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OPEN LOOP OPTIMAL CONTROL OF MULTI-ENGINE AIRCRAFT AFTER ONE ENGINE FAILURE

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SUMMARY

Dynamic response of multi-engine aircraft after one engine failure,general speaking, is crucial, if the pilot could not judge and react correctly and timely. Using optimization technique, four time-dependent open-loop optimal control of two typical twin engine civil aircrafts (Airbus-A300 and Dornier- 28TNT)after one engine failure are found satisfactorily, no matter what initial flight condition is, such as take-off, landing approach or cruise flight. Not only the dynamic behaviour after one engine failure is well controlled, but also the optimal control activities which should be taken by the pilot after one engine failure are easily to be performed by the pilot. The key question of the optimization technique is how to construct the cost function, and this question is discussed in detail as well.

1. INTRODUCTION

The main research task of the Institute of Flight Guidance and Control, Technical University of Braunschweig, is about the aviation safety. A lot of research projects concerns with wind measuring , wind modelling, the influence of wind shear, turbulence and poor visibility on take-off and landing approach (Ref.1,2,3,4).

Digital aircraft flight simulation techniques are widely used to do theoretical analyses, research flight simulators and research aircrafts are also opreated to verify the results.

Besides poor visibility and wind shear, one engine failure of multi- engine aircraft during take-off and landing approach, generally speaking, may be crucial as well, if the pilot could not judge and react correctly and timely.

Using optimization technique to search for the four time-dependent open loop optimal control of multi-engine aircraft which should be taken by the pilot after one engine failure during take-off, landing approach or cruise flight constitutes the aim of this paper.

The mathematical model of the aircraft is briefly introduced at first. Some of the main questions about the use of optimization technique are described secondly. Then some typical numerical optimization results and comparisons with flight simulator results are presented.Detailed analyses, discussions and conclusions will be given at the last.

It could be seen that with the help of optimization technique, the four time-dependent open loop optimal control of multi-engine aircraft after one engine failure could be found successfully, no matter what initial flight condition is, for instance, cruise flight, take-off and final landing approach even with wind shear.

The dynamic behaviour of multi-engine aircraft after one engine failure could be controlled well and the optimal control activities are easily to be performed by the pilot due to the simplicity and smooth.

According to the work of this paper, it seems that if the civil aircraft is designed reasonably and the engine failure occurs not so critical, for example, not very near to the ground, especially if the pilot has been trained well in advance , that means the pilot has good ability to judge and control the event correctly and timely, then generally speaking, the accident due to one engine failure could be avoided.

2. MATHEMATICAL MODEL FOR NUMERICAL SIMULATION

Very realistic and sophisticated mathematical models of two typical twin engine civil aircrafts, Airbus-300 and Dornier-28TNT, have been used to do the numerical optimization calculations. Six degrees of freedom and rigid body non- linear differential motion equations are adopted. Some main parts of these mathematical models could be described briefly as follows.

(2.1)AERODYNAMIC MODEL

The original aerodynamic data based on wind tunnel and flight testing in tabular form are directly used in the programm.

(2.2)ENGINE MODEL

Dynamic model for typical turbo-fan and turbo-propeller engine are used. The engine dynamic behaviour certainly is very important for engine failure simulation.

(2.3)CONTROL SYSTEM MODEL

Actual non-linear kinematic motion relations of all the aircraft control systems are used.

(2.4)LANDIND GEAR MODEL

Dynamic simulated landing gear models are well built for the two typical civil aircrafts. These models allow the aircrafts running, controlling and braking on the runway during take-off and landing.

(2.5)AUTOMATIC CONTROL SYSTEM MODEL

Realistic automatic control system models could be adopted directly but only the yawing damper model of the typical passenger aircraft Airbus-300 is used for the numerical simulation of this paper.

(2.6)NAVIGATION SYSTEM MODEL

All of the navigation system data of the simulated airport, such as VOR and NDB stations, glide-path and localizer transmitters, and markers are also included in the simulation models.

(2.7)CALCULATION OF WIND INFLUENCE

To consider the effect of wind shear on aircraft motion, exponential form wind shear with and without wind direction turn from ground to 1000 meter height are adopted, and different wind speed at the reference height 10 meter are also used (Fig.1).

In summary, a six-degrees of freedom, rigid body, nonlinear aerodynamic and nonlinear equations of motion aircraft mathmatical model is applied for the numerical simulation of this paper.

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In addition, different wind shear models and many of the realistic mathmatical models of the aircraft sub-parts ,such as engine, control systems and so on, are also adopted.

3. OPTIMIZATION TECHNIQUE

Facing such a complicated nonlinear dynamic system, and generally speaking, the derivatives of the cost function is not be able to calculate,a mature method which could be used to solve this kind of optimization problem up to now is still scarce. Linearizing and simplifying the model certainly is a way, but sometimes the results could not conform to the actual situation very well. A good engineering method proposed by H.G.Jacob with his optimization programm "EXTREM", therefore, is adopted for this paper (Ref.5,6). One of the advantages of this method is no need to know the derivatives of the cost function.

This method optimizes the open loop inputs of a dynamic system by observing only its outputs, and is not concerned with the details of the dynamic system to be optimized , so it works for both non-linear and linear systems.

Some of the principle points related to this method will be explained below in a little bit detail.

(3.1)DYNAMIC OPTIMIZATION PROBLEM CONVERTED INTO PARAMETER OPTIMIZATION PROBLEM.

The optimization problem of a dynamic system, generally speaking, is to find the control function time histories which drive the system so as to minimize some quality criterion. By expressing each control function as a finite series of known time functions, for example, polynomial or spline function,the dynamic optimization problem then could be transformed to a static parameter optimization problem (Fig.2). The optimal parameters of the series will be determined by an iterative optimization procedure, named "EXTREM" algorithm program. The type of series and the number of its terms should be chosen so that the expected optimal response could be approximated with sufficient precision and the optimal input function also could be realized, for instance, performed by the pilot easily.

Any prior information available on the shape of the optimum functions could be used to choose the series expansion type.

Three degrees of freedom (cubic) spline function with ten time points for each control function has been used in this paper. That means, for landing approach and cruise flight optimization problems, a forty static parameter optimization problem must be solved, because total four control functions (rudder, elevator,aileron and thrust) should be used in this circumstance. As for take-off, only thirty parameter optimization problem is faced , because the maximum thrust normally is fixed in this case.

(3.2)PERFORMANCE INDEX PI AND COST FUNCTION.

The performance index PI is the value computed by evaluating the system output in terms of the prechosen cost function. The evaluation is stored and compared with the value previously determined.Through comparison, the optimization algorithm could create a new set input parameters in a particular way, and the process is repeated until the performance index ceases to change. This is the principle with which the optimization algorithm operates.

Quite obviously, choosing the appropriate cost function becomes the key question for a specified optimization problem. In other words, the optimization result depends upon the cost function fully.

A great deal of trying, comparison, analysis and computation has been done in the last year to search for the better and suitable cost function. Particularly in this paper, not the single-object cost function but the multi-object cost function has been used (Ref.7). More explanations about cost function will be given below together with the concrete calculations .

(3.3)CONSTRAINTS AND LIMITATIONS.

Constraints may be considered either by adding penalty functions to the quality criterion or by introducing boundaries directly into the search space over which the non-linear programing algorithm operates.

Constraints (either equalities or inequalities) may be imposed on the input, output and/or internal state variables of the system. Any time when an inequality constraint violation is detected, the algorithm is signaled to provide a new set of parameters until a set which violates no boundaries is obtained.

In order to make the optimization results more realistic and the control functions receivable by the pilots, some limitations for the input functions, such as maximum displacements of four cockpit controls and the maximum cockpit control rates of aileron and thrust have been adopted. Some limitations for the internal state variables, such as angle of attack, sideslip angle, Mach Number and maximum dynamic pressure are also added in the programm.

(3.4)INITIAL VECTOR PROBLEM.

A special property of the "EXTREM" optimization algorithm is the initial vector problem. That means the guessed initial vector, given by the user at first, should not lie outside the defined boundaries. This property sometimes could bring much difficulties for the user to start the program, especially when the flight simulation time is longer. Good flight mechanics knowledge and some special software, for example, graphics program are useful to overcom this difficulty.

The another important property of the "EXTREM" algorithm is the unique problem of the optimization solution. Because the cost function, generally speaking, can not be a strict convex function due to its complexity, so the "EXTREM" algorithm is best suited for the search of a local extremum (maximum or minimum)of a multivariabe function,the gradient of which is impossible or difficult to obtain directly. In this respect, how to choose the appropriate initial vector is even more important, for different initial vector perhaps could produce quite different optimization solution.

4.SOME TYPICAL NUMERICAL OPTIMIZATION CALCULATION RESULTS

Using the mathematical models and optimization technique stated above, quite a lot of numerical optimization calculations has been done for the two typical civil aircrafts.

Three representative initial flight conditions (cruise, take-off and landing approach) are used to investigate the time-dependent open loop optimal control of the aircraft after one engine failure. As the space is limited, only some examples could be allowed to present below.

In order to do the numerical calculation, an assumed airport with its geographical coordinate as Fig.3(a) is adopted. That means,take-off and landing approach point just towards the north direction and the wind oppositely comes from the north. For cruise, the direction points also to the north.

(1) CRUISE FLIGHT.

Some main initial conditions for cruise flight optimization calculation are:

Aircraft	A300	Do28
Cruise Altitude H	10,000 M	3,000 M
Cruise Airspeed VA	240m/sec	85m/sec
Opti. Calcu. Time t	60 Sec	60 Sec
Failed Engine	Left	Left

The dynamic behaviour after one engine failure are given in Fig.4 and Fig.5, respectively.

Two curves have been drawn in each picture of the two figures. The bold lines are the numerical optimization results, and the dotted lines show the dynamic behaviour of the aircraft after one engine failure if the pilot has not any control to the aircraft, namely no-control or fixed-control.

The dynamic behaviour are presented in such a sequence, directional- lateral motion first, then the longitudinal motion, and the open loop optimal cockpit controls appear at the last.

From the curves, it is clear to see that the dynamic behaviour of the directional-lateral motion of the aircraft after one engine failure is severe if the pilot can not control the aircraft correctly, for example,the divergence of the bank angle is very quick. In contrast, if the open loop optimal controls are used, then the dynamic behaviour after one engine failure could be controlled easily.

(2) TAKE-OFF.

Some main initial conditions for take-off optimization calculation are:

Aircraft	A300	Do28
Initail Altitude H	50 M	50 M
Initial Airspeed VA	70m/sec	50m/sec
Thrust Lever	Maximum	Maximum
Landing Gear	Up	Up
Flap Deflec. Angle	5/20(Deg.)	5(Deg.)
Yaming Damper	On	No
Wind Condition	No Wind, Wind Shear, and Turned Wind Shear	
Opti. Calcu. Time t	60 Sec	60 Sec
Failed Engine	Left	Left

The dynamic behaviour after one engine failure are given in Fig.6 and Fig.7, respectively.

Three curves have been drawn in each picture of the two figures. One curve of them shows the case of no-control or fixed-control. The another two curves are the numerical optimization results, one belongs to the case of no wind, and the other belongs to the case of wind shear.

From the curves, it is easy to see that the dynamic behaviour of the aircraft after one engine failure, not just the directional-lateral motion but also the longitudinal motion, are very dangerous if the pilot could not control the aircraft timely and correctly, for example, the development of bank angle divergence and flight path deviation are very quick. In contrast, if the open loop optimal controls are used, then the dynamic behaviour after one engine failure also could be controlled easily.

(3) LANDING APPROACH.

Some main initial conditions for landing approach optimization calculation are:

Aircraft	A300	Do28
Initail Altitude H	200 M	200 M
Glide Airspeed VA	70m/sec	45m/sec
Glide Path Angle	-3.0(Deg.)	-2.9(Deg.)
Landing Gear	Down	Down
Flap Deflec. Angle	25/25(Deg.)	20(Deg.)
Yaming Damper	On	No
Wind Condition	No Wind, Wind Shear, and Turned Wind Shear	
Optimization Calculation Time t	80s,No Wind 100s, With Wind Shear	90s,No Wind 120s, With Wind Shear
Failed Engine	Left	Left

The dynamic behaviour after one engine failure are given in Fig.8 and Fig.9, respectively.

Three curves have been drawn in each picture of the two figures as well. One curve shows the case of no-control or fixed-control, and the other two show the case of no wind and wind shear, respectively.

From the curves, it is clear to see that the dynamic behaviour of the aircraft after one engine failure during landing approach is not just dangerous if the pilot could not control the aircraft timely and correctly, but also is very complicated and difficult to control even the pilot would like to control, because both the directional-lateral motion and the longitudinal motion must be controlled accurately and simultaneously in this case. But if the open loop optimal controls are used, then the dynamic behaviour after one engine failure during landing approach also could be fully controlled.

5. COMPARISON OF NUMERICAL RESULTS AND FLIGHT SIMULATOR RESULTS

A typical research flight simulator specially suitable for civil aircraft has been developed in the Institute (Ref.8,9). General purpose computer Micro-VAX2 and high level program language FORTRAN-77 are used to provide the real time capability. Fix-based cockpit equipped with advanced view by window visual system could give the high fidelity view of outside world, and which obviously is very important for simulating take-off and landing approach with wind shear, low visibility and engine failure.

Using this simulator, take-off and landing approach flight simulations of aircraft Do-28TNT after one engine failure together with or without wind shear have been done successfully. Two well experienced pilots are invited to join this job and five to six different wind models are used to complete these investigations.

The results comparisons between numerical calculation and flight simulator of aircraft Do-28TNT take-off and landing approach after one engine failure are given in Fig.10 and Fig.11, respectively.

In flight simulator, two engines operate normally at first. Then left engine failure occurs at about 50 meter altitude for take-off and at about 200 meter altitude for landing approach.

The parameters just at the time which the engine failure occurs in the flight simulator are used as the initial flight conditions for the numerical optimization calculations.

As showing in figure.3(b), the geographical coordinate of the simulated airport used for the flight simulator is different from before. That means, the runway is nearly along the east-west direction, the take-off and landing approach point basically towards the west, and therefore the wind should come from the west as well. The influence of runway direction changing on the cost function is not difficult to consider, and this has been done already in the numerical optimization calculations of this paper.

As for wind, the wind shear model used for flight simulator is also used for the numerical calculations.

6.ANALYSES AND DISCUSSIONS

(6.1) From the numerical calculation results, it is evident that for the both typical civil aircrafts, no matter what the initial flight condition is (cruise, take-off or landing approach), with the help of the optimization technique described in this paper, the four time-dependent open loop optimal control law of the aircraft after one engine failure could be found successfully. That means, not only the dynamic behaviour after one engine failure, for example, the bank angle PH ,rolling velocity PR, yawing velocity RR, pitching velocity QR, flight path angle GA and flight path deviation YG could be controlied very well, but the simple and smooth input function also could be performed by the pilot easily.

(6.2) From the calculation results, it could be seen that after one engine failure, the pilot should push the pedal in the direction of overcoming the unbalanced yawing moment immediately and turn the control wheel to correct the bank angle at the same time.

In order to compensate the thrust lost, generally speaking, the pilot have to use the remainder normal engine to maintain the longitudinal motion, such as air speed and glide path, unless in the case of take-off.

As for the elevator control, depending upon the height of thrust line relative to the center of gravity and the down wash change in the tail area and so on, the control wheel should be moved forward or backward a little amount appropriately.

The control tendency of take-off and landing approach after one engine failure in the wind shear which are used in this paper, is about the same with no wind, but the amount of the control displacement are a little bit more.

A important matter is that the control activities are not very abrupt due to the characteristics of the spline function and not so many time points have been used at the very early stage of the control just after the engine failure.

In addition, all of the optimal control activities are far away from the limitations and boundaries, that means in the whole optimal control course the aircraft still has large control potentiality.

(6.3) From the result comparisons between numerical calculation and flight simulator, it is obvious that with the help of optimization technique, the satisfactoriness of the numerical optimization calculation could be as well as the flight simulator. Other words, the optimization technique could work as well as human pilot to some extent. Certainly the key questions here are how to choose the cost function and the initial vector.

(6.4) The cost functions should be different for the three representative initial flight conditions stated above, because the flying quality requirements after one engine failure are different.

After one engine failure, a large sideslip and bank angle will create quickly due to the unsymmetrical thrust in the directional-lateral motion. The flight path angle and air speed will change as well, due to the thrust lost in the longitudinal motion.

For cruise flight, generally speaking, only the bank angle and sideslip angle in the directional-lateral motion no big change is required. The longitudinal motion requirements could be relaxed, for there are plenty of altitude and air speed to manoeuvre. As the unsymmetrical thrust normally is not so large as take-off in this case, the dynamic responce after one engine failure is moderate and easier to control.

For take-off, only require the bank angle and sideslip angle in the directional-lateral motion no big change is no more enough. Keeping the air speed not below ,for example, minimal safe air speed and keeping the flight path angle at least not less, for example, zero in the longitudinal motion are also needed in this case. Sometimes, keeping the flight path basically along the runway direction also should be considered. The unsymmetrical thrust of take-off is very large, so the dynamic responce is severe, especially if the engine failure happens very near to the ground.

For landing approach, not just the bank angle, sidealip angle and the flight path direction exactly along the runway in directional-lateral motion must be required, but in longitudinal motion the glide airspeed and glide path also must be required. The complexity of the flying quality requirements brings quite a lot of difficulties for the optimal control solution, although the unsymmetrical thrust is not large at this time.

The key question here is, in order to keep the glide path and glide speed in longitudinal motion, the aircraft needs more thrust from the mormal engine to compensate the thrust lost of the failed engine, but the more thrust from the normal engine, the more difficulty to the directional-lateral motion.

The optimal control will be more difficult when landing approach after one engine failure takes place in wind shear, because the aircraft needs even more thrust from the normal engine to compensate the energy lost.

Based on the statement above, a list of cost function will be given below. All of the cost functions are the bases of the off-line simulation of this paper, and quite a lot of labour and computer time has been consumed to get them.

LIST OF COST FUNCTIONS

Aircraft	A 300	DO-28
Cruise Flight	$5.0x10^7x(p^2+q^2+r^2)+1.0xY_g^2$	
Take-Off	$5.0x10^7x(p^2+q^2+r^2)+1.0xY_g^2$ $+50.0x(Va-70)^2$	$5.0x10^7x(p^2+q^2+r^2)+1.0xY_g^2$ $+20.0x(Va-50)^2$
Landing Approach	$5.0x10^7x(p^2+q^2+r^2)+1.0xY_g^2$ $+50.0x(Va-70)^2+1.0(z_g-TAN(3^o)X_g)^2$	$5.0x10^7x(p^2+q^2+r^2)+1.0xY_g^2$ $+20.0x(Va-45)2+1.0(z_g-TAN(2.9^o)X_g)^2$

(6.5) Some interesting points should be pointed from the comparison of cost function.

(a) No matter which of the both aircraft is, the structure of the cost function is the same for each initial flight condition, but only the weighting factor in front of the air speed is changed a little bit. The term of air speed represents the kinetic energy of the aircraft, so the weighting factor should be different to consider the take-off and glide air speed difference of the two aircrafts.

(b) At least for all of the wind conditions which have tested in this paper, the structure and the weighting factor of the cost function basically no need to change.

(c) According to the different flying quality requirements, the complexity of cost function is also different. For cruise is simple, then the take-off, and the landing approach is more complex.

(d) How to construct a better cost function is troublesome. The parameters included in the cost functon must be able to reflect the flying quality requirements, but not the more is the best. The contradiction among the parameters should be well considered as well.

(6.6) The choosing of initial vector plays a very important role for the opimization algorithm. For the optimization technique described above is best suitable to search for the local extreme, the optimal solution depends upon the initial vector very much.

The initial vector must be chosen in such a way, that means during the first simulation no limitation has been reached, otherwise the optimization algorithm could not be started.

In addition, the appropriate initial vector certainly will has good influence to iteration convergence and shorten the computation time.

When the flying quality requirements are complex and the feasible region is tight such as landing approach, choosing of a better initial vector is time consuming and sometimes is rather difficult.

Good understanding and experiences in advance, quite a lot of trail and error, and perhaps a little of good luck are needed here.

(6.7) When wind influence is considered for both numerical calculation and flight simulator, generally speaking, it only needs more thrust and longer simulation time for landing approach, and makes the control activities more complex, especially for the wind with some turn. But there are no big difficulties for the working of the optimization algorithm, except choosing of the initial vector sometimes is headache indeed.

(6.8) Basically speaking, the bad dynamic behaviour of multi-engine aircraft after one engine failure comes from the engine position relative to the aircraft center of gravity. The more the engine nears to the center of gravity, the better is the dynamic behaviour after one engine failure.

7. CONCLUSIONS

Using optimization technique, the four time-dependent open loop optimal control of multi-engine civil aircraft after one engine failure could be found satisfactorily, no matter what the initial flight condition is, such as cruise flight, take-off and landing approach even with wind shear.

Not just the dynamic behaviour after engine failure could be controlled very well, but the optimal control activities also could be easily performed by the pilot.

Through the result comparisons of numerical optimization calculation and flight simulator, it could be seen that with the help of optimization technique, the aircraft flying quality after one engine failure could be controlled as well as the pilot in the flight simulator. The key question here is the choosing of cost function.

Three appropriate forms of cost function which are suitable for two typical civil aircrafts and available for three representative initial flight conditions are presented. The different structures of the cost function are interesting and instructive for automatic control system design and the pilot activity imitation.

The basic reason which makes the dynamic behaviour of multi-engine aircraft after one engine failure severe is the relative position of the engine to the aircraft center of gravity. So pay good attention to this problem at the very early stage of aircraft design is important.

So far as the work which has been done in this paper, it seems that the accident due to one engine failure of a multi-engine civil aircraft during take-off, landing approach or cruise flight could be avoided , provided that:

--- the aircraft has been resonably designed;

--- the engine failure occurs not so emergent, for example, not very near to the ground;

--- the pilot has been well trained in advance; and

--- the pilot could judge and act correctly and timely.

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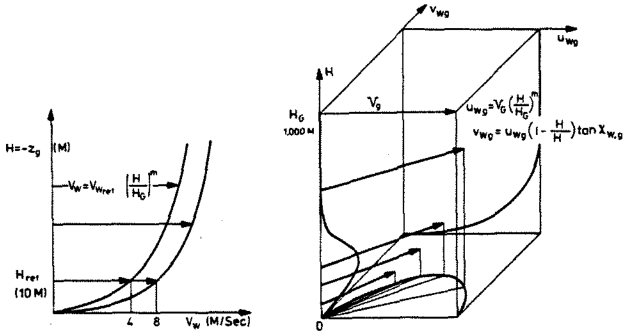
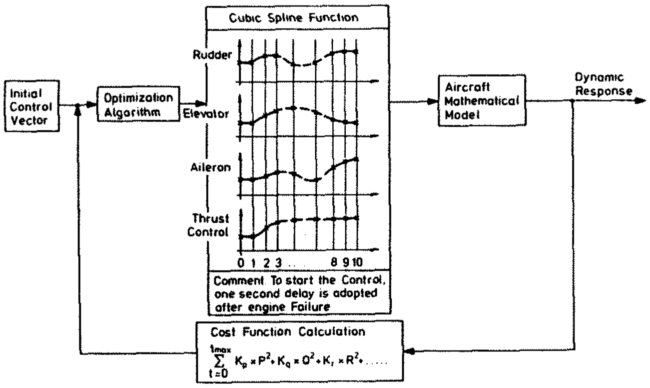
REFERENCE

1. Schanzer, G. Influence of Wind shear on Flight Safety, AGARD, 62nd Symposium of the Fight Mechanics Panel, Athens, Greece, 10-13, May, 1983
2. Vorsmann, P. Ein Beitrag zur Bordautonomen Windmessung,Doktor Dissertation, Institut fur Flugfuhrung, TU Braunschweig, 1985
3. Kruspe, P. Beitrage zur Langsbewegung von Flugzeugen in Windscherungen, Doktor Dissertation, Institut fur Flugfuhrung,TU Brunschweig, 1983
4. Swolinsky, M. Beitrage zur Modellierung von Scherwind fur Gefahrdungsuntersuchungen, Doktor Dissertation, Institut fur Flugfuhrung, TU Brunschweig, 1986
5. Jacob, H.G. Rechnergestutzte Optimierung Statischer und Dynamischer Systeme, Springer-Verlag, 1982
6. Jacob, H.G. An Engineering Optimization Method with Application to STOL-Aircraft Approach and Landing Trajectories, NASA TN D-6978, 1972
7. Jacob, H.G., Deng, J.X. Rechnergestuetzte Mehrzielige Parameteroptimierun am Beispiel eines Flugregelsystems, Automatisierungstechnik , Band 34 (1986), Heft 9,
8. Kaufmann, B. Design of Realtime Software with Special Regards to a Research Flight Simulator System, International 87 Karlsruhe Conference Modelling and Simulation, West Germany, July,20-22, 1987
9. Brandt, V. Structure of a Research Flight Simulator, International 86 Sorrento Conference Modelling and Simulation, Italy, Sept.29 - Oct.1, 1986
10. Schanzer, G. Flugmechanik, Vorlesungsmanuskript zur Vorlesung am Institut fur Flugfuhrung, TU Braunschweig, 1986



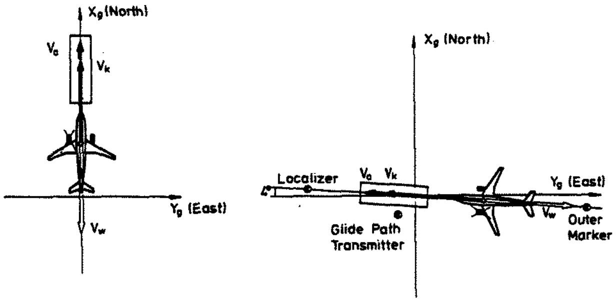
a) Exponential Form Wind Shear b) Turned Wind Shear (Ref. 4)

Fig. 1. Wind Shear Model



Comment. To start the Control, one second delay is adopted after engine Failure

Fig. 2. Dynamic Optimization Converts to static Parameter Optimization



(a) For Numerical Calculation (b) For Flight Simulator

Fig. 3. Geographical Coordinate for Numerical Calculation and Flight Simulator

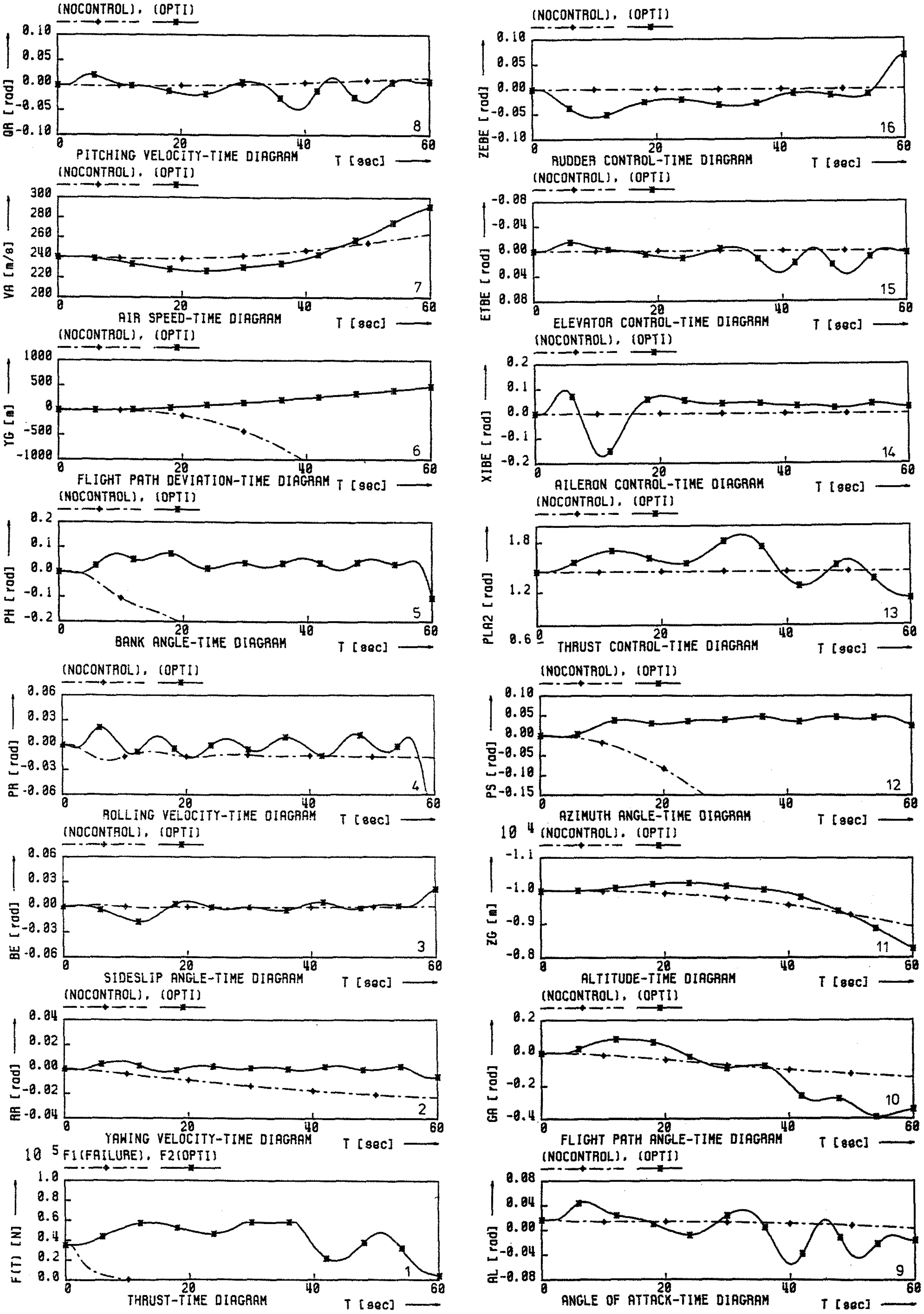


Fig.4. Dynamic Behaviour of A300 After One Engine Failure During Cruise Flight.

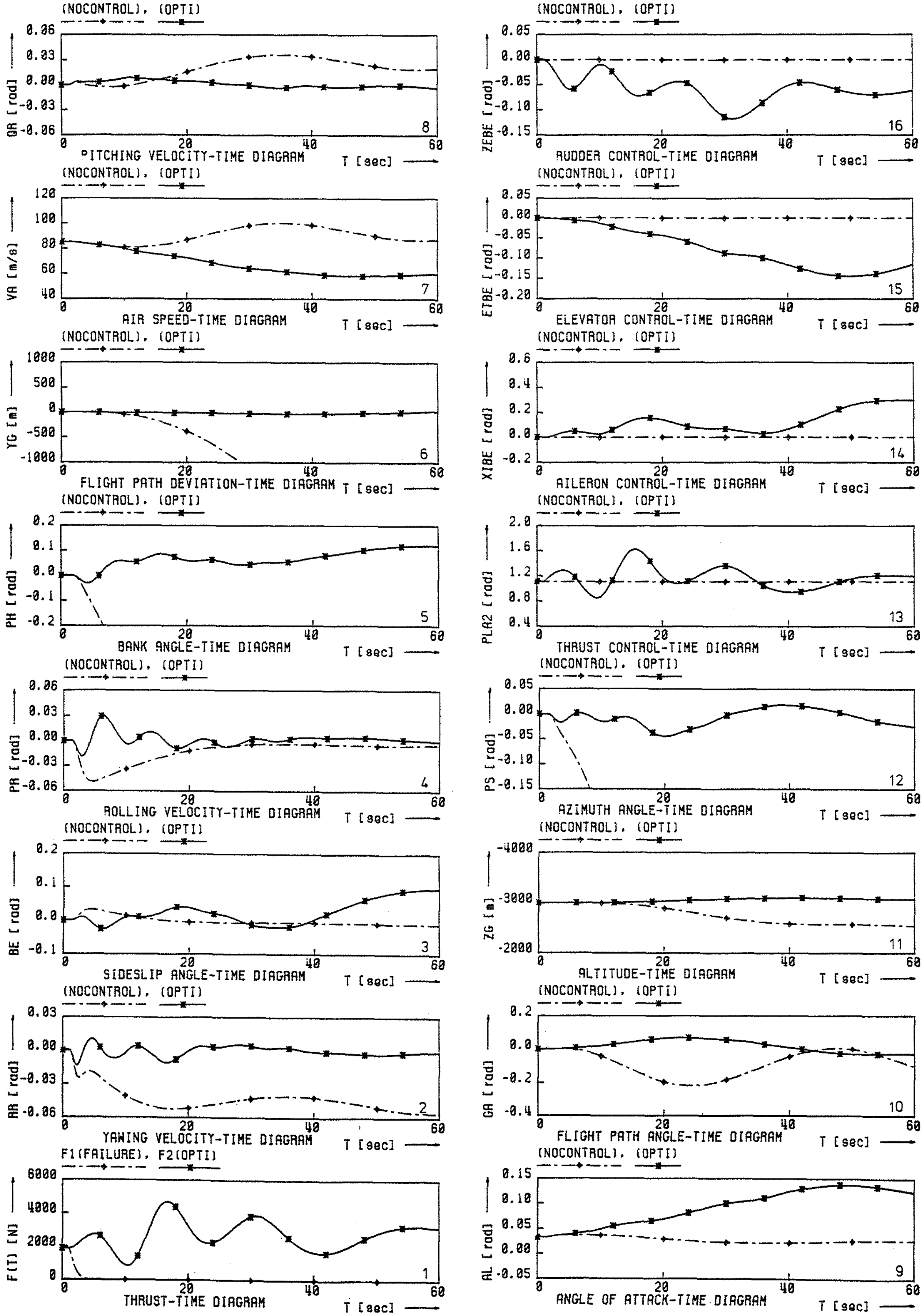


Fig.5. Dynamic Behaviour of Do28 After One Engine Failure During Cruise Flight.

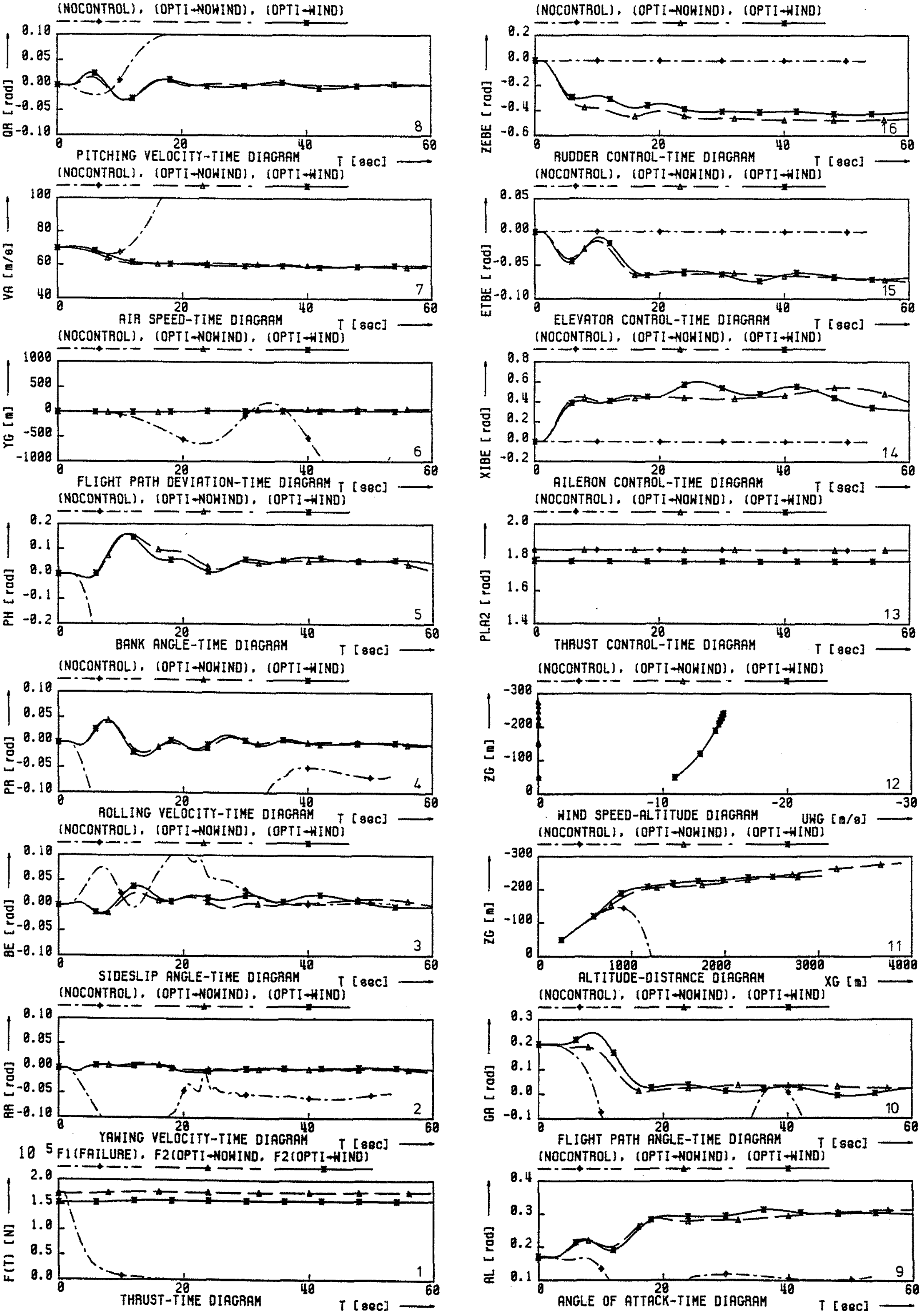


Fig.6. Dynamic Behaviour of A300 After One Engine Failure During Take-Off.

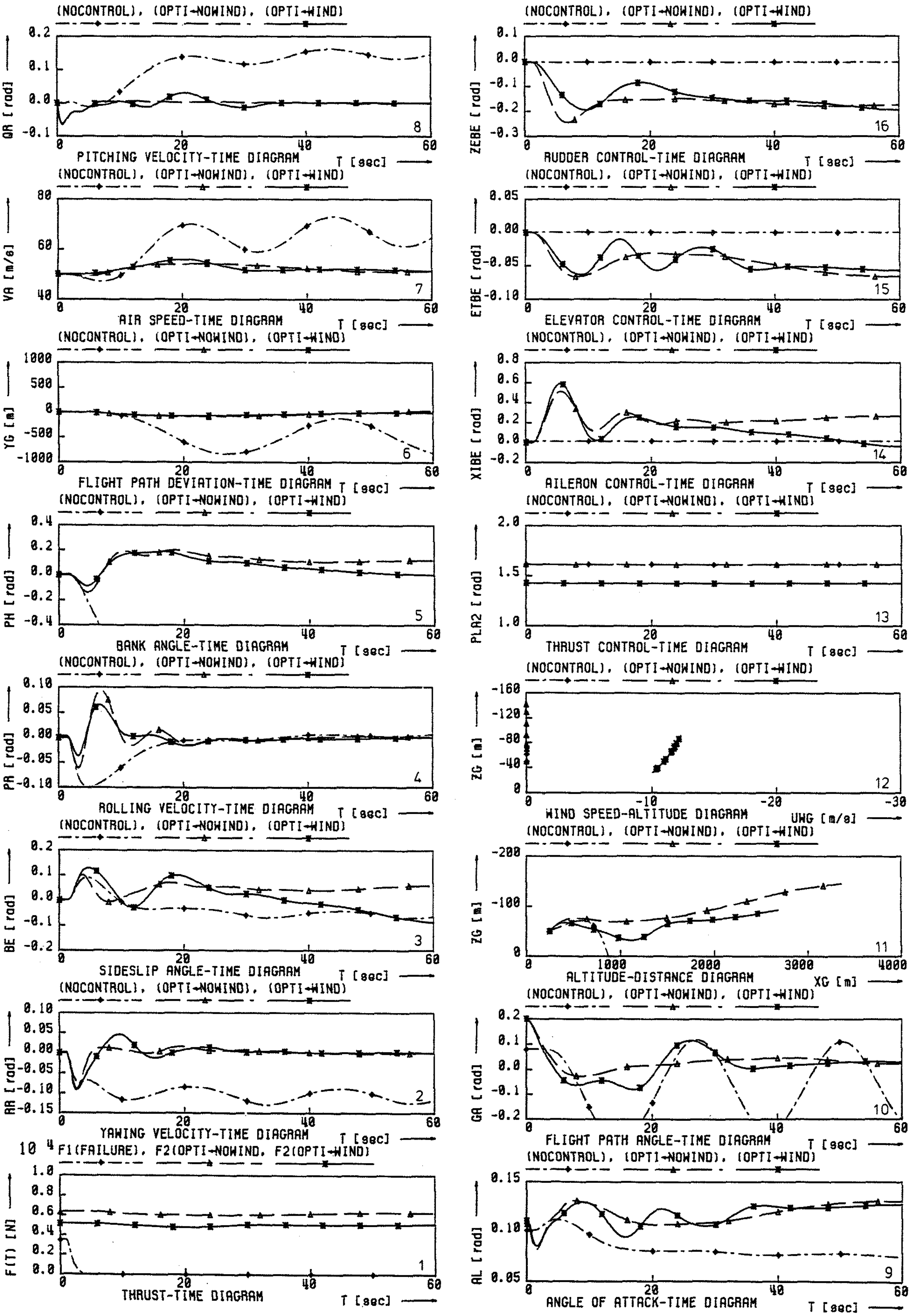


Fig.7. Dynamic Behaviour of Do28 After One Engine Failure During Take-Off.

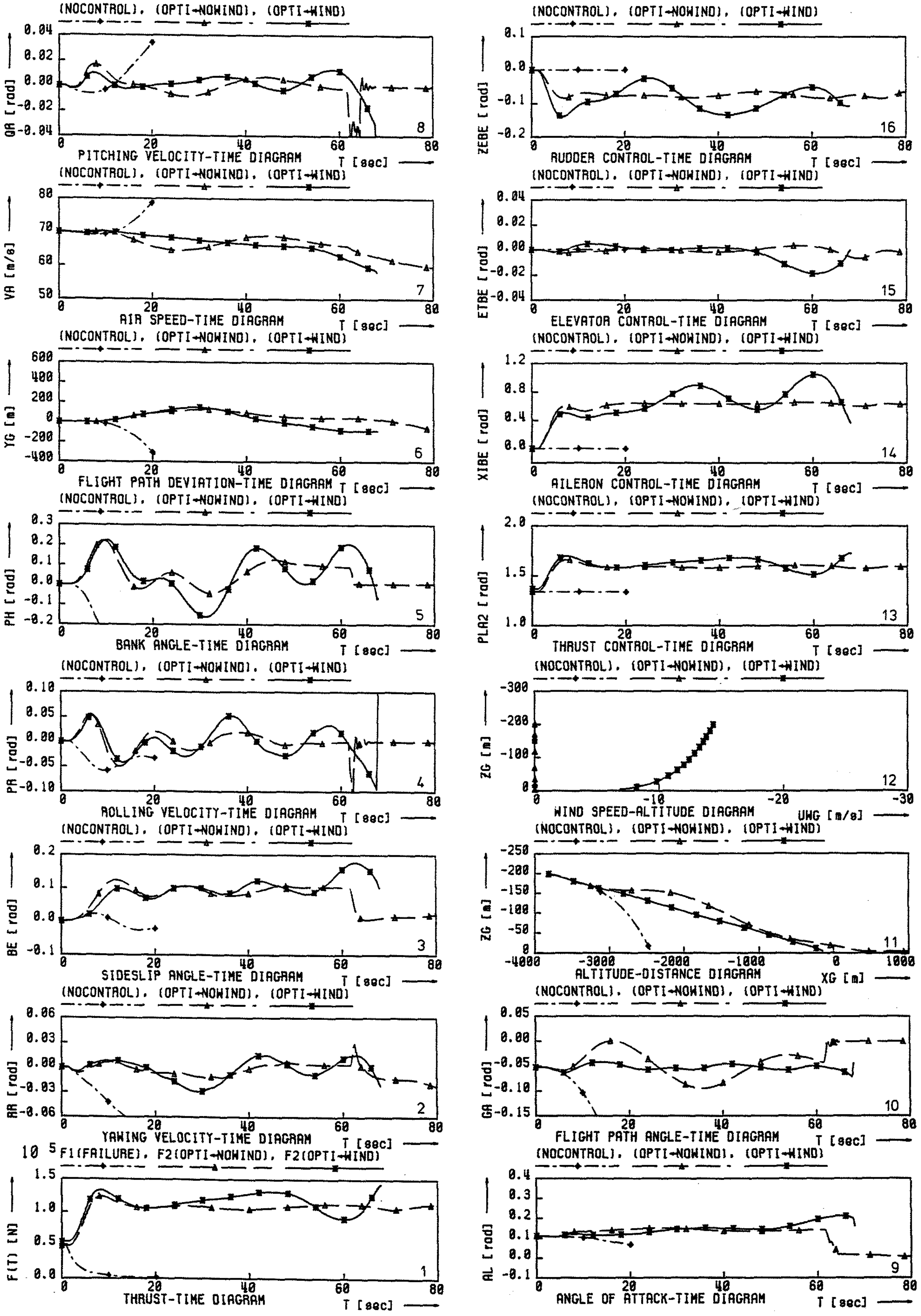


Fig.8. Dynamic Behaviour of A300 After One Engine Failure During Landing Approach.

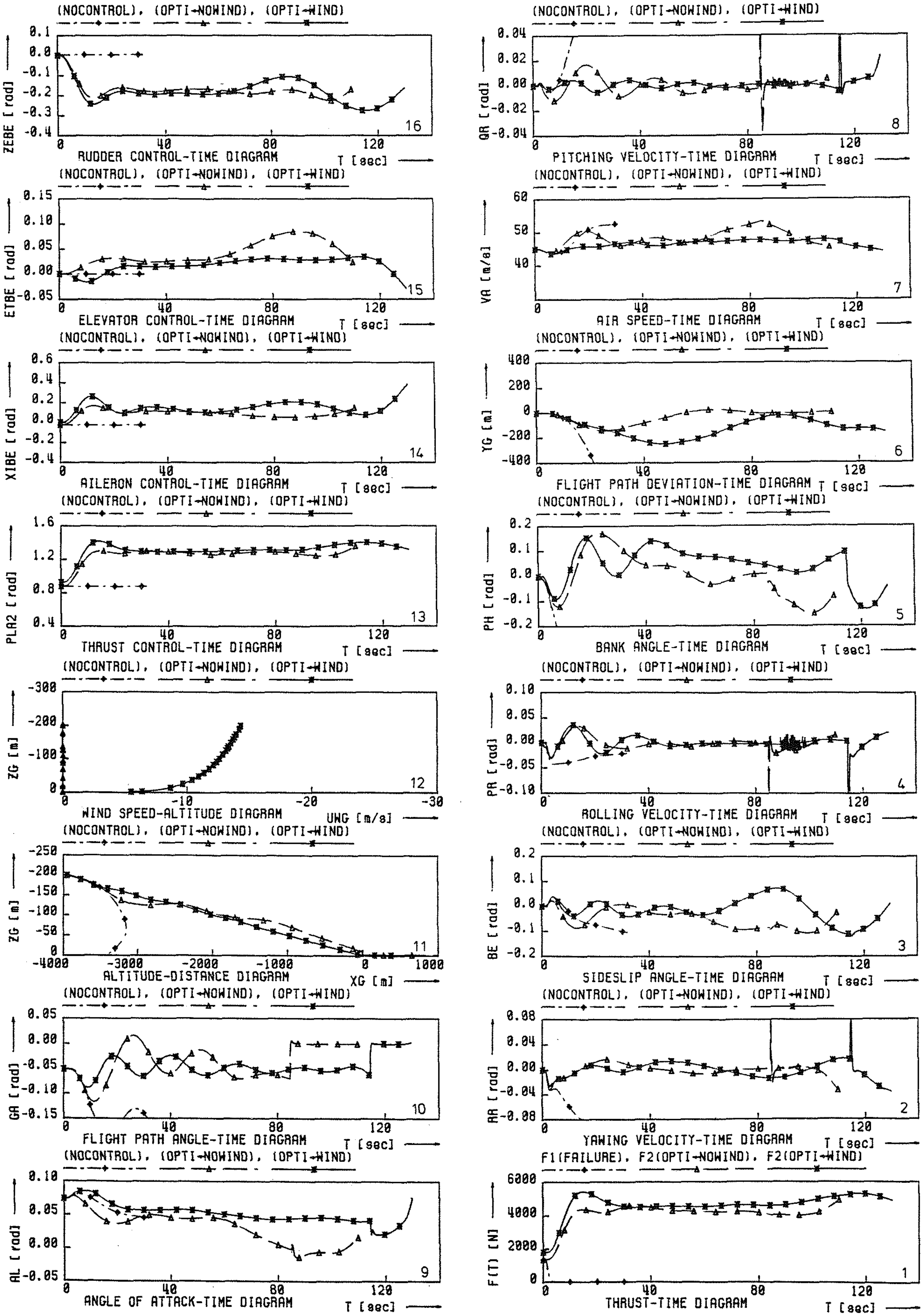


Fig.9. Dynamic Behaviour of Do28 After One Engine Failure During Landing Approach.

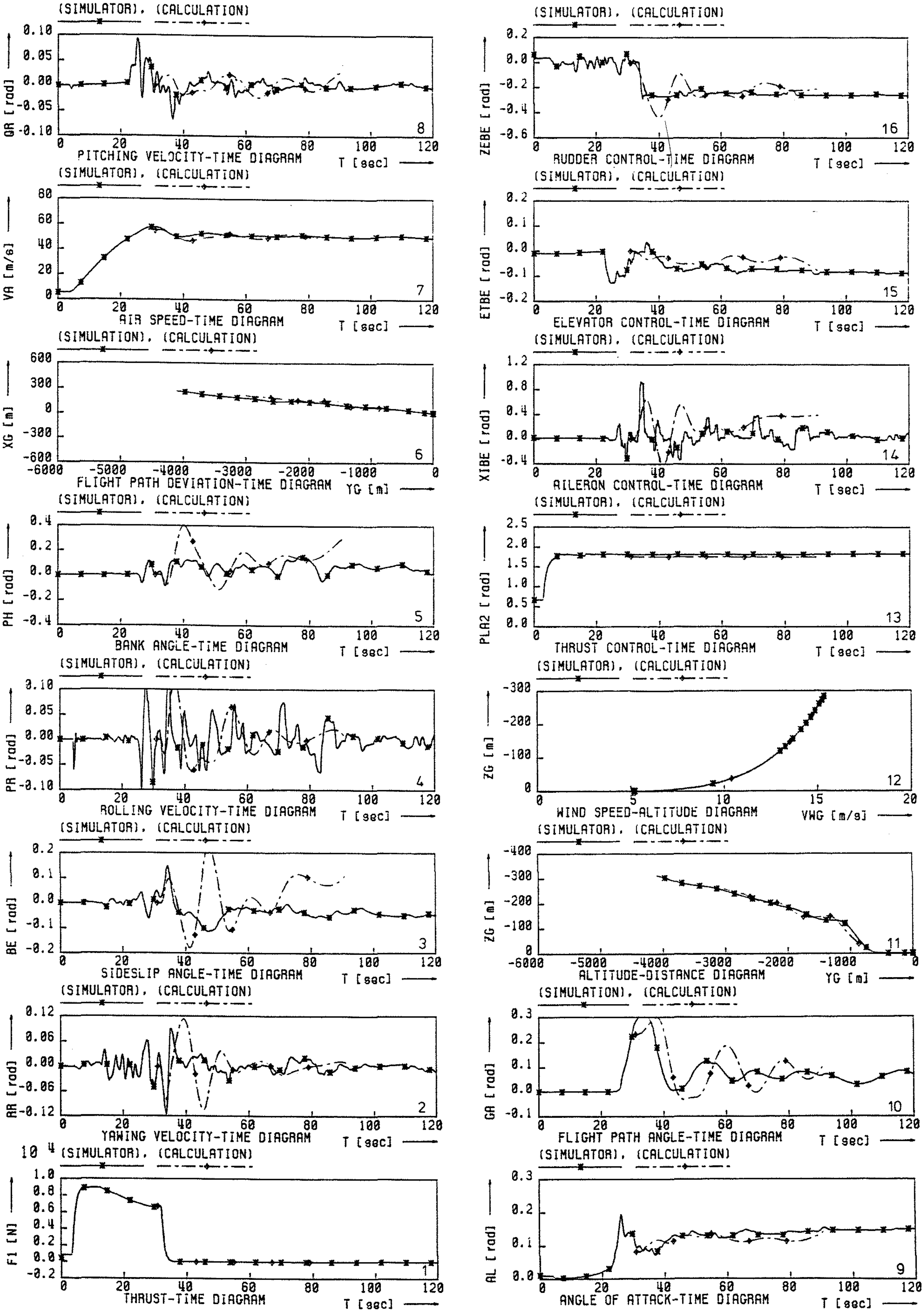


Fig.10. Results Comparison Between Numerical Calculation And Flight Simulator of Do28 During Take-Off.

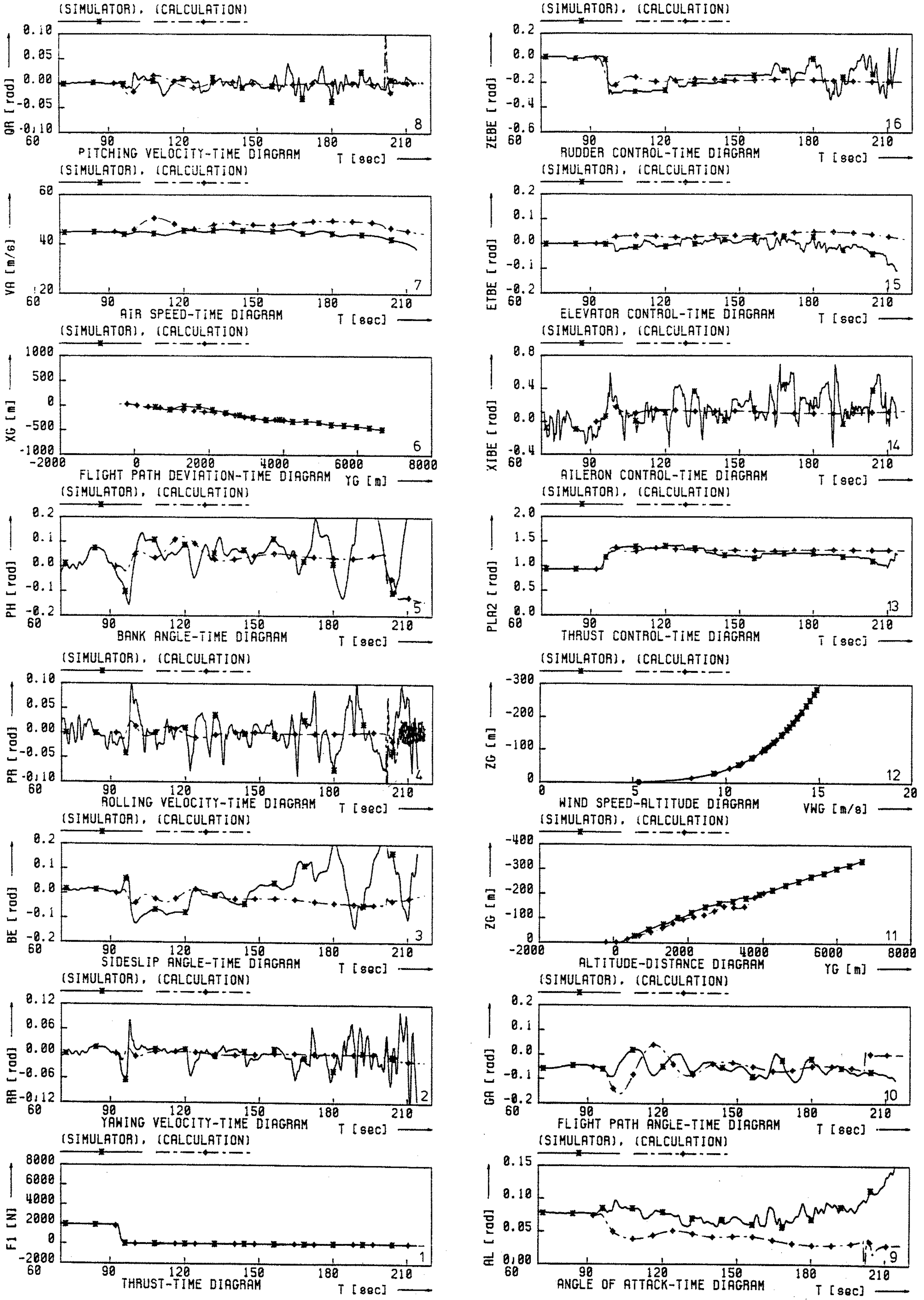


Fig.11. Results Comparison Between Numerical Calculation And Flight Simulator of Do28 During Landing Approach.