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ABSTRACT

This paper is concerned with the guidance of an aircraft flight in the presence of windshear. Based on following a nominal approach path relative to the ground, and subject to a minimum airspeed constraint, two guidance laws are synthesized by inverse dynamics technique for take off and landing respectively. Simulation tests are performed in a six degree-of-freedom flight simulator for different windshear histories and different flight conditions, these results illustrate that the controlled aircraft could take off safely and follow the nominal landing path approximately in windshear, and the designed robust controllers are insensitive to both external windshear disturbance and the model parameters variation with change in flight conditions. The different results between manual operation and autopilot control for against windshear are also compared.

Key words : Simulation research, Flight control, Inverse dynamics control, Take off, Landing, Windshear

概　要

本報告は，ウインドシア中を飛行する航空機の制御について述べる。逆ダイナミックス法を用いて，最低速度に対する制限のもとで地面に対する設定径路を維持するための制御則を，離陸及び着陸の各々の場合について構築し，6自由度を持つ飛行シミュレータを用いて異なるウインドシア及び異なる飛行条件に対するシミュレーション試験を行った。その結果，ウインドシア中においても，制御対象の航空機は安全に離陸でき，着陸時にはほぼ設定径路を維持できることが分かった。さらに，設計された制御則は，ウインドシアによる外乱及び飛行条件の変化によるモデルパラメータの変動の双方に対してロバスト性を持つことが示された。また，ウインドシア遭遇時における，パイロットによる手動操縦と本報告に示した制御則による自動操縦の違いも示した。

1. Introduction

One of the most dangerous situations for an aircraft during flight is caused by the presence of low altitude windshears associated with microburst phenomena. A microburst is a strong, localized downdraft that strikes the ground, producing winds that diverge radially from the impact point. An aircraft penetrating through a symmetric downburst will initially encounter an increasing headwind, followed by a strong downdraft and rapidly increasing tailwind. The effects of downdraft and increasing tailwind may easily exceed the performance capabilities of aircraft, causing unavoidable accident, so the control of aircraft encountering windshear has gained considerabel importance in the recent past. Studies involved this problem have been carried out on different aspects such as modeling and identifying windshear as well as the design of controllers to enhance the chance for survival of aircraft while encountering windshear.

As is well known, once the aircraft becomes airborne during take off, the pilot has no choice but to fly through the windshear, so the study of how to control the aircraft effectively is very important. Primary among these studies, the so-called simplified gamma guidance scheme and acceleration guidance scheme are developed in References [1]-[3] based on attain-

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ing near optimal trajectories in the presence of a given windshear structure, another approach to solving the problem has been via deterministic control of uncertain system[4]-[7], the control of climb rate by means of the deviation of angle of attack from its nominal value is presented in Reference [4], in References [5][6] all the state variables and only the relative path inclination are stabilized respectively by the control of angle of attack, Reference [7] considers the stabilization of climb rate about a desired value utilizing an adaptive strategy with only the climb rate information is used.

For the control problem of aircraft landing in windshear, studies have been carried out on two aspects, i.e., abort landing and penetration landing. Clearly, if the initial altitude is high enough, abort landing is a safer procedure than penetration landing; on the other hand, due to the low nominal thrust setting and engine time delay, it may not be possible to abort the landing if the encounter altitude is low, so proceeding with the approach is safer in this case. In another aspect, the aircraft might have to traverse only a part of the shear region during penetration landing, but the aircraft might have to traverse the whole of the shear region in the abort landing. For abort landing another difficulty which should be overcome is the detection of downburst, reliable downburst detection and warning, especially by airborne forward look systems is still the subject of research, the downburst is difficult to detect until the aircraft starts into it. Probably the most effective approach to the accident prevention is still the pilot awareness and training, the study of control laws is therefore helpful since it suggests the piloting strategies for crew training and assists in the development of autopilots.

Among these studies the important efforts have been made in the past to study the approach landing of aircraft in windshear. In Reference [8] the problem has been solved by using a dynamic optimization method, in which the deviations from nominal altitude path and airspeed are penalized; Optimization study is conducted in Reference [9], and the limiting of windshear cases for safe landing penetration are determined; A proposed thrust law that maintains the inertial speed at the nominal value with the minimum airspeed constraint is developed in Reference [10] by using a simplified first-order aircraft model; Reference [11] determines the minimum airspeed along the landing path during windshear using a tilted vortex pair method; An active control technique is presented for aircraft landing approach through the wind field in Reference [12]; In Reference [13], a combination of feedforward and feedback concept is used to track airspeed and glide slope for aircraft landing approach proceeding.

The main emphases of these papers mentioned above involving the control of aircraft flight in windshear are on the feasibility of the proposed concepts, about how these control schemes can be realized by actual aircraft control and the details of design of practical autopilots are not considered.

In the opinion of author, the control of aircraft flight in the presence of windshear is a problem of stabilizing the flight path while the safe airspeed is guaranteed, this control problem can be solved by the effective inverse dynamics control theory, the minimum airspeed constraint is considered by selection the values of controlled command variables. No a prior information or assumptions about the bounds of the uncertain windshear is needed in deriving the controller. As the power is set maximum during take off especially in presence of windshear, only the elevator control is determined by the designed control law.

Having obtained two controls design for take off and landing respectively, different windshear models and different flight conditions are considered. For all these test cases the controllers are found to be strong robust control strategy to against the windshear encountered.

2. General Theory of Inverse Dynamics Control

For the form of general dynamic system

$$\dot{\boldsymbol{x}}(t)=\boldsymbol{A}(\boldsymbol{x})+\boldsymbol{B}(\boldsymbol{x})\boldsymbol{u}(t) \tag{1a}$$

$$\boldsymbol{y}=\boldsymbol{C}\boldsymbol{x} \tag{1b}$$

where $\boldsymbol{x}=(\boldsymbol{n}\times 1)$ state vector, $\boldsymbol{u}=(\boldsymbol{m}\times 1)$ control vector, $\boldsymbol{y}=(\boldsymbol{m}\times 1)$ output vector, $\boldsymbol{A}(\boldsymbol{x})=(\boldsymbol{n}\times 1)$ matrix, $\boldsymbol{B}(\boldsymbol{x})=(\boldsymbol{n}\times \boldsymbol{m})$ matrix, and $\boldsymbol{C}=(\boldsymbol{m}\times \boldsymbol{n})$ constant matrix $(\boldsymbol{m}\leq \boldsymbol{n})$.

Defining the $\boldsymbol{k}$th-order differentiation operator $\boldsymbol{L}_A^k(\cdot)$ as:

$$\boldsymbol{L}_A^k(\boldsymbol{x})=[\frac{\partial}{\partial \boldsymbol{x}}\boldsymbol{L}_A^{k-1}(\boldsymbol{x})]\boldsymbol{A}(\boldsymbol{x}) \tag{2a}$$

$$L_A^0(x) = x \tag{2b}$$

$$L_A^1(x) = A(x) \tag{2c}$$

Differentiating the individual element of y a sufficient number of times until a term containing a u appears.

$$\dot{y}_i = C_i\dot{x} = C_iA(x) + C_iB(x)u$$

$$= C_iL_A^1(x) + C_i[\frac{\partial}{\partial x}L_A^0(x)]B(x)u \tag{3a}$$

$$\ddot{y}_i = C_i\ddot{x} = C_i[\frac{\partial}{\partial x}L_A^1(x)]A(x) + C_i[\frac{\partial}{\partial x}L_A^1(x)]B(x)u$$

$$= C_iL_A^2(x) + C_i[\frac{\partial}{\partial x}L_A^1(x)]B(x)u \tag{3b}$$

$$\cdots$$

$$y_i^j = C_ix^j = C_i[\frac{\partial}{\partial x}L_A^{j-1}(x)]A(x) + C_i[\frac{\partial}{\partial x}L_A^{j-1}(x)]B(x)u$$

$$= C_iL_A^j(x) + C_i[\frac{\partial}{\partial x}L_A^{j-1}(x)]B(x)u \tag{3c}$$

The differential order d_i of system (1) can be defined as follows for $i = 1, 2, \cdots, m$.

$$d_i = min\{j: C_i[\frac{\partial}{\partial x}L_A^{j-1}(x)]B(x) \neq 0; \quad j = 1, 2, \cdots, n\} \tag{4}$$

After differentiating the m elements of output vector y, each an appropriate number of times, the output dynamics can be represented as

$$y^{(d)} = \begin{bmatrix} y_1^{(d_1)} \\ y_2^{(d_2)} \\ \cdots \\ y_m^{(d_m)} \end{bmatrix} = \begin{bmatrix} C_1L_A^{d_1}(x) \\ C_2L_A^{d_2}(x) \\ \cdots \\ C_mL_A^{d_m}(x) \end{bmatrix} + \begin{bmatrix} C_1\frac{\partial}{\partial x}L_A^{d_1-1}(x) \\ C_2\frac{\partial}{\partial x}L_A^{d_2-1}(x) \\ \cdots \\ C_m\frac{\partial}{\partial x}L_A^{d_m-1}(x) \end{bmatrix} B(x)u \tag{5}$$

Let

$$A_i^*(x) = C_iL_A^{d_i}(x) \tag{6a}$$

$$B_i^*(x) = C_i[\frac{\partial}{\partial x}L_A^{d_i-1}(x)]B(x) \tag{6b}$$

This allows (5) to be rewritten as

$$y^{(d)} = A^*(x) + B^*(x)u \tag{7}$$

For general system (1), if the decoupling control law exists on real space R,

$$u(t) = -F(x) + G(x)v(t) \tag{8}$$

where $v(t) = (m \times 1)$ vector, system (1) is decoupled by the control u on R if the i th input v_i affects only the i th output y_i for all $i = 1, 2, \cdots, m$, where v_i and y_i are the i th components of $v(t)$ and $y(t)$ respectively. The sufficient and necessary condition for the existence of control law (8) is that $B^*(x)$ be nonsingular on R[14].

If this is the case, then a series of matrices can be constructed

$$G(x) = [B^*(x)]^{-1} \tag{9a}$$

$$F(x) = [B^*(x)]^{-1}A^*(x) \tag{9b}$$

Substituting Eqs.(8) and (9) to Eq.(7) and it can be rewritten in the simple integrator-decoupled form.

$$y^{(d)} = v \tag{10}$$

That means y is decoupled by u. The inverse system model of system (1) can be represented as

$$\dot{x} = [A(x) - B(x)F(x)] + B(x)G(x)v \tag{11a}$$

$$u(t) = -F(x) + G(x)v(t) \tag{11b}$$

where $v = y^{(d)}$ and u are the input and output of inverse system respectively.

To improve the response behavior of output vector y, the input v can be chosen as

$$v = -\sum_{i=0}^{d-1} P_iy^{(i)} + P_0y_c \tag{12}$$

where $y^{(i)}$ is the i th derivative of the output vector y, and P_i chosen as $(m \times m)$ constant diagonal matrices; y_c is the new external control input, valued as the desired command of output vector. Therefore,

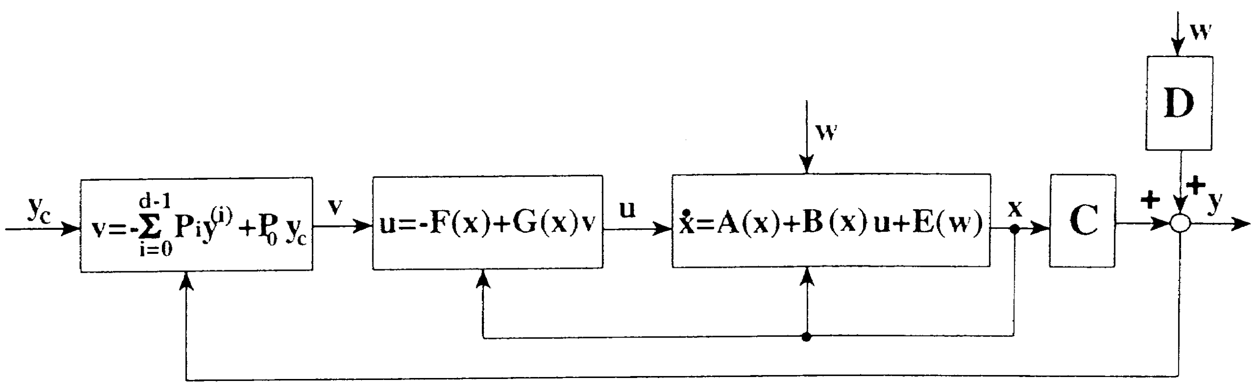

Fig.1 Block Diagram of Inverse Dynamics Control

the original system can be decoupled as a linear time-invariant dynamics.

$$y^{(d)}+P_{d-1}y^{(d-1)}+\cdots+P_0y=P_0y_c \qquad (13)$$

It is clear that as long as the coefficient matrices P_i ($i=0,1,\cdots,d-1$) are chosen appropriately, Eq.(13) has stable solution y_c. Substituting Eqs.(9) and (12) into Eq.(8) yields the inverse dynamics control law of general dynamic system.

Synthesizing the analyses above, the inverse dynamics approach to develop the control system is illustrated in Fig.1.

3. Equations of Motion

The longitudinal dynamics of aircraft flight in variable winds are modeled using perturbation equations written in a hybrid coordinate system consisting of combined body axes and earth axes. They are linearized about a reference equilibrium condition of constant flight speed, these equations may be written in the form

$$\Delta\dot{x}(t)=A(\Delta x)+B\Delta u(t)+E(\Delta w) \qquad (14a)$$

$$\Delta y=C\Delta x+D\Delta w \qquad (14b)$$

where Δx is the perturbation state vector, Δu is the perturbation control vector, and Δw is the perturbation longitudinal wind velocity vector, which is expressed in inertial coordinates and assumed to be uniform over the length and span of aircraft.

$$\Delta x=(\Delta u_a,\ \Delta w_a,\ \Delta q,\ \Delta\theta,\ \Delta\delta_T)^T \qquad (15a)$$

$$\Delta u=(\Delta\delta_e,\ \Delta\delta_{Tc})^T \qquad (15b)$$

$$\Delta w=(\Delta w_x,\ \Delta w_z)^T \qquad (15c)$$

$$\Delta y=(\Delta u_e,\ \Delta h)^T \qquad (15d)$$

Where Δu_a, Δw_a and Δu_e are the components of relative velocity and absolute velocity in the body axes respectively, Δh is the height deviation from the nominal landing trajectory. Δw_x and Δw_z are the horizontal and vertical wind components respectively. In this definition, $\Delta w_x>0$ is tailwind, and $\Delta w_z>0$ is downdraft.

The simulated aircraft is a research aircraft Dornier-228-200 of 5700kg gross weight. For take off flight the linearization reference equilibrium condition used for robust controller design is named condition 1, here $h_0=15.24$m(50ft), $\delta_f=5$(deg), $\delta_{TO}=100$(deg), $\delta_{e0}=0$(deg), $v_0=61.2$m/s(120kt), $\gamma_0=9.16$(deg). To test the robustness of designed controller in the flight condition different from the nominal design case, another reference equilibrium condition named condition 2 is also considered, where $h_0=15.24$m(50ft), $\delta_f=5$(deg), $\delta_{TO}=100$(deg), $\delta_{e0}=0$(deg), $v_0=56.1$m/s(110kt), $\gamma_0=10.01$(deg).

For landing flight the nominal condition used for controller design is named condition 3, here $h_0=152.4$m(500ft), $\delta_f=30$(deg), $\delta_{TO}=25.3$(deg), $\delta_{e0}=0$(deg), $v_0=42.33$m/s(83kt), $\gamma_0=-3$(deg), $\alpha_0=2.95$(deg). Another reference equilibrium condition named condition 4 is considered to test the robustness of designed control law, where $h_0=152.4$m(500 ft), $\delta_f=20$(deg), $\delta_{TO}=23$(deg), $\delta_{e0}=0$(deg), $v_0=44.37$m/s(87kt), $\gamma_0=-3$(deg), $\alpha_0=3.99$(deg). The height of flare switch point $h_{sw}=15.24$m(50ft). The resulting modal characteristics of flight conditions are summarized in Table 1.

4. Control System Design

For the control problem of aircraft flight in windshear, the flight path and airspeed are very important for the safety of aircraft, and the designed controller should exhibit normal behavior when there is no windshear and responds in a safe manner to the

Table 1. Summary of natural mode characteristics of Do-228

Flight Conditions	Take off		Landing	
Mode	short-period	phugoid	short-period	phugoid
Eigenvalues	$-1.4143\pm2.1240i$	$-0.0063\pm0.1673i$	$-1.0081\pm1.4565i$	$-0.0144\pm0.2483i$
ξ	0.5542	0.0376	0.5691	0.0579
ω_n(rad/s)	2.5518	0.1674	1.7713	0.2487
ω(rad/s)	2.1240	0.1673	1.4565	0.2483
$T_{1/2}$, $T_2(s)$	0.4900	110.0	0.6874	48.1250
$T(s)$	2.9567	37.5374	4.3117	25.2920

presence of a downburst. Besides, for landing flight a safe approach requires that the touchdown position be close to the specified location and that the inertial speed and sink rate at touchdown be reasonable. In order to stabilize the nominal flight path, altitude and inertial speed are chosen as two controlled outputs, thrust and elevator are two controls. The guidance problem is to regulate the following two outputs as accurately as possible,

$$y_1(x) = \Delta h = h(x) - h_n(x) \tag{16a}$$

$$y_2(x) = \Delta u_e = u_e(x) - u_{en}(x) \tag{16b}$$

and subject to various control bounds as well as a minimum airspeed constraint:

$$v_a \geqq v_{min} \tag{17}$$

where $h_n(x)$ and $u_{en}(x)$ describe the nominal flight path, v_a is the airspeed, the minimum airspeed is limited v_{min}=38.25m/s(75kt) to prevent the stall of aircraft.

Altitude command value Δh_c is selected to be zero. The selection of a suitable $(\Delta u_e)_c$ value requires the assessment of practical downburst characteristics, when the windshear especially the tailwind is encountered, the airspeed will decrease greatly and may be below than the allowed minimum airspeed while the aircraft maintains the inertial speed. To insure the controllability and to avoid stall, the airspeed must be constrained above a certain minimum level, so $(\Delta u_e)_c$ should be selected as the function of horizontal wind encountered.

$$(\Delta u_e)_c = \begin{cases} 0; & \Delta w_x < 0 \\ \lambda \Delta w_x; & \Delta w_x > 0 \end{cases} \tag{18}$$

A proper value of λ represents a compromise between maintaining the minimum airspeed limit and following the nominal flight path. A large λ causes the control to act as soon as the airspeed begins to deviate toward the minimum value, the airspeed constraint is then well maintained at the expense of a larger deviation from the nominal path. On the other hand, a small λ concentrates the control effort on keeping the nominal path until the violation of the minimum airspeed constraint is imminent. A conservative dealing method is that $(\Delta u_e)_c$ can be selected as the maximum value of tailwind speed especially the tailwind is constant.

Generally speaking, the nominal airspeed is higher than the allowed minimum airspeed greatly for normal take off, the minimum airspeed constrain is not a severe problem, usually λ can be selected as zero, except the encountered tailwind is very strong. But during the approach landing period, the normal flight speed is very low, in the simulation test of this paper, λ is selected as 0.65.

Table 2. Diagonal elements of constant matrices of control laws

Flight Phases	Take off			Landing		
Command Variables	P_2	P_1	P_0	P_2	P_1	P_0
Δu_e	0	0.45	1.65	0	2.45	0.25
Δh	0.55	0.65	1.05	6.25	2.75	14.25

Using the series of aircraft motion equations, two inverse dynamics control laws are derived by differentiating Δu_e twice, and Δh three times. As mentioned in general theory of control design, the sufficient and necessary condition for the existence of inverse dynamics control law is that $B^*(x)$ must be invertible, so any flight conditions that cause it to be singular must be avoided. For both take off and landing problems involved here, $|B^*(x)|$ are positive constants, so the inverse dynamics controllers can be constructed.

The elements of constant diagonal matrices of control law are chosen based on the response feature of the controlled aircraft in windshear. These coefficients determine the closed loop roots of the system of Eq.(13), they are presented in Table 2.

5. Simulations and Discussions

For the purposes of examining the robustness of designed controllers, two general downburst profiles are used in the simulation test.

Model M1. This downburst wind field model is referred to Ref.15, this model simulates three wind components in the low-altitude wind field that have special variations in wind velocity similar to those measured in the atmosphere during severe convective disturbances. As shown in Fig.2, v_{z0} is 10(m/s), neither the downdraft exists outside the shear column of 600(m) radius, nor the horizontal flow higher than 300(m). As this windshear model is fixed in the space, the intensity of windshear is the function of position. In the case of penetration landing, the initial height is taken as 304.8m(1000ft) to test more severe wind profile.

Model M2. This is the model in which Δw_x and

Δw_z are given as functions of the time rather than position, the horizontal wind is given by

$$\Delta w_x = -\Delta w_{x0} \sin(2\pi t/T_0) \quad \text{(19a)}$$

and the vertical wind is given by

$$\Delta w_z = \Delta w_{z0}[1-\cos(2\pi t/T_0)]/2 \quad \text{(19b)}$$

where Δw_{x0} and Δw_{z0} are given constants reflecting the windshear intensity, here $\Delta w_{x0}/\Delta w_{z0} = 12/8$ (m/s) is considered. T_0 is the total flight time through the downburst, usually it can be taken as 60 (s).

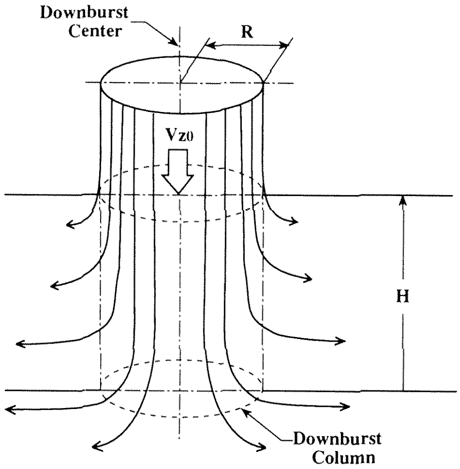

Fig.2 Structure of Windshear Model 1

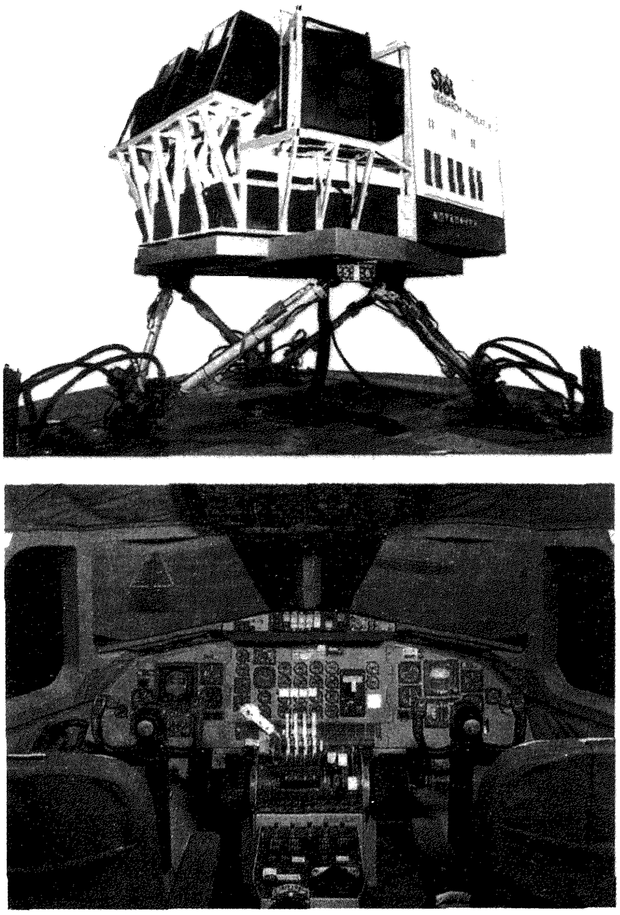

Fig.3 Six Degree-of-Freedom Flight Simulator

In the relative harsh climate conditions, there are also some rough random turbulence existing besides the windshear, during the simulation tests the severe turbulence model from MIL-F-8785B (30m) is considered. The intensity of turbulence $\sigma_{ug} = 1.43$ (m/s), and the probability of exceedance is 10%.

The performance of inverse dynamics controllers for different windshear models and different flight conditions are examined in a six degree-of-freedom ground simulator, it is shown in Fig.3. In the simulation test, the aircraft is assumed to be in an equilibrium state before it encounters any winds, the longitudinal motion of aircraft is controlled by the autopilot and the lateral-directional motions are eliminated by the pilot. Besides, the pilot manual operation for against windshear is also tested.

5.1 Take off

During the flight of take off especially in presence of windshear, the throttle is set maximum, so only the elevator angle $\Delta\delta_e$ is determined by the designed control law. These test results are presented in Figs.4 and 5.

For two windshear models involved in this paper, the aircraft controlled by autopilot can climb continuously, and the flight trajectories are more smooth and more close to the nominal take off trajectory than the manual operation cases. For the relative weak windshear model M1, the test pilot even does not feel the effect of exogenous wind inputs when the designed autopilot is switched on. For the test case of pilot operation in the relative severe windshear model M2, as affected by windshear the aircraft flies deviating from the nominal trajectory, the altitude profile is characterized by an initial climb, followed by descending flight, and there is some unavoidable height loss, that is presented in Fig.5(f). The results from the test of autopilot case illustrate, the designed autopilot has enough robustness to suppress the height deviation within certain range, the controlled aircraft can still climb smoothly while the minimum value of airspeed v_a is about 45.9m/s (90kt), as shown in Fig. 5(a) which is higher than the limited v_{min} greatly.

5.2 Penetration Landing

The simulation results presented in Figs.6 and 7

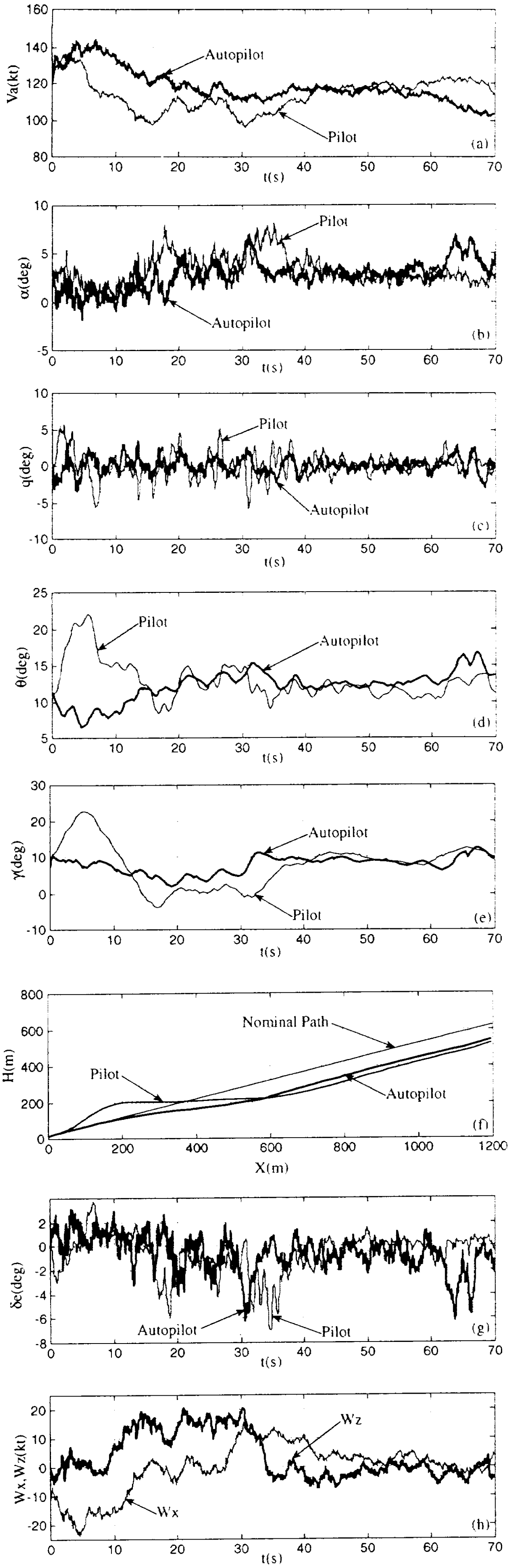

Fig.4 Simulation Result of Aircraft Take off in Windshear M1

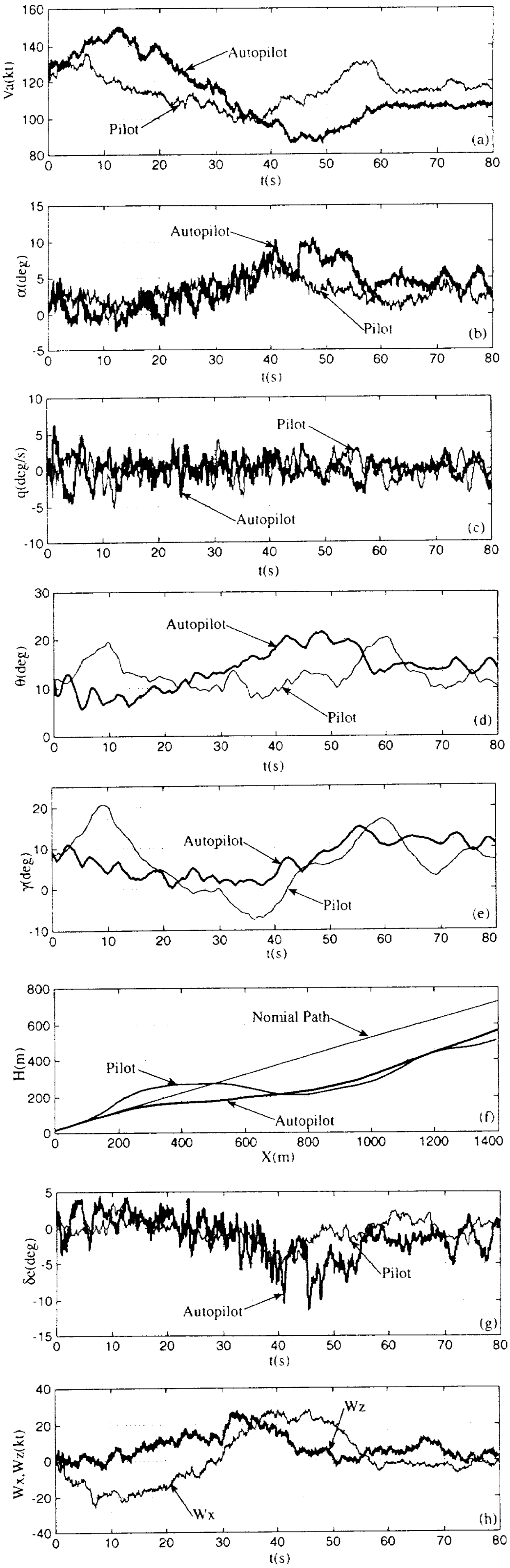

Fig.5 Simulation Result of Aircraft Take off in Windshear M2

provide much insight into landing approach through a downburst. As shown of the time histories of aircraft controlled by the pilot, the aircraft flies deviating from the nominal approach path due to the effect of windshear, the height increases in the headwind and decreases greatly in the tailwind and downburst. As shown of the time histories of aircraft controlled by the autopilot, the designed controller has enough robustness to suppress the deviation of flight path within certain small range even for the relative severe wind field.

For the relative weak windshear model M1, the maximum height decrease from the nominal path is about 70(m) when pilot control the aircraft, but the penetration landing path of aircraft controlled by autopilot is almost the same as the nominal path, these results are presented in Fig.6(g). For the relative severe windshear model M2, the tests are performed four times for pilot operation, two times are successful, and two times unsuccessful. For the successful penetration landing, as shown in Fig.7(g) the minimum altitude is less than 6(m) above the ground, if in the real flight it is also very dangerous. For the penetration landing controlled by the autopilot, the maximum deviation from the nominal landing path is only about 5(m), while the airspeed is

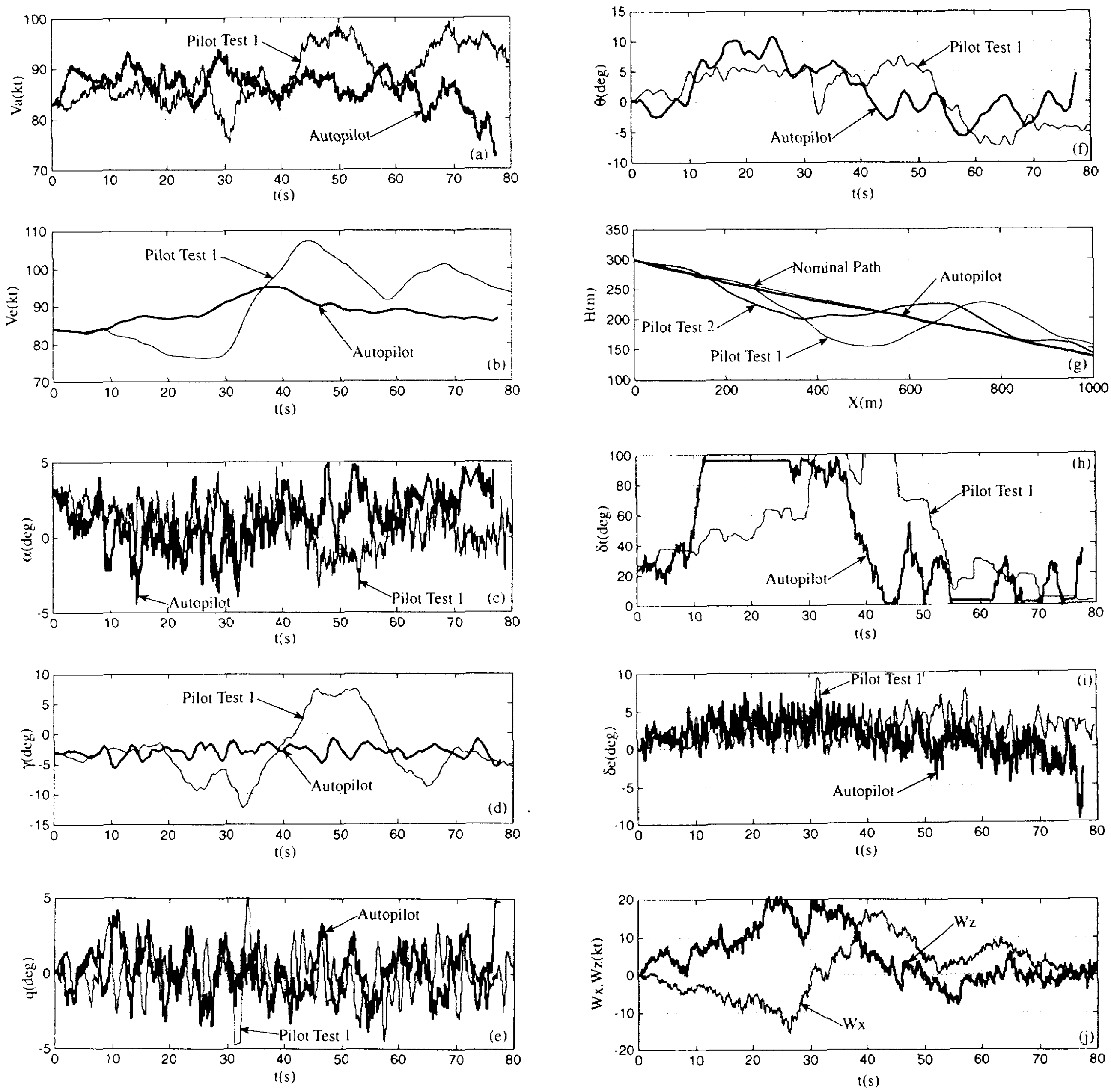

Fig.6 Simulation Result of Aircraft Landing in Windshear M1

kept above the allowed minimum value, and the touch-down point is almost the same of the specialized nominal point. These results mean the automatically controlled aircraft is able to capture the nominal landing path in these wind scenarios approximately even for the relative severe windshear while the safety of aircraft is also guaranteed.

Simulations show there are some compromise between minimum airspeed constraint and flight path following, generally speaking, higher v_{min} requires more control effort for airspeed, thus leaving less for the nominal path following, but with too low a v_{min} one runs the risk of stalling the aircraft in a fast-changing horizontal wind. Comparing these test results of aircraft flight in windshear, the safety problem of airspeed constraint for take off is not as severe as the case of penetration landing.

The simulation results also illustrate that the control bounds limit the aircraft performance in wind field. These control bounds determine the amount of downburst energy that an aircraft can handle. For take off flight the aircraft can not climb continuously while some very strong downbursts are encountered, and there are some unavoidable height loss. For penetration landing case, a large downdraft causes height loss thus calls for a large thrust compensation and

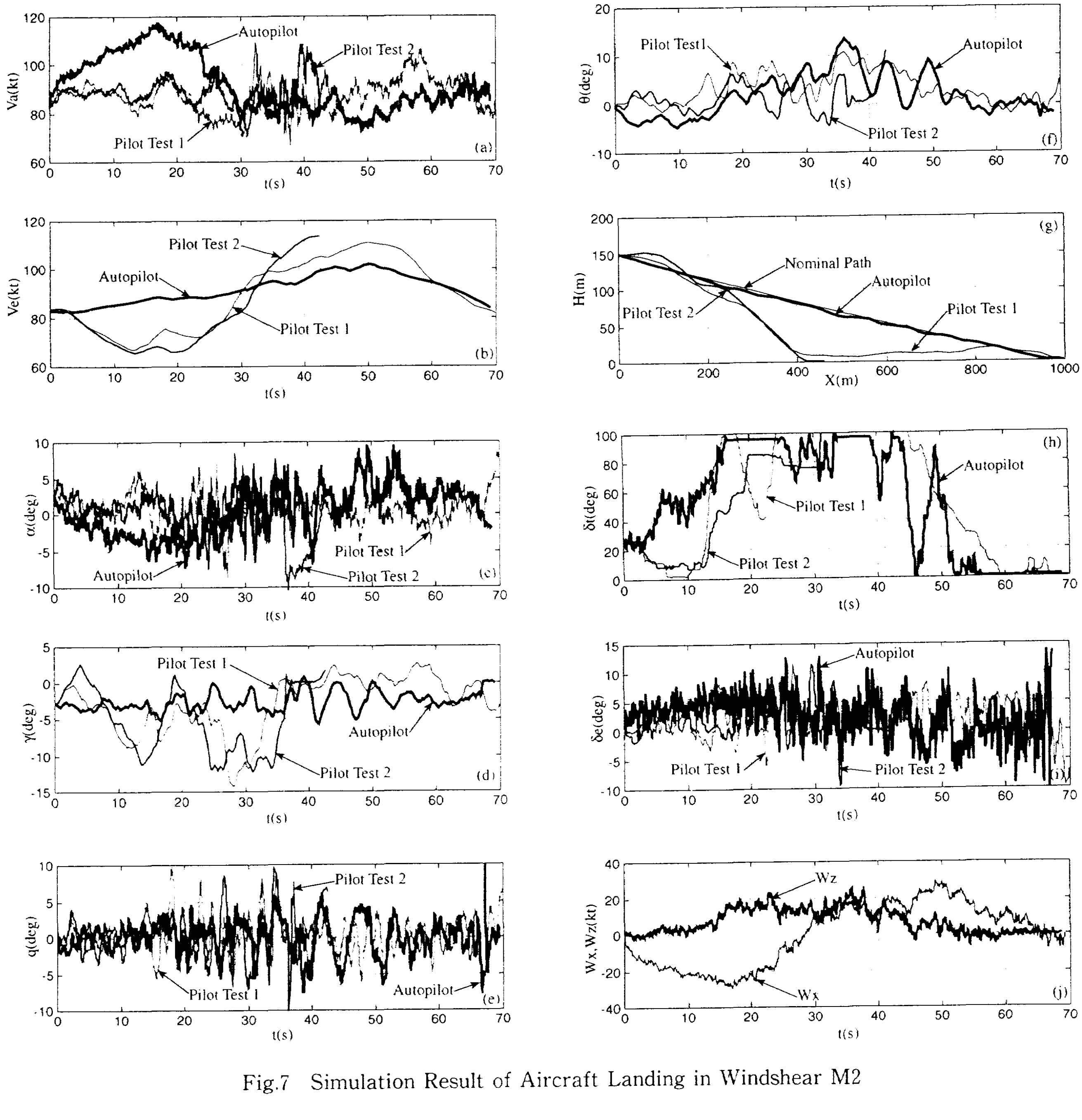

Fig.7 Simulation Result of Aircraft Landing in Windshear M2

may cause a thrust saturation with the upper bound. A strong tailwind makes it difficult to keep the minimum airspeed while maintaining inertial speed as the upper and lower bounds of thrust, that may cause the aircraft to deviate from the nominal altitude path, some very strong downburst may not be survivable as these limitations.

Lastly, the robustness of controllers applied in other flight conditions 2 and 4 are also tested respectively, the response histories of aircraft are almost the same as in conditions 1 and 3, although the controllers are not designed on these conditions, but they still have sufficient robustness to the windshear disturbance. As the nominal airspeed in condition 4 is higher than condition 3, the aircraft has higher capability to against the windshears. These guidance laws are indeed insensitive to both different windshear models and flight conditions.

6. Conclusions

The proposed guidance strategy for an aircraft flight in the presence of windshear has been studied. Two autopilots for research aircraft Do-228 are designed by inverse dynamics control technique, which maintain the nominal altitude and inertial speed as functions of horizontal distance, under a minimum airspeed constraint, and no a prior information or assumptions about windshear structure or intensity is required. The proposed guidance strategy exhibits normal behavior when there is no wind, maintains the flight path as accurately as possible in the presence of different downburst profiles. The choice of minimum airspeed constraint presents a compromise between following the nominal path and preventing the aircraft from accidental stall. Control saturations determine the limits of the balancing effects of any control strategies, some very strong downbursts cause some unavoidable height loss for take off, and also are not penetrable for landing.

The simulation test illustrates, the designed controllers have sufficient robustness to both external windshear which contains certain energy and is limited in scale within certain range, as well as the model parameter variation with changes in flight condition. The controlled aircraft is able to tolerate moderate to relatively severe windshears, the safety of aircraft encountering windshear can be increased greatly.

7. Acknowledgments

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