



1
00:00:00,460 --> 00:00:01,600

[Music]

2
00:00:01,720 --> 00:00:08,360

>>Over 41,000 airports are scattered across our planet, housing more than 23,000 airplanes.

3
00:00:08,520 --> 00:00:14,480

Everyday, everywhere, air traffic controllers keep pilots and passengers safe from not only

4
00:00:14,480 --> 00:00:17,460

collisions, but also wake encounters, which can be just as dangerous.

5
00:00:17,560 --> 00:00:20,280

[Airplane flying]

6
00:00:20,460 --> 00:00:23,940

A wake is created whenever a vehicle passes through a medium.

7
00:00:23,949 --> 00:00:29,199

A common example are the waves created by a boat moving across a body of water.

8
00:00:29,199 --> 00:00:31,279

Aircraft wakes are a bit different.

9
00:00:31,279 --> 00:00:35,950

>>When a vehicle is flying, it generates high pressure underneath and low pressure on top.

10
00:00:35,950 --> 00:00:42,050

So the high pressure wants to go to the low pressure, and so behind an aircraft, you have

11
00:00:42,050 --> 00:00:44,550

these counter-rotating vortices.

12
00:00:44,550 --> 00:00:51,370
There is this invisible wake with this upwash
portion on the outboard part of that counter-rotating,

13
00:00:51,370 --> 00:00:52,750
and then a downward on the inside.

14
00:00:52,750 --> 00:00:57,150
Just think of them as horizontal tornadoes.

15
00:00:57,150 --> 00:01:01,760
>>Wake vortices are invisible and can continue
for several minutes before dissipating, so

16
00:01:01,760 --> 00:01:05,610
air traffic controllers must keep several
miles' distance between airplanes.

17
00:01:05,610 --> 00:01:09,920
This can result in inefficient flight paths
and delays, especially if portions of airspace

18
00:01:09,920 --> 00:01:14,220
are shut down due to things like volcanic
ash plumes or severe thunderstorms.

19
00:01:14,500 --> 00:01:17,620
[Music]

20
00:01:18,080 --> 00:01:22,210
Engineers at NASA's Armstrong Flight Research
Center are testing new technologies and methods

21
00:01:22,210 --> 00:01:28,740
to help aircraft identify where wakes are,
and avoid them- or even ride them.

22
00:01:28,740 --> 00:01:31,840

[Music/cockpit ambience]

23

00:01:32,000 --> 00:01:37,060

>>NASA's been interested in improving the efficiency of flight from its initial inception.

24

00:01:37,070 --> 00:01:42,070

Some conventional, and some unconventional; and this is really one of the unconventional

25

00:01:42,070 --> 00:01:43,420

ways.

26

00:01:44,560 --> 00:01:47,100

It's really biologically inspired.

27

00:01:47,110 --> 00:01:51,890

If you've ever seen a flock of geese, the reason they fly in a 'v' is that the trailing

28

00:01:51,890 --> 00:01:58,619

birds are really gaining efficiency from the lead bird by flying in the upwash caused by

29

00:01:58,619 --> 00:02:01,659

vortices generated by the wing in flight.

30

00:02:01,659 --> 00:02:07,110

Some of the early formation flights were military, in the early 1900s.

31

00:02:07,110 --> 00:02:15,400

In 2000 and 2001, Armstrong flew F-18s in formation, but really close, like within 150

32

00:02:15,400 --> 00:02:19,010

feet or so of one another, and showed efficiency that way.

33

00:02:19,010 --> 00:02:24,270

We've also done it in partnership with the Air Force on large transports, the C-17.

34

00:02:24,270 --> 00:02:27,880

>>In this experiment, it's one of the first times that this has ever been tried with a

35

00:02:27,880 --> 00:02:30,940

civilian airplane.

36

00:02:31,080 --> 00:02:35,880

[Music]

37

00:02:36,380 --> 00:02:43,180

Civilian are typically not quite as structurally robust as military aircraft, and the military

38

00:02:43,180 --> 00:02:45,580

aircraft tend to have their own specialized data links.

39

00:02:45,580 --> 00:02:51,120

One of the the barriers to transitioning wake surfing technology into the commercial sector

40

00:02:51,120 --> 00:02:56,560

is the cost that would be required to equip a lot of different airplanes with a specialized

41

00:02:56,560 --> 00:02:58,709

data link.

42

00:02:58,709 --> 00:03:03,760

Currently the air traffic control system uses ground based radar to track aircraft, and

43

00:03:03,760 --> 00:03:08,990

ground based radar have a fairly slow sweep rate, so you only get a position update from

44
00:03:08,990 --> 00:03:13,720
an aircraft about once every 12 seconds- you
can imagine a typical airliner flies quite

45
00:03:13,720 --> 00:03:16,120
a large distance in 12 seconds.

46
00:03:18,200 --> 00:03:22,790
Automatic Dependent Surveillance Broadcast
is an improvement upon that, where the airplane

47
00:03:22,790 --> 00:03:27,910
transmits its position and velocity information
twice per second and it can be very accurate

48
00:03:27,910 --> 00:03:30,500
if the airplane is equipped with GPS.

49
00:03:30,500 --> 00:03:34,850
So what we're interested in looking at is
'can we use this new data link, ADS-B, that

50
00:03:34,850 --> 00:03:42,730
the FAA has mandated for all airplanes operating
in Class A, B, and C airspace by 2020, can

51
00:03:42,730 --> 00:03:47,130
we use that data link for an application such
as wake surfing?'

52
00:03:47,130 --> 00:03:52,580
>>We're using the data link ADS-B between the
two vehicles, and predicting where that wake

53
00:03:52,580 --> 00:03:58,140
would be, and then flying near that wake to
try to gain efficiency.

54

00:03:58,140 --> 00:04:04,830

In doing so, we're really trying to also prove that we can use ADS-B as a way to do coordinated

55

00:04:04,830 --> 00:04:09,520

flight between multiple vehicles; if you wanted to, for instance, avoid the wake, you could

56

00:04:09,520 --> 00:04:14,920

still fly closer than what is currently allowed by the FAA, so that you could have an increase

57

00:04:14,920 --> 00:04:16,280

in aircraft density.

58

00:04:16,280 --> 00:04:19,520

>>What we're doing is looking at taking the next step and rather than trying to avoid

59

00:04:19,520 --> 00:04:24,840

the wake, we're trying to fly in a particular portion of the wake that has an updraft.

60

00:04:24,840 --> 00:04:29,600

The wake consists of two parts- the outboard parts, the air is rising, and in the center

61

00:04:29,600 --> 00:04:33,881

of the wake, the air is falling- so if you fly in the area where the air is rising, it's

62

00:04:33,881 --> 00:04:38,190

like gliders that soar in thermal updrafts, you can extract energy from that.

63

00:04:38,190 --> 00:04:43,340

Flying on the outboard part, the upwash, allows a trailing airplane to re-trim itself at a

64

00:04:43,340 --> 00:04:49,850

lower angle of attack, which reduces its induced drag; the less drag you have, the less engine

65

00:04:49,850 --> 00:04:54,330

thrust that you need, the less engine thrust you need, the less fuel you have to burn,

66

00:04:54,330 --> 00:04:58,300

and of course, the less fuel you burn, the fewer emissions come out the back of the airplane,

67

00:04:58,300 --> 00:05:03,210

so the ultimate objective of flying in the upwash portion of the wake is to reduce the

68

00:05:03,210 --> 00:05:06,480

fuel burn and the emissions of the trailing airplane.

69

00:05:06,480 --> 00:05:16,100

[Music/jet engine revving up]

70

00:05:21,440 --> 00:05:22,680

>>Ok, it's pilot's airplane.

71

00:05:24,860 --> 00:05:31,320

>>Copy that, and let's go ahead and start moving on to Card 9, and give 808 the lead.

72

00:05:32,800 --> 00:05:38,660

>>We would begin first by positioning ourselves about 4,000 feet back, and then to the side

73

00:05:38,669 --> 00:05:41,600

of and above where we estimated where the wake would be.

74

00:05:41,600 --> 00:05:45,610

And then we'd take what's called a tare, which is just a test point, it's vocabulary used

75
00:05:45,610 --> 00:05:50,979
from the wind tunnel, where you take data
with the wind off in a wind tunnel, and compare

76
00:05:50,979 --> 00:05:51,979
that to the wind on.

77
00:05:51,979 --> 00:05:57,020
We're gonna compare flight outside the wake
and flight inside the wake, and then we would

78
00:05:57,020 --> 00:06:01,630
step in and down to where we estimated where
the wake was.

79
00:06:01,630 --> 00:06:06,540
>>As we get closer to the wake, what we're doing
is we're looking at the data from the instrumentation

80
00:06:06,540 --> 00:06:11,630
that we have onboard, to try determine if
we're getting into the wake's area of influence.

81
00:06:11,630 --> 00:06:16,490
It's difficult to see that in fuel flow until
you get deep into the wake, but what you can

82
00:06:16,490 --> 00:06:21,520
start to see, because one area of the trailing
airplane is experiencing more upwash than

83
00:06:21,520 --> 00:06:24,449
the other wing, it tends to cause the airplane
to roll.

84
00:06:24,449 --> 00:06:30,180
And so our experimental autopilot was designed
to trim that out, and so when we looked at

85
00:06:30,180 --> 00:06:35,830
the roll command that our autopilot was having
to put in, we could tell that it was starting

86
00:06:35,830 --> 00:06:40,380
to sense where the wake was and starting to
have to do some work in order to trim its

87
00:06:40,380 --> 00:06:41,120
effects out.

88
00:06:41,220 --> 00:06:42,460
>>PPA is engaged...

89
00:06:42,680 --> 00:06:44,020
>>TCS released...

90
00:06:46,040 --> 00:06:47,060
>>saw the engage...

91
00:06:47,400 --> 00:06:48,500
roll command
is climbing...

92
00:06:49,500 --> 00:06:52,420
we're getting some long-term oscillations, so I think we're close...

93
00:06:53,440 --> 00:06:55,880
>>we're
gonna do a 5 foot step-in, to a cross-track

94
00:06:55,880 --> 00:06:57,040
of minus 75...

95
00:06:57,040 --> 00:06:57,680
>>ok...

96
00:06:57,680 --> 00:07:00,520

>>activating new command, 3, 2, 1-
activate...

97

00:07:01,580 --> 00:07:05,480

>>we're getting a little bit of buffeting, very slight, can you guys feel that in back?

98

00:07:06,300 --> 00:07:09,820

>>Just a little bit, but yeah.

99

00:07:09,830 --> 00:07:14,740

>>So wake surfing, particularly for commercial
aircraft, has a number of barriers to its

100

00:07:14,740 --> 00:07:15,740

adoption.

101

00:07:15,740 --> 00:07:17,889

One of the prime ones is passenger ride quality.

102

00:07:17,889 --> 00:07:20,350

>>You can't see it, but the aircraft can feel
it.

103

00:07:20,350 --> 00:07:24,949

>>When you fly in the wake of another airplane,
there's the potential that there are some

104

00:07:24,949 --> 00:07:30,039

unsteady aerodynamics that cause some vibration
in the wing and that gets transmitted to the

105

00:07:30,039 --> 00:07:35,460

passenger's seat, and they'll feel some vibration,
maybe something similar to light turbulence.

106

00:07:35,460 --> 00:07:40,331

And so we have special instrumentation onboard
to measure sound levels within the cabin of

107

00:07:40,331 --> 00:07:47,190

the airplane, as well as vibration in the seat rails, so that we can use some metrics

108

00:07:47,190 --> 00:07:52,300

on passenger ride quality to evaluate 'what would the comfort level be? or the degradation

109

00:07:52,300 --> 00:07:55,080

in comfort level be? when you're doing wake surfing.'

110

00:07:55,080 --> 00:07:57,550

So that's one of the concerns that we're trying to answer.

111

00:07:57,550 --> 00:08:00,660

Another is 'what are the effects on the aircraft's structure?'

112

00:08:00,660 --> 00:08:05,660

Typically, airplanes are designed for flying in a continuous airfield, not necessarily

113

00:08:05,660 --> 00:08:09,610

flying in the vortex of another airplane for any long period of time.

114

00:08:09,610 --> 00:08:14,130

It doesn't do any good to implement a technology that saves fuel if it requires the operator

115

00:08:14,130 --> 00:08:18,240

to do more maintenance and to take the airplane out of service more frequently so that they

116

00:08:18,240 --> 00:08:22,270

can inspect it and replace parts and things like that, so we want to make sure that this

117

00:08:22,270 --> 00:08:26,060

technology doesn't wear the airplane out quicker than it would normally.

118

00:08:26,800 --> 00:08:27,960

>>PPA is engaged...

119

00:08:28,120 --> 00:08:29,240

>>TCS released...

120

00:08:30,420 --> 00:08:33,540

>>ok, pilots, this is TC, as I imagine you can feel, we're right on the

121

00:08:33,540 --> 00:08:38,640

wake, so we're going try to sit here as long as we can, hopefully we can do about 5 minutes

122

00:08:38,660 --> 00:08:39,660

here.

123

00:08:39,669 --> 00:08:46,769

>>What we're noticing about this flight, I think, is that the power required to maintain a constant

124

00:08:46,769 --> 00:08:52,610

position when our wing tip is in the wake is less, than is required when we're not in

125

00:08:52,610 --> 00:08:57,579

the wake, which means we're gonna save fuel, that's the idea.

126

00:08:57,579 --> 00:09:03,350

>>For aircraft, that are flying 16-18 hours a day, it's a lot of fuel, even to save 1

127

00:09:03,350 --> 00:09:04,970

or 2 percent.

128

00:09:04,970 --> 00:09:10,740

So that's what we were looking at, was ways that you could improve the efficiency of vehicles by

129

00:09:10,740 --> 00:09:16,980

not changing the vehicles at all, but by changing how we use them, or operational efficiencies.

130

00:09:17,420 --> 00:09:20,440

>>Ok, and point complete...

131

00:09:20,440 --> 00:09:25,120

>>Ok, pilots this is TC, I'm gonna do a 300 step out to minus 400.

132

00:09:25,960 --> 00:09:30,640

[Airplane landing]

133

00:09:30,840 --> 00:09:34,700

[Music]

134

00:09:34,920 --> 00:09:41,319

>>I was even surprised by some of the flight dynamics, and things that we saw in flight.

135

00:09:41,319 --> 00:09:45,449

There really is no substitute for taking an experiment to flight.

136

00:09:45,449 --> 00:09:52,589

You learn things that sometimes you don't want to learn, but you also see the beauty

137

00:09:52,589 --> 00:09:59,379

of the real atmosphere and the challenges that are associated with real vehicles being

138

00:09:59,379 --> 00:10:04,399

flown by real systems and real pilots.

139

00:10:04,399 --> 00:10:09,389

So you can do lots of simulation, and you can do lots of experiments, but you eventually

140

00:10:09,389 --> 00:10:14,779

have to take it to flight, and that was really the focus of this experiment, was, even though

141

00:10:14,779 --> 00:10:19,739

there were lots of predictions that were well sustained, we wanted to take it all the way

142

00:10:19,739 --> 00:10:25,829

to flight to find out the things that we don't know, because you're often surprised by the

143

00:10:25,829 --> 00:10:26,989

things you don't know.

144

00:10:26,989 --> 00:10:33,120

>>So based on the results of these flight tests, we believe that we'll be able to show a significant

145

00:10:33,120 --> 00:10:38,239

amount of drag reduction and also make a determination as to whether the ride quality associated