108***b* being airborne, within a predetermined zone and predetermined altitude of the ownship aircraft **108***a*, and large enough to generate a wake turbulence that can potentially affect the ownship aircraft **108***a*. Conversely, the control unit **102** filters out the target aircraft **108***b* from further analysis if the target aircraft **108***b* is not airborne, outside of the predetermined zone and/or the predetermined altitude, and/or too small to generate a wake turbulence that can potentially affect the ownship aircraft **108***a*.
[0041] If after the filtering operation described above the control unit **102** continues to analyze the target aircraft **108***b* in relation to the ownship aircraft **108***a*, the control unit **102** determines and projects a wake turbulence for the target aircraft **108***b*. The projected wake turbulence for the target aircraft **108***b* can be based on predetermined data for the target aircraft **108***b*. For example, the projected wake turbulence for the target aircraft **108***b* can be determined from particular regulations from one or more regulatory authorities (such as the United States Federal Aviation Administration (FAA)), such as in relation to radar separation for aircraft.
[0042] The control unit **102** projects the wake turbulence behind the target aircraft **108***b*, which continues to be tracked by the tracking sub-system **120**. The control unit **102** can further base the wake turbulence based on a historical path of the target aircraft **108***b* while airborne, such as the

historical path of the target aircraft from a preceding 30 seconds, 1 minute, 2 minutes, or more. The control unit **102** can further project the wake turbulence based on a wing span or width of the target aircraft **108***b*, as received from the aircraft data sources **124**. For example, the control unit **102** determines as width of the wake turbulence of the target aircraft as a width of the wingspan of the target aircraft **108***b*.

[0043] In at least one example, the control unit **102** further projects the wake turbulence behind the target aircraft **108***b* based on a predetermined descent rate. For example, the control unit **102** determines that a wake turbulence generated at an initial altitude descends at a predetermined rate, such as 400 feet per minute. As an example, a wake turbulence generated at a particular position at an initial altitude of 2000 feet will be at 1200 feet two minutes after initially generated.

[0044] In at least one example, the control unit **102** further projects the wake turbulence based on a wind correction. The control unit **102** receives weather data, including wind speed and direction, from the weather sub-system **122**. The wind affects the wake turbulence. That is, depending on wind speed and direction, the wake turbulence generated by the target aircraft **108***b* moves in response thereto. The control unit **102** provides a wind correction for the projected wake turbulence.

[0045] As described, in at least one example, the control unit **102** determines a projected wake turbulence behind the target aircraft **108***b* based on one or more of a determined wake length (such as based on data from one or more regulatory authorities), a historical path of the target aircraft **108***b*, a wing width (that is, a wingspan from wing tip to wing tip) of the target aircraft **108***b*, a descent rate of the wake turbulence, and/or weather conditions, such as wind direction and wind speed. In at least one example, the control unit **102** determines a projected wake turbulence behind the target aircraft **108***b* based on the determined wake length (such as based on data from one or more regulatory authorities), the historical path of the target aircraft **108***b*, the wing width (that is, a wingspan from wing tip to wing tip) of the target aircraft **108***b*, the descent rate of the wake turbulence, and the weather conditions, such as the wind direction and the wind speed.

[0046] The control unit **102** shows the ownship aircraft **108***a* and the target aircraft **108***b*, as tracked by the tracking sub-system **120**, on the display **116** of the ownship aircraft **108***a*. If the projected path of the ownship aircraft **108***a* does not intersect the projected wake turbulence of the target aircraft **108***b*, the control unit **102** continues to monitor the ownship aircraft **108***a* and the target aircraft **108***b* without outputting a wake turbulence alert. If, however, the projected path of the ownship aircraft **108***a* intersects the projected wake turbulence of the target aircraft **108***b*, the control unit **102** outputs the wake turbulence alert to the ownship aircraft **108***a*. The wake turbulence alert can be shown on the display **116** and/or broadcast through the speaker **119** of the ownship aircraft **108***a*. The control unit **102** can show the projected path of the ownship aircraft **108***a* and/or the projected wake turbulence of the target aircraft **108***b* on the display **116**. Optionally, the control unit **102** may not show the projected path of the ownship aircraft **108***a* or the projected wake turbulence of the target aircraft **108***b* on the display **116**.

[0047] In response to receiving the wake turbulence alert, the ownship aircraft **108***a* is operated to move out of the projected wake turbulence, and therefore out of wake turbulence generated by the target aircraft **108***b*. In at least one example, the ownship aircraft **108***a* can be automatically operated to move out of and/or remain outside of the projected wake turbulence. For example, one or more control units can automatically operate one or more of the controls **112** of the ownship aircraft **108***a* to ensure that the ownship aircraft **108***a* is outside of the projected wake turbulence. In at least one example, the control unit **102** automatically operates one or more of the controls **112** of the ownship aircraft **108***a* to ensure that the ownship aircraft **108***a* is outside of the projected wake turbulence of the target aircraft **108***b*. Optionally, the ownship aircraft **108***a* may not be automatically operated to remain outside of the projected wake turbulence.

[0048] The projected path of the ownship aircraft **108***a* can be a projected line for a predetermined time period into the future (such as 30, 35, 40, 45, 60 seconds or more) of the ownship aircraft

108*a* based on a current heading, airspeed, and altitude of the ownship aircraft **108***a*. In at least one example, the control unit **102** determines a pending time based on distance for an intersection of the projected path of the ownship aircraft **108***a* and the projected wake turbulence of the target aircraft **108***b*. The pending time decreases with decreased distance between the ownship aircraft **108***a* and the target aircraft **108***b*. Conversely, the pending time increases with increased distance between the ownship aircraft **108***a* and the target aircraft **108***b*. For example, the pending time can be 2 seconds or more for the detected intersection between the projected path of the ownship aircraft **108***a* and the projected wake turbulence of the target aircraft **108***b* when the ownship aircraft **108***a* and the target aircraft **108***b* are a relatively far distance from each other (such as 3000 feet). As the relative distance between the ownship aircraft **108***a* and the target aircraft **108***b* decreases, the pending time decreases. For example, if the relative distance is 1000 feet or less, the pending time can be 0.5-1 second. If the intersection between the projected path of the ownship aircraft **108***a* and the projected wake turbulence of the target aircraft **108***b* exceeds the pending time, the control unit **102** outputs the wake turbulence alert to the ownship aircraft **108***a*. If, however, the intersection is less than the pending time, the control unit **102** refrains from outputting the wake turbulence alert. In this manner, the control unit **102** refrains from alerting pilots of aircraft **108** that are only in a projected wake turbulence for a brief period of time (such as if maneuvering to a different heading, altitude, or the like).

[0049] In at least one example, the control unit **102** can also determine a predetermined cool down time with respect to a wake turbulence alert for a particular target aircraft **108***b*. For example, in response to outputting a wake turbulence alert for a target aircraft **108***b*, the control unit **102** may refrain from outputting another wake turbulence alert for that particular target aircraft for a predetermined period of time (such as 30, 45, or 60 seconds). In this manner, the control unit **102** may refrain from outputting repetitive wake turbulence alerts. Optionally, the control unit **102** may not determine a predetermined cool down time.

[0050] As described herein, the system **100** includes the control unit **102**, which is configured to monitor a first position of the ownship aircraft **108***a* within the airspace **109**. The control unit **102** is further configured to determine a projected path for the ownship aircraft **108***a* within the airspace **109**. The control unit **102** is further configured to monitor a second position of one or more target aircraft **108***b* within the airspace **109**, and determine a projected wake turbulence of the target aircraft(s) **108***b* within the airspace **109**. The ownship aircraft **108***a* is operated to avoid the projected wake turbulence, such as by remaining outside of the projected wake turbulence, or moving outside of the projected wake turbulence. In at least one example, the ownship aircraft **108***a* can be automatically operated, such as by one or more control units (for example, the control unit **102**) to avoid the projected wake turbulence. In at least one example, the control unit **102** outputs a wake turbulence alert to the ownship aircraft in response to detecting that the projected path intersects one or more portions of the projected wake turbulence.

[0051] FIG. **2** illustrates a front view of a display **116**, according to an example of the present disclosure. Referring to FIGS. **1** and **2**, the display **116** is of an ownship aircraft **108***a*. A position of the ownship aircraft **108***a* is shown on the display **116**. The control unit **102** determines the predetermined zone **130** for the ownship aircraft **108***a*. As shown, the target aircraft **108***b*, **108***c*, and **108***d* are within the predetermined zone **130**. Conversely, the target aircraft **108***e* is outside of the predetermined zone **130**.

[0052] The control unit **102** can show the predetermined zone **130** on the display **116**. Optionally, the control unit **102** may not show the predetermined zone **130** on the display **116**.

[0053] FIG. **3** illustrates a front view of a display **116**, according to an example of the present disclosure. Referring to FIGS. **1** and **3**, the display **116** is of an ownship aircraft **108***a*. The control unit **102** determines a projected path **140** for the ownship aircraft **108***a*, and a projected wake turbulence **142** for a target aircraft **108***b*. In response to detecting that the projected path **140** of the ownship aircraft **108***a* intersects at least a portion of the projected wake turbulence **142** of the target aircraft **108**_b_, the control unit **102** outputs a wake turbulence alert **144**, which is shown on the display **116**.

[0054] The control unit **102** can show the projected path **140** and the projected wake turbulence **142** on the display **116**. Optionally, the control unit **102** may not show the projected path **140** and/or the projected wake turbulence **142** on the display **116**.

[0055] FIG. **4** illustrates a front view of a display **116**, according to an example of the present disclosure. As shown, a projected wake turbulence **150** of a target aircraft **108**_b_ is shifted from a historical path **152** of the target aircraft **108**_b_. For example, the control unit **102** shifts the projected wake turbulence **150** from the historical path **152** based on weather data including wind speed and direction.

[0056] The control unit **102** can show the projected wake turbulence **150** and the historical path **152** on the display **116**. Optionally, the control unit **102** may not show the projected wake turbulence **150** and/or the historical path **152** on the display **116**.

[0057] FIG. **5** illustrates a flow chart of a method, according to an example of the present disclosure. Referring to FIGS. **1-5**, at **200**, the control unit **102** monitors a position of an ownship aircraft **108**_a_ within the airspace **109**. At **202**, the control unit **102** determines a projected path of the ownship aircraft **108**_a_. At **204**, the control unit **102** monitors a position of a target aircraft **108**_b_ within the airspace **109**.

[0058] At **206**, the control unit **102** determines whether or not to filer the target aircraft **108**_b_ from further analysis. If so, the method returns to **200**. If, however, the control unit **102** does not filter the target aircraft **108**_b_ from further analysis, but instead continues to analyze the target aircraft **108**_b_, the method proceeds from **206** to **208**, at which the control unit **102** determines a projected wake turbulence of the target aircraft **108**_b_. Next, at **210**, the control unit **102** determines if the projected path of the ownship aircraft **108**_a_ intersects one or more portions of the projected wake turbulence of the target aircraft **108**_b_. If not, the method proceeds from **210** to **212**, at which the control unit **102** refrains from outputting a wake turbulence alert.

[0059] If, however, the projected path intersects one or more portions of the projected wake turbulence at **210**, the method proceeds to **214**, at which the control unit **102** outputs the wake turbulence alert to the ownship aircraft **108**_a_. The control unit **102** may show the wake turbulence alert on the display **116** of the ownship aircraft **108**_a_, and/or broadcast the wake turbulence alert through the speaker **119** of the ownship aircraft **108**_a_. The ownship aircraft **108**_a_ is then operated to avoid the projected wake turbulence. For example, the ownship aircraft **108**_a_ is operated (either by one or more pilots, or automatically by one or more control units) to remain outside of the projected wake turbulence, and/or move outside of the projected wake turbulence.

[0060] FIG. **6** illustrates a schematic block diagram of the control unit **102**, according to an example of the present disclosure. In at least one example, the control unit **102** includes at least one processor **300** in communication with a memory **302**. The memory **302** stores instructions **304**, received data **306**, and generated data **308**. The control unit **102** shown in FIG. **6** is merely exemplary, and non-limiting.

[0061] As used herein, the term “control unit,” “central processing unit,” “CPU,” “computer,” or the like may include any processor-based or microprocessor-based system including systems using microcontrollers, reduced instruction set computers (RISC), application specific integrated circuits (ASICs), logic circuits, and any other circuit or processor including hardware, software, or a combination thereof capable of executing the functions described herein. Such are exemplary only, and are thus not intended to limit in any way the definition and/or meaning of such terms. For example, the control unit **102** may be or include one or more processors that are configured to control operation, as described herein.

[0062] The control unit **102** is configured to execute a set of instructions that are stored in one or more data storage units or elements (such as one or more memories), in order to process data. For example, the control unit **102** may include or be coupled to one or more memories. The data storage units may also store data or other information as desired or needed. The data storage units may be in the form of an information source or a physical memory element within a processing machine.

[0063] The set of instructions may include various commands that instruct the control unit **102** as a processing machine to perform specific operations such as the methods and processes of the various examples of the subject matter described herein. The set of instructions may be in the form of a software program. The software may be in various forms such as system software or application software. Further, the software may be in the form of a collection of separate programs, a program subset within a larger program, or a portion of a program. The software may also include modular programming in the form of object-oriented programming. The processing of input data by the processing machine may be in response to user commands, or in response to results of previous processing, or in response to a request made by another processing machine.

[0064] The diagrams of examples herein may illustrate one or more control or processing units, such as the control unit **102**. It is to be understood that the processing or control units may represent circuits, circuitry, or portions thereof that may be implemented as hardware with associated instructions (e.g., software stored on a tangible and non-transitory computer readable storage medium, such as a computer hard drive, ROM, RAM, or the like) that perform the operations described herein. The hardware may include state machine circuitry hardwired to perform the functions described herein. Optionally, the hardware may include electronic circuits that include and/or are connected to one or more logic-based devices, such as microprocessors, processors, controllers, or the like. Optionally, the control unit **102** may represent processing circuitry such as one or more of a field programmable gate array (FPGA), application specific integrated circuit (ASIC), microprocessor(s), and/or the like. The circuits in various examples may be configured to execute one or more algorithms to perform functions described herein. The one or more algorithms may include aspects of examples disclosed herein, whether or not expressly identified in a flowchart or a method.

[0065] As used herein, the terms “software” and “firmware” are interchangeable, and include any computer program stored in a data storage unit (for example, one or more memories) for execution by a computer, including RAM memory, ROM memory, EPROM memory, EEPROM memory, and non-volatile RAM (NVRAM) memory. The above data storage unit types are exemplary only, and are thus not limiting as to the types of memory usable for storage of a computer program.

[0066] Referring to FIGS. **1-6**, examples of the subject disclosure provide systems and methods that allow large amounts of data to be quickly and efficiently analyzed by a computing device. For example, the control unit **102** can receive and analyze data from hundreds, thousands, or more flight information sources **104** with respect to numerous ownship aircraft and numerous target aircraft. As such, large amounts of data, which may not be readily discernable by human beings, are being tracked and analyzed. The vast amounts of data are efficiently organized and/or analyzed by the control unit **102**, as described herein. The control unit **102** analyzes the data in a relatively short time in order to quickly and efficiently determine projected wake turbulence, and output alerts when necessary. As such, examples of the present disclosure provide increased and efficient functionality, and vastly superior performance in relation to a human being reviewing the vast amounts of data.

[0067] In at least one example, components of the system **100**, such as the control unit **102**, provide and/or enable a computer system to operate as a special computer system for determining wake turbulences, and generating wake turbulence alerts. The control unit **102** improves upon standard computing devices by determining such information and automatically communicating with individuals (such as operators of aircraft) in an efficient and effective manner.

[0068] In at least one example, the control unit **102** uses machine learning algorithms which automatically consider factors that influence wake turbulence generated by aircraft. In at least one example, all or part of the systems and methods described herein are or otherwise include an

artificial intelligence (AI) or machine-learning system that can automatically perform the operations of the methods also described herein. In at least one example, the control unit **102** can be or otherwise include a deterministic or rules based evaluation system. In at least one example, the control unit **102** can be an artificial intelligence or machine learning system. These types of systems may be trained from outside information and/or self-trained to repeatedly improve the accuracy with how data is analyzed to determine wake turbulence generated by aircraft, and output alert messages when necessary. Over time, these systems can improve by determining and communicating with increasing accuracy and speed, thereby significantly reducing the likelihood of any potential errors. For example, the AI or machine-learning systems can learn and determine models, associate such models with received data, and determine potential conflicts. The AI or machine-learning systems described herein may include technologies enabled by adaptive predictive power and that exhibit at least some degree of autonomous learning to automate and/or enhance pattern detection (for example, recognizing irregularities or regularities in data), customization (for example, generating or modifying rules to optimize record matching), and/or the like. The systems may be trained and re-trained using feedback from one or more prior analyses of the data, ensemble data, and/or other such data. Based on this feedback, the systems may be trained by adjusting one or more parameters, weights, rules, criteria, or the like, used in the analysis of the same. This process can be performed using the data and ensemble data instead of training data, and may be repeated many times to repeatedly improve the determinations and communications described herein. The training minimizes conflicts and interference by performing an iterative training algorithm, in which the systems are retrained with an updated set of data, and based on the feedback examined prior to the most recent training of the systems. This provides a robust analysis model that can better determine wake turbulence generated by aircraft, and determine when to output alert messages to ownship aircraft regarding wake turbulence within an airspace.
[0069] FIG. **7** illustrates a perspective front view of an aircraft **108**, according to an example of the present disclosure. The aircraft **108** includes a propulsion system **412** that includes engines **414**, for example. Optionally, the propulsion system **412** may include more engines **414** than shown. The engines **414** are carried by wings **416** of the aircraft **108**. In other examples, the engines **414** may be carried by a fuselage **418** and/or an empennage **420**. The empennage **420** may also support horizontal stabilizers **422** and a vertical stabilizer **424**. The fuselage **418** of the aircraft **108** defines an internal cabin **430**, which includes a flight deck or cockpit, one or more work sections (for example, galleys, personnel carry-on baggage areas, and the like), one or more passenger sections (for example, first class, business class, and coach sections), one or more lavatories, and/or the like. FIG. **7** shows an example of an aircraft **108**. It is to be understood that the aircraft **108** can be sized, shaped, and configured differently than shown in FIG. **7**.
[0070] Further, the disclosure comprises examples according to the following clauses:
[0071] Clause 1. A system comprising:
a control unit configured to: [0072] monitor a first position of an ownship aircraft within an airspace, [0073] determine a projected path for the ownship aircraft within the airspace, [0074] monitor a second position of a target aircraft within an airspace, and [0075] determine a projected wake turbulence of the target aircraft within the airspace,
wherein the ownship aircraft is configured to be operated to avoid the projected wake turbulence.
[0076] Clause 2. The system of Clause 1, wherein the control unit is further configured to output a wake turbulence alert to the ownship aircraft in response to detecting that the projected path of the ownship aircraft intersects one or more portions of the projected wake turbulence of the target aircraft.
[0077] Clause 3. The system of Clause 2, wherein the ownship aircraft comprises a user interface including one or both of a display or a speaker, and wherein the control unit is further configured to one or both of show the wake turbulence alert on the display or broadcast the wake turbulence alert through the speaker.

[0078] Clause 4. The system of any of Clauses 1-3, wherein the control unit is configured to determine the projected wake turbulence based on the second position of the target aircraft, weather within the airspace, and one or both of a size or a shape of the target aircraft.
[0079] Clause 5. The system of Clause 4, wherein the weather comprises a wind speed and wind direction.
[0080] Clause 6. The system of any of Clauses 1-5, wherein the control unit is further configured to filter out one or more other target aircraft that do not affect the ownship aircraft.
[0081] Clause 7. The system of Clause 6, wherein the control unit is configured to filter based on whether the one or more other target aircraft are one or more of (a) airborne, (b) within a predetermined zone of the ownship aircraft, (c) within a predetermined altitude of the ownship aircraft, or (d) large enough to affect the ownship aircraft.
[0082] Clause 8. The system of Clause 7, wherein the control unit is configured to filter based on whether the one or more other target aircraft are (a) airborne, (b) within the predetermined zone of the ownship aircraft, (c) within the predetermined altitude of the ownship aircraft, and (d) large enough to affect the ownship aircraft.
[0083] Clause 9. The system of any of Clauses 1-8, wherein the ownship aircraft is configured to be automatically operated to avoid the projected wake turbulence.
[0084] Clause 10. The system of Clause 9, wherein the control unit is further configured to automatically operate one or more controls of the ownship aircraft to automatically operate the ownship aircraft to avoid the projected wake turbulence.
[0085] Clause 11. The system of any of Clauses 1-10, wherein the control unit is an artificial intelligence or machine learning system.
[0086] Clause 12. A method comprising: [0087] monitoring, by a control unit, a first position of an ownship aircraft within an airspace; [0088] determining, by the control unit, a projected path for the ownship aircraft within the airspace; [0089] monitoring, by the control unit, a second position of a target aircraft within an airspace; and [0090] determining, by the control unit, a projected wake turbulence of the target aircraft within the airspace, [0091] wherein the ownship aircraft is configured to be operated to avoid the projected wake turbulence.
[0092] Clause 13. The method of Clause 12, further comprising outputting, by the control unit, a wake turbulence alert to the ownship aircraft in response to detecting that the projected path of the ownship aircraft intersects one or more portions of the projected wake turbulence of the target aircraft.
[0093] Clause 14. The method of Clause 13, further comprising one or both of showing, by the control unit, the wake turbulence alert on a display of the ownship aircraft, or broadcasting, by the control unit, the wake turbulence alert through a speaker of the ownship aircraft.
[0094] Clause 15. The method of any of Clauses 12-14, wherein said determining the projected wake turbulence comprises determining the projected wake turbulence based on the second position of the target aircraft, weather within the airspace, and one or both of a size or a shape of the target aircraft, and wherein the weather comprises a wind speed and a wind direction.
[0095] Clause 16. The method of any of Clauses 12-15, further comprising filtering, by the control unit, one or more other target aircraft that do not affect the ownship aircraft, wherein said filtering is based on whether the one or more other target aircraft are one or more of (a) airborne, (b) within a predetermined zone of the ownship aircraft, (c) within a predetermined altitude of the ownship aircraft, or (d) large enough to affect the ownship aircraft.
[0096] Clause 17. The method of any of Clauses 12-16, further comprising automatically operating the ownship aircraft to avoid the projected wake turbulence.
[0097] Clause 18. The method of Clause 17, wherein said automatically operating comprises automatically operating, by the control unit, one or more controls of the ownship aircraft to automatically operate the ownship aircraft to avoid the projected wake turbulence.
[0098] Clause 19. The method of any of Clauses 12-18, wherein the control unit is an artificial

intelligence or machine learning system.

[0099] Clause 20. A non-transitory computer-readable storage medium comprising executable instructions that, in response to execution, cause one or more control units comprising a processor, to perform operations comprising: [0100] monitoring a first position of an ownship aircraft within an airspace; [0101] determining a projected path for the ownship aircraft within the airspace; [0102] monitoring a second position of a target aircraft within an airspace; and [0103] determining a projected wake turbulence of the target aircraft within the airspace, [0104] wherein the ownship aircraft is configured to be operated to avoid the projected wake turbulence.

[0105] As described herein, examples of the present disclosure provide systems and methods for detecting wake turbulence of aircraft within an airspace. Further, examples of the present disclosure provide systems and methods for effectively and efficiently alerting an operator of an aircraft of wake turbulence that can potentially affect the aircraft.

[0106] While various spatial and directional terms, such as top, bottom, lower, mid, lateral, horizontal, vertical, front and the like can be used to describe examples of the present disclosure, it is understood that such terms are merely used with respect to the orientations shown in the drawings. The orientations can be inverted, rotated, or otherwise changed, such that an upper portion is a lower portion, and vice versa, horizontal becomes vertical, and the like.

[0107] As used herein, a structure, limitation, or element that is “configured to” perform a task or operation is particularly structurally formed, constructed, or adapted in a manner corresponding to the task or operation. For purposes of clarity and the avoidance of doubt, an object that is merely capable of being modified to perform the task or operation is not “configured to” perform the task or operation as used herein.

[0108] It is to be understood that the above description is intended to be illustrative, and not restrictive. For example, the above-described examples (and/or aspects thereof) can be used in combination with each other. In addition, many modifications can be made to adapt a particular situation or material to the teachings of the various examples of the disclosure without departing from their scope. While the dimensions and types of materials described herein are intended to define the aspects of the various examples of the disclosure, the examples are by no means limiting and are exemplary examples. Many other examples will be apparent to those of skill in the art upon reviewing the above description. The scope of the various examples of the disclosure should, therefore, be determined with reference to the appended claims, along with the full scope of equivalents to which such claims are entitled. In the appended claims and the detailed description herein, the terms “including” and “in which” are used as the plain-English equivalents of the respective terms “comprising” and “wherein.” Moreover, the terms “first,” “second,” and “third,” etc. are used merely as labels, and are not intended to impose numerical requirements on their objects. Further, the limitations of the following claims are not written in means-plus-function format and are not intended to be interpreted based on 35 U.S.C. § 112 (f), unless and until such claim limitations expressly use the phrase “means for” followed by a statement of function void of further structure.

[0109] This written description uses examples to disclose the various examples of the disclosure, including the best mode, and also to enable any person skilled in the art to practice the various examples of the disclosure, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the various examples of the disclosure is defined by the claims, and can include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if the examples have structural elements that do not differ from the literal language of the claims, or if the examples include equivalent structural elements with insubstantial differences from the literal language of the claims.

Claims

1. A system comprising: a control unit configured to: monitor a first position of an ownship aircraft within an airspace, determine a projected path for the ownship aircraft within the airspace, monitor a second position of a target aircraft within an airspace, and determine a projected wake turbulence of the target aircraft within the airspace, wherein the ownship aircraft is configured to be operated to avoid the projected wake turbulence.

2. The system of claim 1, wherein the control unit is further configured to output a wake turbulence alert to the ownship aircraft in response to detecting that the projected path of the ownship aircraft intersects one or more portions of the projected wake turbulence of the target aircraft.

3. The system of claim 2, wherein the ownship aircraft comprises a user interface including one or both of a display or a speaker, and wherein the control unit is further configured to one or both of show the wake turbulence alert on the display or broadcast the wake turbulence alert through the speaker.

4. The system of claim 1, wherein the control unit is configured to determine the projected wake turbulence based on the second position of the target aircraft, weather within the airspace, and one or both of a size or a shape of the target aircraft.

5. The system of claim 4, wherein the weather comprises a wind speed and wind direction.

6. The system of claim 1, wherein the control unit is further configured to filter out one or more other target aircraft that do not affect the ownship aircraft.

7. The system of claim 6, wherein the control unit is configured to filter based on whether the one or more other target aircraft are one or more of (a) airborne, (b) within a predetermined zone of the ownship aircraft, (c) within a predetermined altitude of the ownship aircraft, or (d) large enough to affect the ownship aircraft.

8. The system of claim 7, wherein the control unit is configured to filter based on whether the one or more other target aircraft are (a) airborne, (b) within the predetermined zone of the ownship aircraft, (c) within the predetermined altitude of the ownship aircraft, and (d) large enough to affect the ownship aircraft.

9. The system of claim 1, wherein the ownship aircraft is configured to be automatically operated to avoid the projected wake turbulence.

10. The system of claim 9, wherein the control unit is further configured to automatically operate one or more controls of the ownship aircraft to automatically operate the ownship aircraft to avoid the projected wake turbulence.

11. The system of claim 1, wherein the control unit is an artificial intelligence or machine learning system.

12. A method comprising: monitoring, by a control unit, a first position of an ownship aircraft within an airspace; determining, by the control unit, a projected path for the ownship aircraft within the airspace; monitoring, by the control unit, a second position of a target aircraft within an airspace; and determining, by the control unit, a projected wake turbulence of the target aircraft within the airspace, wherein the ownship aircraft is configured to be operated to avoid the projected wake turbulence.

13. The method of claim 12, further comprising outputting, by the control unit, a wake turbulence alert to the ownship aircraft in response to detecting that the projected path of the ownship aircraft intersects one or more portions of the projected wake turbulence of the target aircraft.

14. The method of claim 13, further comprising one or both of showing, by the control unit, the wake turbulence alert on a display of the ownship aircraft, or broadcasting, by the control unit, the wake turbulence alert through a speaker of the ownship aircraft.

15. The method of claim 12, wherein said determining the projected wake turbulence comprises determining the projected wake turbulence based on the second position of the target aircraft, weather within the airspace, and one or both of a size or a shape of the target aircraft, and wherein the weather comprises a wind speed and a wind direction.

16. The method of claim 12, further comprising filtering, by the control unit, one or more other target aircraft that do not affect the ownship aircraft, wherein said filtering is based on whether the one or more other target aircraft are one or more of (a) airborne, (b) within a predetermined zone of the ownship aircraft, (c) within a predetermined altitude of the ownship aircraft, or (d) large enough to affect the ownship aircraft.

17. The method of claim 12, further comprising automatically operating the ownship aircraft to avoid the projected wake turbulence.

18. The method of claim 17, wherein said automatically operating comprises automatically operating, by the control unit, one or more controls of the ownship aircraft to automatically operate the ownship aircraft to avoid the projected wake turbulence.

19. The method of claim 12, wherein the control unit is an artificial intelligence or machine learning system.

20. A non-transitory computer-readable storage medium comprising executable instructions that, in response to execution, cause one or more control units comprising a processor, to perform operations comprising: monitoring a first position of an ownship aircraft within an airspace; determining a projected path for the ownship aircraft within the airspace; monitoring a second position of a target aircraft within an airspace; and determining a projected wake turbulence of the target aircraft within the airspace, wherein the ownship aircraft is configured to be operated to avoid the projected wake turbulence.