NASA-TM-77463

NASA-TM-77463 19850004213

NASA TECHNICAL MEMORANDUM NASA TM 77463

WIND SHEAR MEASURING ON BOARD AN AIRLINER

P. Krauspe

Translation of Contributions to the Tenth Symposium on Aircraft Integrated Data Systems, held March 26-27, 1980 in Aachen, West Germany; Deutsche Forschungs- und Versuchsanstalt fuer Luft and Raumfahrt, Institute fuer Flugfuehrung, Braunschweig, West Germany, Report DFVLR-Mitt.80-09, pp. 96-119.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20231 MAY 1984

STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
TM-77463		
4. Title and Subtitle WIND SHEAR MEASURING ON BOARD AN AIR-LINER		5. Report Date May, 1984 6. Performing Organization Code
7. Author(s) P. Krauspe		8. Performing Organization Report No. 10. Work Unit No.
9. Performing Organization Name and Address Leo Kanner Associates Redwood City, CA 94063		11. Contract or Grant No. NASw-3199 13. Type of Report and Period Covered translation
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration, Washington, D.C. 20546		14. Sponsoring Agency Code

15. Supplementary Notes

Translation of "Bordintegrierte Flugdatensysteme' in beitraege zum 10 symposium on 26 and 27 March, 1980, Report DFVLR-Mitt. 80-09, pp. 96-119.

16. Abstract

A research project is introduced which continuously determines the wind vector on board an airliner during take-off and landing. The project is planned for one year and is intended to deliver sufficient statistical background concerning the low frequency wind changes in the atmospheric boundary layer as well as extended knowledge about deterministic wind shear modeling. First results of the recently started reserach program will be demonstrated.

17. Key Words (Selected by Author(s))	18. Distribution Statement
	unlimited-unclassified

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22.
unclassified	unclassified		

N81-20011 (ORIGINAL)
N85-12521#
N-154,663

Foreward

The research project described in the following report was financed within the framework of the special research area 58 "Flight Management" of the Technical University of Braunschweig by the German Research Association (DFG) and was made possible by the obliging cooperation of the Deutsche Lufthansa AG, which besides an aircraft of the airbus A300 type, made available considerable personal and technical means. We would like to express our hearty thanks here in particular to Messrs. Filz, Ladwig, Ledermann, Mueller and Voigt in Hamburg, also Messrs. Demmler, Muenchhof and Simon in Frankfurt.

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1. Introduction /99*

A series of serious aircraft crashes at take-off and landing in recent years drew the attention of the international aeronautical research to a phenomenon, to which previously apparently too little attention had been paid: the problem of wind shear in the critical flight phases, in which the aircraft flies in the lowermost region of atmosphere /1/. Only the progressive use of navigation plans, which allow an onboard determination of the ground speed, and the simultaneous extension of the recordings of the flight recorder made it possible to analyze comprehensively the interactions between the aircraft movement and the movements of the atmosphere. In this connection it is repeatedly established that statistical statements on the wind shears which may be designated also as variations of the wind with very low frequency or high wave length, are only available incompletely. This is to be attributed among other things to the fact that wind measurements on high towers are limited to the structural height of the towers, while the structural works for obvious reasons are mostly not near commercial airports. Balloon flights for wind measurement give only few measurement values in the altitude range of interest here of about 1 km of the large measurement intervals (every minute).

To lay out the flight regulators compensating wind shear and the filters needed for this purpose to separate the high frequency gust component and the low frequency deterministic shear wind disturbances, an effective increase of knowledge on the statistical properties of these wind variations is needed. The measurement described hereafter should serve for this purpose.

*Numbers in the margin indicate pagination in the foreign text.

2. Principles of Wind Measurement

On the example of an aircraft crash during the approach for landing /2/, the dangers of wind shear will be indicated briefly. At the same time, the possibilities of determining the wind components will be discussed.

Approaches for landing are today carried out in most cases with constant speed of flight, at about 1.3 times the stalling speed of the aircraft, and also with constant angle of position, which is pregiven for example in instrument landing by a glide path transducer. Constant /100
head wind components or to a limited extent also permissible tail wind components are taken into consideration by pilots by suitable adjustment of the propulsion unit thrust. If the wind velocity varies, the trajectory speed must be adjusted to maintain the flight velocity constant, for this inertial velocity $\vec{V}_K$ measured with regard to the earth's reference system consists of the relative speed V of the aircraft against resting air (space or flight velocity) and the speed $\vec{V}_W$ of the air masses against the earth (wind velocity) (Figure 1):

$$\vec{V}_K = \vec{V} + \vec{V}_W \; . \qquad (1)$$

In June, 1975 a Boeing B 727 aircraft flew at the New York Kennedy Airport in the horizontal secondary squall front of a storm (Figure 2). Because of the sudden increase of the head wind the aircraft got above the intended glide path. By adjusting the thrust level the pilot was able however to correct this effect. In the course of the further approach to the storm center, which at that time was almost directly above the airport, the horizontal wind component decreased because of the flight mechanical laws, on which this meteorological process was based, while an incorporated eddy movement caused a strong anabatic wind and downwash component to act on the aircraft. Since there was obviously no reaction of the pilot to this wind variation, finally the aircraft crashed about 1 km before the runway and was totally destroyed. But a suitable correction of the propulsion unit power would have allowed a safe flying through the situation, as it was possible to prove in simulation calculations /3/.

The decisive cause of the accident was a wind shear, that is the variation of the wind vector (here in amount and direction) along the pregiven trajectory. If we wish to measure the wind velocity in amount and direction, we must form according to the equation (1) the difference between the trajectory speed of the aircraft and the space velocity.

To this end it is necessary to represent the components of the three velocity vectors in a reference system of coordinates, for example, in a geodesic system of axes (Figure 3). In the required phase transformation no less than seven different angles of rotation must be taken into consideration.

The following quantities must be known individually: /101

a) Air Data:
   (1) Angle of attack of the air with regard to the aircraft:
       Angle of incidence α
       Sideslip angle β
   (2) Value of the face velocity V

b) Inertial Data:
   (1) Angle of the flight trajectory in space:
       Trajectory angle γ
       Track angle χ
   (2) Value of the trajectory speeds V_K
   (3) Position of the aircraft in space
       True heading ψ
       Angle of pitch θ
       Angle of bank Φ

An idealized example will show (Figure 4) how important it is to know completely all the above-mentioned quantities.

Let us assume that a measurement aircraft flies at constant altitude on a geodesically established circumference with constant angle of bank and constant velocity of flight, which can be assured for example by suitable adjustment of the propulsion unit power. A constant north wind component as an example will then be found again in the trajectory speed, as shown in Figure 4b.

Only in places (1) and (3) in which the aircraft course above ground and the wind direction are parallel to each other, can the wind velocity be obtained directly from the figure, in all intermediate positions, the wind can be described only in a spatial representation. Only the knowledge of the trap angle allows us to obtain by calculation the constant wind component, while here for many other quantities highly simplifying assumptions were made. It can easily be imagined that for any maneuvers in aircraft operation, in which the simplifying assumptions do not apply, all the above-mentioned parameters must be known.

3. Wind Measurements on Board an Airliner /102

The prerequisite for the reliable description of the statistical properties of wind shears is, like for all statistical investigations, a sufficiently large number of individual measurements. In this research project this means the recording and evaluation of flight data of the largest possible number of take-off and landing phases. The high number of flight movements required for this purpose is only found in commercial airlines.

Now the aircraft of commercial airlines are operated primarily under the aspect of economy and not as a basis of scientific research programs. On the other hand the modern jet commercial aircraft, and in particular here the large capacity aircraft are for various reasons particularly predestined precisely for the above-mentioned purposes:

--Because of the manifold flight management and flight monitoring missions the modern aircraft are equipped with an extraordinarily large number of sensors, which measure all the imaginable flight and operating state quantities and represent them as electrical signals. Thus they provide almost at any moment information on the corresponding flight information and the operating state of partial systems such as drive, control, etc., but also on environmental conditions, such as for example wind and external temperature;

--The commercial airline companies are seeking increasingly to increase the extent of the flight data currently recorded on board over and above the minimum required by the licensing authorities for aircraft accident recorders /4/ (at present five parameters: time/pressure level/indicated flight velocity/ vertical acceleration/control cause). Here the purpose is to improve the flight safety and economy of flight operation, say by early determination of defects in partial systems (for example propulsion units) or by the automatic monitoring of the intensive cost operating sequences with subsequent trend analysis (for example specific fuel consumption over the time).

For this purpose a large number of parameters are recorded with an aircraft integrated data system (AIDS), prepared for a recording and later evaluated in a ground station.

The technical possibilities described provided in this case almost /103 ideal conditions under the scientific aspect, to carry out current on board measurements of winged data during normal flight operation over a long period. But on the other hand a number of problems arose in very different sectors, which required primarily a comprehensive solution. On one hand the results of the planned research project which should be used primarily to improve the knowledge of the properties of wind shears, cannot be considered as of direct economic benefit for the airline concerned, here the Deutsche Lufthansa under the aspect of gain orientation. The instrument technology investments needed for implementing the measurements have therefore to be taken over by the project planner, in this case the special research area 58 "Flight Management" in the framework of the support on the part of the German Research Association (DFG), while the airbus A300 (Figure 5) was selected as "measurement aircraft".

On the other hand the higher purpose of the reserach, the improvement of flight safety in take-off and landings, even under shear conditions, is fully in the interest of the airline company. For this reason the Deutsche Lufthansa very kindly took over the incorporation of the measurement plan described below including the maintenance and operation, as well as the costs for implementing the measurements, that is for the flight hours.

Another problem in the implementation of the research project was in the legal area. Keeping in mind the Federal Data Protection Law /5/ it had to be assured with absolute certainty, that no personal data could be stored or transmitted. This had to be ensured by the special structure of the measurement plant and the separate transmission of data which were not personally critical, such as the take-off and landing airport by means of an aircraft circulating list. Since we were only interested in recording and issuing in a tabulated form the prevailing wind conditions and take-off and landing, on which the pilots have no effect at all, it was possible to omit entirely the assignment with regard to the participating flight personnel, so that the measurements take place practically anonymously.

4. Structure of the Measurement Plant in the DLH Airbus /104

The structure of a suitable measurement plant proved to be necessary for another reason besides the already indicated aspects of data protection. The required inertial state quantities (trajectory speed V_K, flight track angle χ) occur as digital quantities at the outlet of the inertia platforms existing in the modern large capacity aircraft (Inertial Navigation System, INS), but are at present not yet recorded in the routine AIDS.

The data on wind velocity and wind direction, which are obtained in modern aircraft operation in the central inertial navigation computer and which can be made available to the pilot of the control display unit (CDU) on requirement, have a precision which is too low for the planned measurements. This is because to calculate the values in the computer of the INS plant, highly simplified equations are used, which lead for example in curvilinear flight with large angle of bank to very large errors /6/. The relationships used are sufficient for the original purpose, the determination of the wind in the cruising flight. To calculate exactly all components of the wind vector, however the complete use of all the crude data described already in Section 2 are inaccessible /7/.

To record the data the existing AIDS plant in the airbus was practically doubled. The routine plant in the airbus (Figure 6) consists of the flight data acquisition unit (FDAU), which converts the various (analog/digital) signal structures into a uniform digital structure in pulse code modulation (PCM), also the data recording instrument (Performance and Maintenance Recorder, PMR) a magnetic tape recorder equipped with cassettes. These cassettes have the capacity of 50 hours recording time and are changed on a routine basis. The PCM data structure includes a main frame of 4 seconds duration, which is subdivided into four subframes each of 1 second and an extent of each time 64 by 12 bit data words. Thus it was possible to record at maximum 256 data words of 12 bit lengths or more data words of lower bit length. For example one bit is sufficient for the functional control of switch positions. The structurization corresponds to the standard ARINC 573 /8/. The /105
inertial data contained in the serial data flow of the inertial platform have on the other hand a length of 32 bits, while 21 bits are available as pure data content. Therefore an additional instrument had

to be set up, which would make it possible to make available the 12 most significant bits (MSB) for the desired inertial quantities, transforming the latter into an FDAU compatible series data format and transmitting them on a synchronized pulse to the FDAU. This special interface was developed (Table 1) for the four quantities:

Trajectory speed	V_K	(ground speed, G/S)
True heading		(true heading, THD)
Track angle		(track angle, TRK)
Total air temperature	T_t	(total air temperature, TAT)

The signals of the additional device reach just like the data obtained parallelly from the Air Data Computer (ADC) and the other measurement quantities, the input of an additionally incorporated FDAU equipment and are processed there for recording in a PMR recorder, which is used only for shear wind measurements. This magnetic tape recorder is connected through a special time circuit in such a way that:

that it remains operating:
in the landing from the extension of the undercarriage or below 1,000 feet altitude above ground until landing,
for a possible missed approach or in take-off after lifting off — each time 4 minutes after connection.

An incorporated logical circuit (Figure 7) gives the connection and disconnection pulses needed for this purpose. In this way it is achieved that only the desired wind data from the take-off and landing phase are recorded, so that the cassette needs to be changed only about once a week.

The additionally installed measurement plant was designed according /10 to the following principles:

a) The priority consideration is safety of the flight, which must not be affected adversely or influenced under any circumstances by operating the plant. Therefore the absolutely safe operation of all the incorporated devices must be assured. These include among others the freedom from electrical repercussions through high resistance signal inputs, the protection against electromagnetic interference beams, but also the operating and loading safety in case of possible fire, for sudden quick change of pressure among others. Before the final incorporation the additional equipment built was made to undergo an airworthiness testing, which was carried out by the Deutsche Lufthansa in aeronautical operation (EA 15).

b) The minimum possible density, construction in standard fibers (half or 1 ATR);

c) Operation of the plant with minimum possible additional costs for the flight and maintenance personnel. It was possible to achieve this by the automatic operation of the measurement plant with a time switching logical device and by using a magnetic recording of the same time as the one already used on a routine basis as PMR device. The need for changing the cassette is signaled optically after describing completely the magnetic tracks, and the cassettes are then changed during the routine maintenance of the standard recorder.

5. Implementation of the Research Program /107

Altogether 23 different parameters are recorded on a routine basis (Table 2). The interrogation rate of the individual quantities is between 0.25 and 4 Hz, while signals in the most different format (analog/synchro/digital/discrete series) exist. Through the time switching logical unit the magnetic tape has a continuous sequence of data of take-off-landing-take-off-landing, etc.

After changing the cassette the PCM data are demodulated in the large computer plant of the Lufthansa base in Frankfurt taking into account the corresponding sensor characteristics, reconverted into physical quantities (engineering units), such as angles, speeds, etc. There are actually no calibration curves of the sensors used in the indicated "measurement aircraft", since the calibration in the automatic measurement range, as is easily apparent, cannot be implemented. All measurement sensors are however subject to strict tolerance requirements of the airline and are changed when these limits are exceeded, so that the measurement errors can be sufficiently limited by this means.

The parameters of wind measurements are converted in the sliding representation on the 9-channel magnetic tape and can then be evaluated in a computer plant of the Technical University of Braunschweig (NOVA 3 D from Data General). The evaluation includes the following areas:

1) Representation of the variations of the longitudinal, lateral and vertical wind components over the parameters time, aircraft and flight altitude;

2) Establishment of the deterministic shear wind models from the variations according to 1) with simultaneous consideration of the corresponding meteorological boundary data. For this purpose the transmission of the weather recordings from the logbook of the aircraft for the corresponding take-off and landing was combined. These data were supplemented by weather maps and meteorological weather information (meteorological air reports, METAR) of the German Weather Service in Offenbach;

3) Investigation of the relationships between wind shears and temperature variations and the stability properties of the atmosphere;

4) Statistical evaluation of the wind data with regard to: /108
the frequency of occurrence of wind shears as a function of the place and the atmospheric boundary conditions; characteristic quantities of the wind shears such as shear layer thickness, shear gradients and their combinations, the frequency range and wavelengths of these low frequency wind variations.

To this end the ordinary statistical evaluation methods such as power density spectra, autovariancy functions, distribution density, etc. are used.

The airline network of the airbus includes the European area as well as some North African airports. Although these geographical regions are not among the typical areas of strong wind shears (according to the little experience acquired up to now they lie in the tropical belt and mostly on the east side of the large continents, such as East America or East Asia), it should be interesting to learn how frequently and with what intensity such weather phenomena occur also in our latitudes.

6. Summary

The want of applicable wind models to represent wind shears lead to the conception of the research program, which would provide over one year on board an Airbus A300 of the Deutsche Lufthansa data on wind and gusts in the take-off and landing phase. The equipment of an airline aircraft with an additional aeronautically compatible data recording plan secures the necessary large number of measurements, without injuring the flight safety or the continuity of normal flight operation. The first results are expected in the course of this year.

REFERENCES

/1/ Krauspe, P. Danger to Flight Safety from Shear Wind. DGLR Yearbook, 1977, Vol. 1, Chapter 29.

/2/ Eastern Air Lines Inc., "Aircraft Accident Report - Boeing 727-225", N 8845 E, Jamaica, New York, June 24, 1975; National Transportation Safety Board, USA, NTSB-AAR-76-8, March, 1976.

/3/ Brockhaus, R. and Wuest, P., "Open-Loop Compensation of Windshear Effects in Low Level Flight," in AGARD-CP-240, Guidance and Control Design Considerations for Low Altitude and Terminal Area Flight, Dayton, October, 1977.

/4/ Operating Orders for Aeronautical Instruments (Air BO). Federal German Institution for Flight Safety, February, 1979.

/5/ Federal German Protection Law BDSG of 27 January 1977, (BGBl. I. page 201); Law for the Protection against Abuse of Personal Data in Data Processing.

/6/ Clement, O. R. "INS Wind Computations during Turns - Concorde", Memorandum DE-76-3210-42 of June, 1976, Delco-Electronics, Milwaukee.

/7/ Krauspe, P. and Klenner, J., "Consideration of the Effect of the Wind in Flight Mechanical Equations", Z. Flugwiss. Weltraumforsch. 3 (1979), Heft 1, pages 23-28.

/8/ ARINC 573 - Aircraft Integrated Data System, Mark 2, Aeronautical Radio, Inc., December, 1974.

/9/ Higgins, P. R. and Roosme, A., "Hazards of Landing Approaches and Take-offs in a Windshear Environment", Boeing Airliner. The Boeing Company, Seattle, January, 1977.

TABLE 1: SPECIFICATION OF DIGITAL DATA WORDS

Word	Bits (INS/TRC)	FDAU		
		Subframe	Word	Source
ground speed	16 - 27	1, 2, 3, 4	2, 18, 34, 50	digital # 4
true heading	18 - 29	1, 2, 3, 4	5	DADS
	30 - 32	1	23 (1 - 3)	DADS
track angle	18 - 29	1, 3	21	DADS
	18 - 29	2, 4		
	30 - 32	1	23 (5 - 7)	
TAT	20 - 31	2, 4	55	DADS

first transmitted bit: least significant bit (LSB)

last transmitted bit : most significant bit (MSB) bzw. Status

TABLE 2: DATA ADDRESSES FOR WIND MEASUREMENTS ON BOARD DLH AIRBUS D-AIBA

Data Addresses for Shear Wind Measurements on Board the DLH-A 300

Positions: 7/79

Word	Parameter	Sub- *) frame	Range	Signal	Bit
1	synchronization			digital	1 - 12
2	ground speed		819,2kts(16-27)	digital # 4	1 - 12
3	outer marker			discrete serie	1, 2
3	middle marker			discrete serie	1, 2
3	magnetic heading			synchro	3 - 12
4					
5	true heading		± 180° (18-29)	digital DADS	1 - 12
6					
7					
8					
9	vertical speed		250 mV/1000 fpm	AC # 1	3 - 12
10	lat. acceleration			LLDC	1 - 12
11	angle of attack			Poti	1 - 12
12	altitude press. fine			synchro	1 - 12
13	event marker			discrete serie	1
13	vert. acceleration			LLDC	3 - 12
14					
15	long acceleration			LLDC	3 - 12
16					
17	roll attitude			synchro	3 - 12
18	ground speed			digital # 4	1 - 12
19					
20	indicated airspeed			synchro	1 - 12
21	track angle		± 180° (18-29)	digital DADS	1 - 12
22					
23	matrix true heading	1	INS BITS 30-32	digital DADS	1 - 3
23	matrix track angle	1	INS BITS 30-32	digital DADS	5 - 7
24	radio altimeter # 2			HLDC	1 - 12
25					
26	lat. acceleration			LLDC	1 - 12
27	angle of attack			Poti	3 - 12
28					
29	vert. acceleration			LLDC	1 - 12
30					
31	long.acceleration			LLDC	3 - 12
32					
33					
34	ground speed			digital # 4	1 - 12
35					
36					
37	GMT minutes	1		digital	1-4, 7-10
37	GMT hours	3		digital	1-4, 7-10
38					
39					
40	True airspeed		46,6 kts/V **)	DC # 2	3 - 12
41					
42	lat. acceleration			LLDC	1 - 12
43	angle of attack			Poti	3 - 12
44	altitude press. fine			synchro	1 - 12
45	vert. acceleration			LLDC	3 - 12
46					
47	long. acceleration			LLDC	3 - 12
48					
49					
50	ground speed			digital # 4	1 - 12
51	pitch attitude			synchro	3 - 12
52					
53					
54					
55	Static Air Temperature	1, 3		DC # 2	
55	Total Air Temperature	2, 4	***)	digital	3 - 12
56	radio altimeter			HLDC	1 - 12
57					
58	lat. acceleration			LLDC	1 - 12
59	angle of attack			Poti	3 - 12
60					
61	vert. acceleration			LLDC	3 - 12
62					
63	long. acceleration			LLDC	3 - 12
64					

*) fur Subframes 1 - 4, wenn nicht anders vermerkt!

) $E_{SAT}/E_{ref} = 0{,}000310186$ TAS   *) $E_{SAT}/E_{ref} = 1{,}2087 \cdot 10^{-2} \sqrt{SAT}$

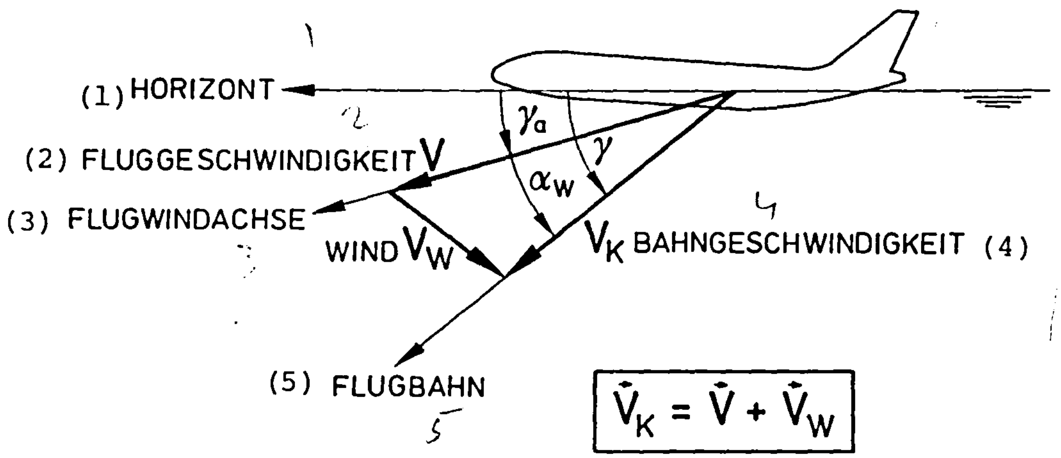


Figure 1: Angles and speeds in the aircraft plane of symmetry.
Key: (1)horizon; (2)flight velocity; (3)axis of the flight wind; (4)trajectory speed; (5)flight trajectory.

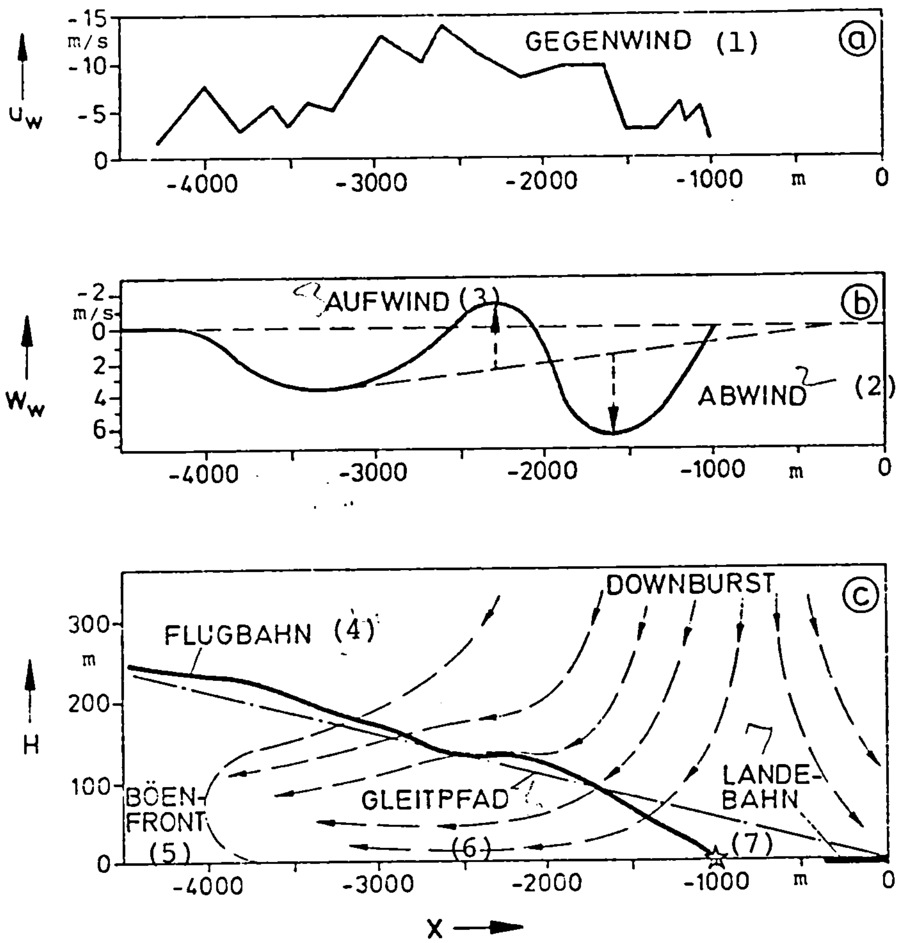
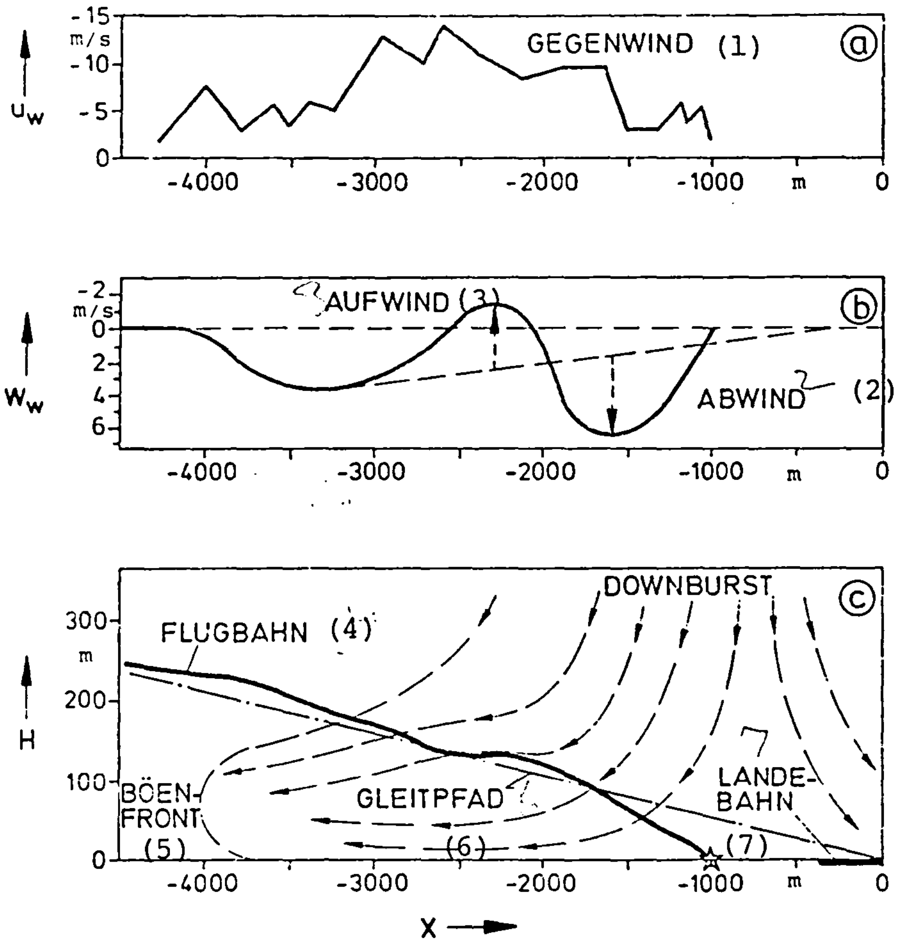


Figure 2: Conditions of the New York accident.
a) Variation of the horizontal wind over the path
b) Variation of the vertical wind over the path
c) Flight trajectory profile and flow line picture (according to /9/)

Key: (1) head wind; (2) downwash; (3) anabatic wind; (4) flight trajectory; (5) secondary squall front; (6) gliding path; (7) runway.



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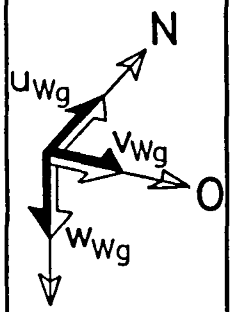

(1) Südwindkomponente: $u_{Wg} = V_K \cos\gamma \cos X - V \cos\gamma_a \cos X_a$

(2) Westwindkomponente: $v_{Wg} = V_K \cos\gamma \sin X - V \cos\gamma_a \sin X_a$

(3) Abwindkomponente: $w_{Wg} = -V_K \sin\gamma + V \sin\gamma_a$

(4) mit: α, β, V = (5) Luftdaten

γ, X, V_K = (6) Inertialdaten

ψ, Θ, Φ = (7) Lagewinkel des Flugzeugs

$\gamma_a, X_a = f(\psi, \Theta, \Phi, \alpha, \beta)$

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Figure 3: To calculate the wind speed component.

Key: (1) south wind component; (2) west wind component; (3) downwash component; (4) with; (5) air data; (6) inertial data; (7) position angle of the aircraft.

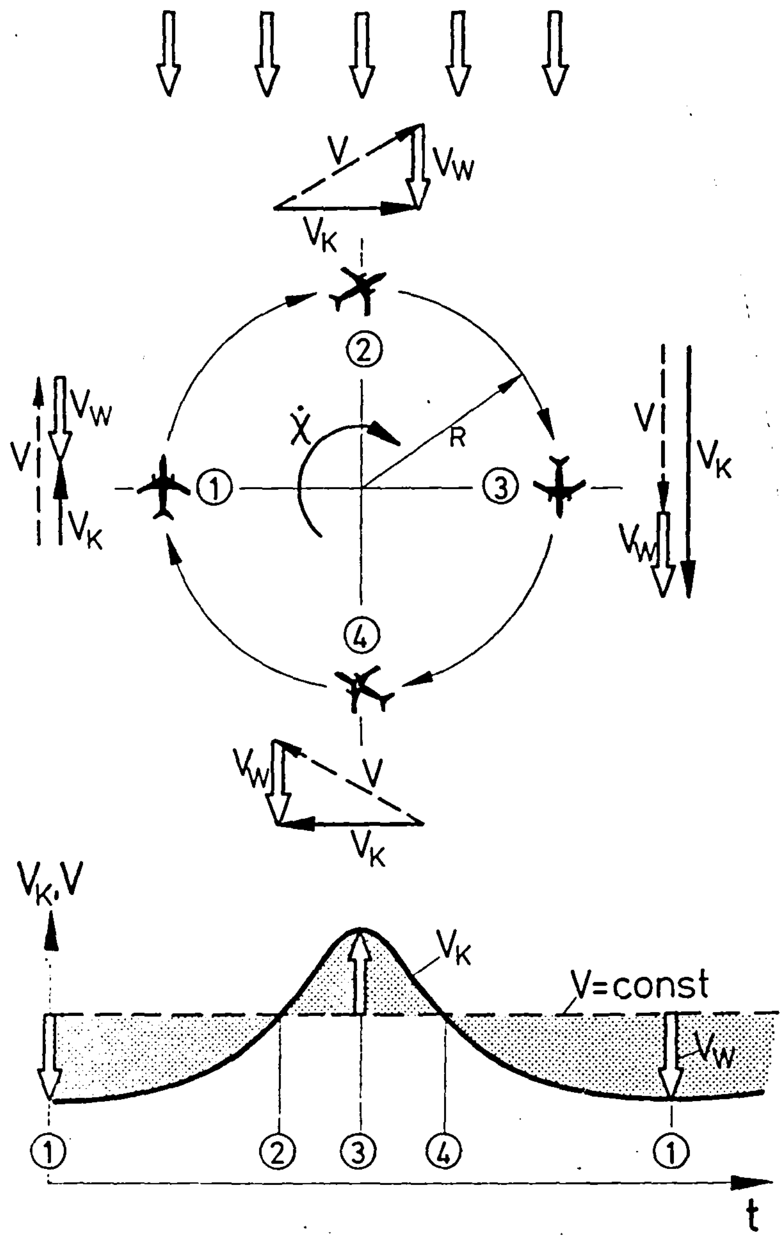

Figure 4: Idealized example of the wind measurement in flight.

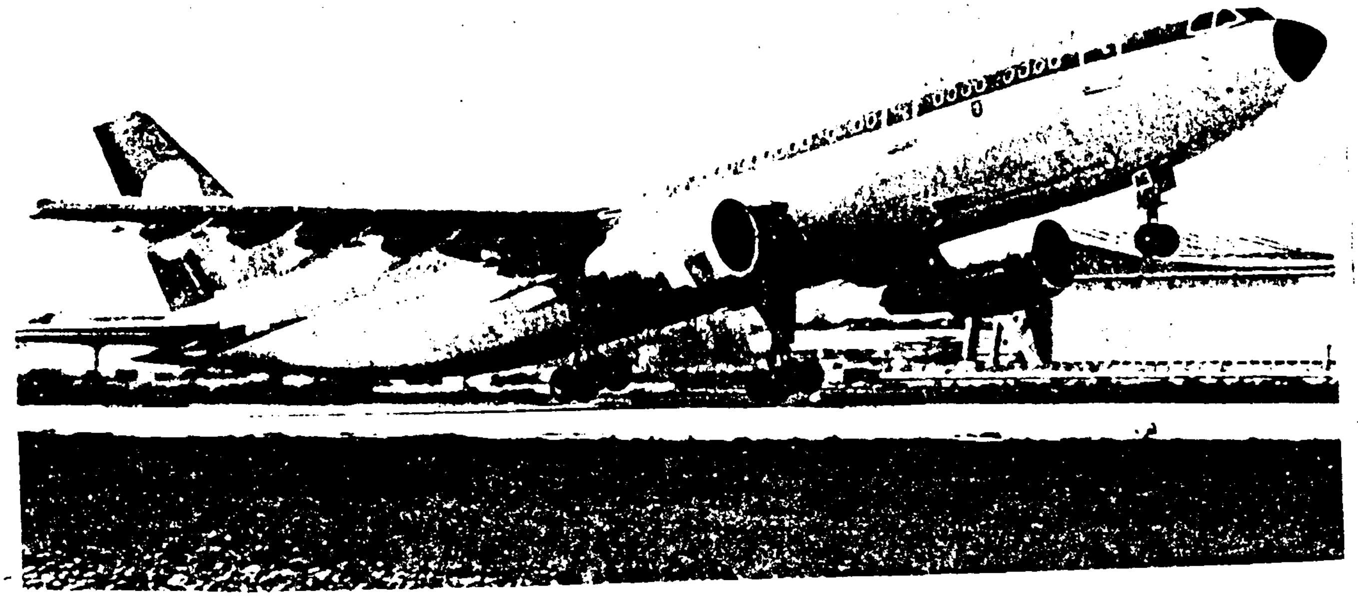

Figure 5: Basic aircraft airbus A 300 for shear wind measurements.

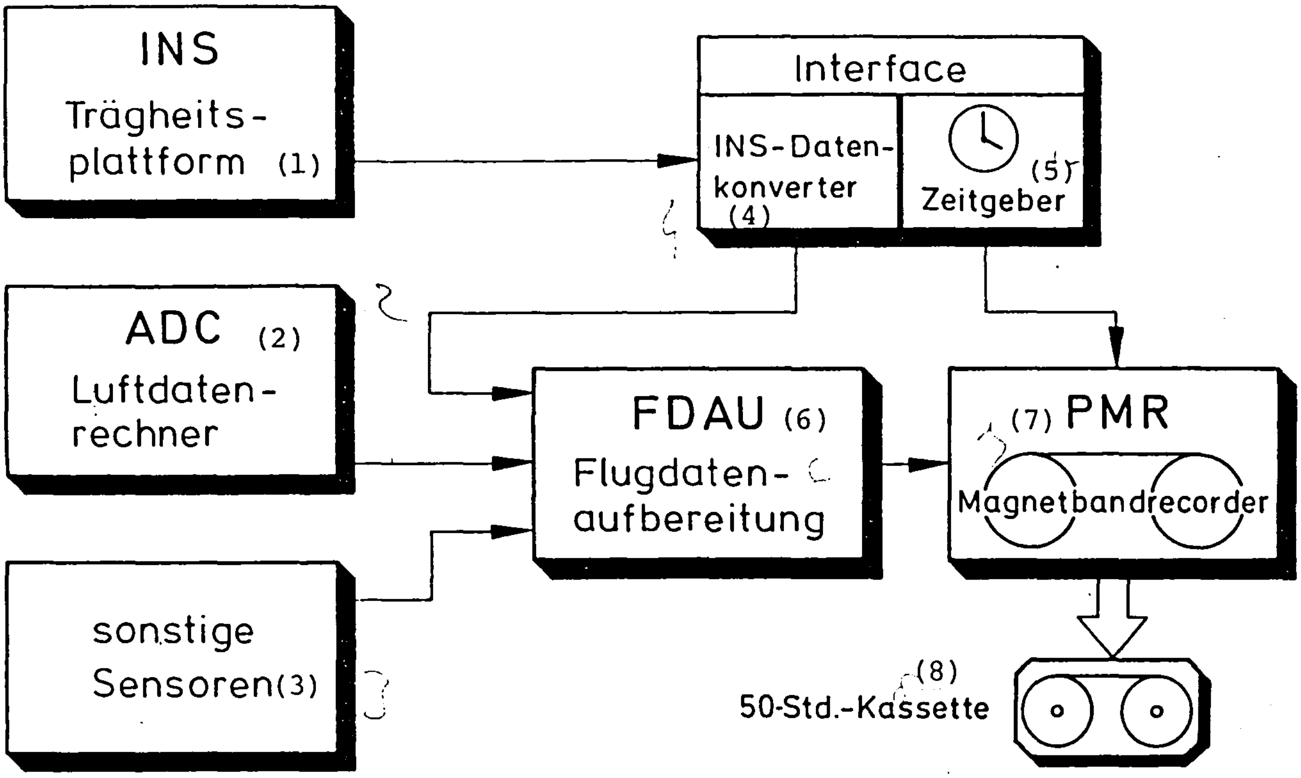

Figure 6: Structure of the measurement unit of wind shear measurement.
Key: (1)inertia platform; (2)air data computer; (3)other sensors; (4)INS data converter; (5)timer; (6)flight data processing; (7)tape recorder; (8)50 hour cassette.

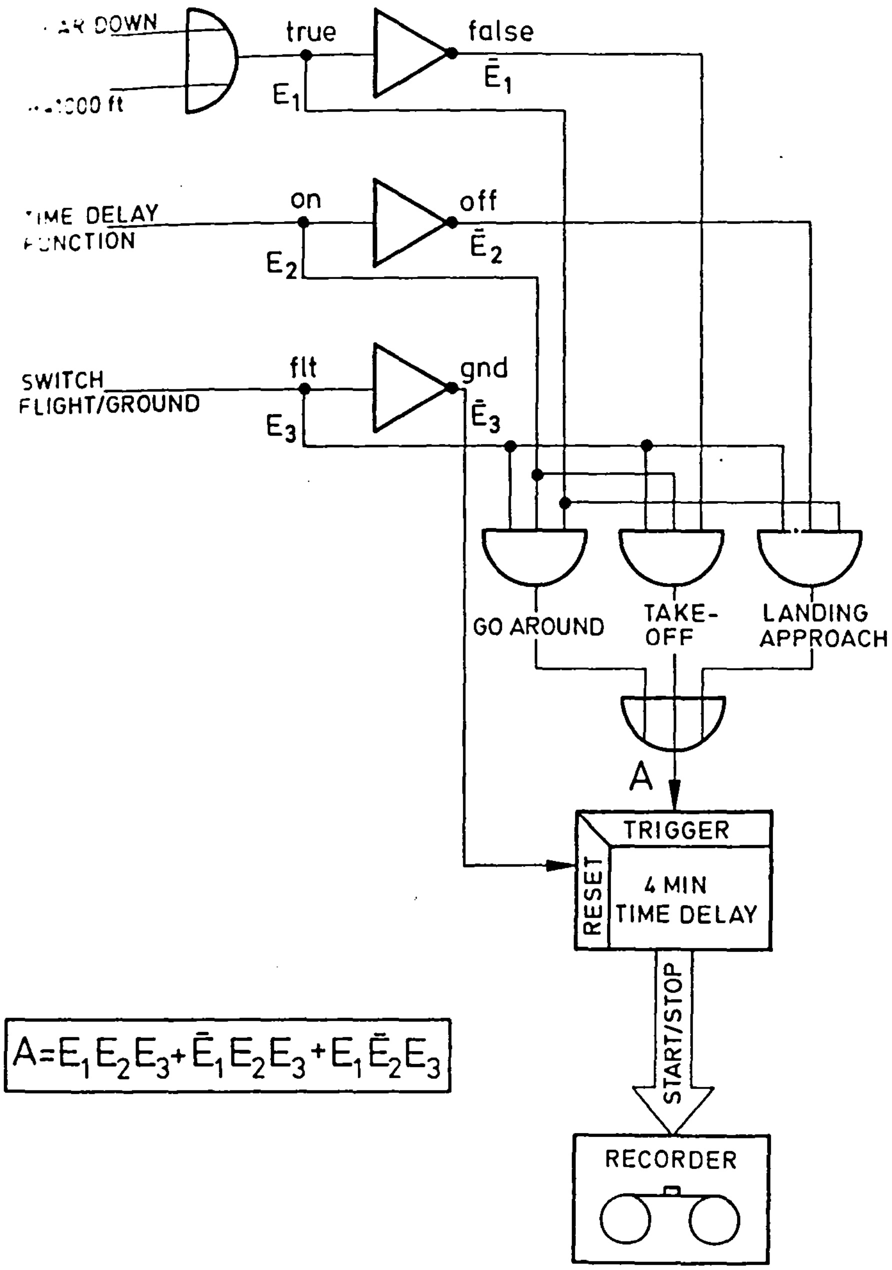

Figure 7: Switching logic for PMR time circuit.

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