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DEEP STALL CHARACTERISTICS OF MU-300

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16. Abstract

The deep stall characteristics of the MU-300 Diamond aircraft are described. The MU-300 obtained type certification from FAA in 1981, and from Canada, West Germany, and England in 1983, and has achieved a high angle of attack. The aerodynamic design, structural dimension, and flight test of the MU-300 are described.

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1. INTRODUCTION

Since MU-300 DIAMOND 1 was given a model certification by FAA in November 1981, the aircraft was given the similar certification from Canada, West Germany and Great Britain in 1983. As for the mass production model of the same type aircraft, fifty eight airplanes of this model have been delivered. Flight characteristics of MU-300 have been highly praised through these airplanes.(1)(2) One of the keys which enabled the superior flight characteristics of MU-300 is the placement of the engine at the rear part of the fuselage which permitted the placement of the main wings and tail wings within the area of the clean air flow under the normal flight range through the arrangement of the T-tail wings. Since the BAC-111 accident, low wings, rear engine placement and arrangement of the T-tail wings are said to be somewhat related to the cause of the deep stall. Accordingly, many aircraft models which adopted the above design characteristics are equipped with a stick pusher in order to cope with the problem of deep stall. MU-300 was successful in maintaining a large margin toward deep stall. Therefore, adequate stall characteristics as well as the characteristics of high angle of elevation have been accomplished without the installment of a stick pusher.

2. DEEP STALL

Deep stall also known as super stall or stable stall (locked in deep stall) is a phenomenon that is likely to be experienced by the type of aircraft that is characterized by low wings, engine placement at the rear of the fuselage and arrangement of the T-tail wings. It is the phenomenon in which recovery from the stalled condition within the stall angle far exceeding the normal stall angle ($\alpha \approx 35$ to 40 degrees) becomes impossible. The condition of the lock in deep stall is shown in Fig. 1. If the flight condition exceeds the state of an ordinary stall and enters the state of deep stall, then a range characterized by $Cm > 0$ is developed at the high (elevation) angle range, and a secondary stability (elevation) angle is developed making the stall condition unrecoverable even if the pilot pushes the elevator all the way towards the nose down direction. Air dynamics related reasons for the deep stall are as follows. The horizontal tail wings become positioned within the rear flow of the exfoliated main wings and the nacelle as shown in Fig. 2 at the time of high (elevation) angle, and the effect of the horizontal tail wings and the elevator becomes reduced to approximately 1/10 of that of the normal flight creating the condition characterized by $Cm > 0$ as shown in Fig. 3.

Examples of accidents caused by the deep stall are many including the widely known BAC-111. (4) Not too long ago, a Challenger belonging to the Canadia Company was involved in a deep stall related accident during a test flight. (5) In many of the aircraft models which have poor deep stall characteristics, attempts are being made to avoid the condition of deep stall by equipping these aircraft with a stick pusher as mentioned earlier. Yet, there are reports of deep stall related accidents during the stall test among those airplanes which are equipped with such a device. (6) There are instances where successful recovery from the deep stall range has been made through the re-design of the tail wings necessitated by deep stall related accidents of the test model or others. Deep stall characteristics which are extremely important from the standpoint of the aircraft safety are considered to be some of the most important items in the determination of the aircraft configuration.

3. DESIGN OF AIR DYNAMICS AND AIR TUNNEL TEST

Some of the concerns in the original design of MU-300 characterized by the placement of the engine at the rear of the fuselage, low wings and the arrangement of the T-tail wings include (1) noise level of the passenger compartment, (2) engine air intake characteristics, (3) convenience in embarkation and disembarkation, (4) convenience of fuel service, (5) styling and others. According to the basic styling of the aircraft, deep stall characteristics have been put into consideration. Accordingly, the wing span of the horizontal tail was made larger than average.

High (elevation) angle characteristics have been put in consideration in the discussion of the shape of the aircraft from the beginning of the air tunnel test. One of the questions that needs to be answered at the time of designing the aircraft is the determination of the peak figure of Cm of Cm vs alpha curve in high (elevation) angle. Based on the discussion on the result of the simulation test by NASA (7) which states that "the only important thing is the fact that the peak figure of Cm is a negative figure, and the size of the margin has little to do with the recovery characteristics" as well as the data of DC-9 (Ref. to Fig. 5), it was determined that the design objective was to be the deep stall margin approximately the same level as DC-9's. In other words, the objective of the design was set as "Cm peak =< -0.03 in the case where the elevator is operated at full nose down at the stabilizer navigational angle under the trimmed down condition of 1.3 Vs".

High elevation angle wind tunnel test of MU-300 was conducted under the sting support method at the low speed wind tunnel facility of Nagoya Aircraft Plant, Mitsubishi Heavy Industries Corporation. The result of the initial wind tunnel test was good enough to satisfy the objective although there was hardly no room for a margin. As the process of design was developed changing the shapes of the aircraft body, a situation developed in which the initial objective of the original design could not be satisfied. There was a period when the span of the horizontal tail wings was extended a little. Under the condition of low deep stall margin as described above, deep stall characteristics were influenced every time there was a change in the shape of the aircraft, eg. change in the position of the nacelle or the shape of the pyron, making it necessary to conduct an air tunnel test for confirmation. Furthermore, additional air tunnel tests were necessitated as the absolute figure of the small figure of the pitching moment became the problem in the vicinity of alpha ≒ 40 degrees far exceeding the stall condition. Accordingly, the original design objective was changed to reflect the thought "a shape which is capable of withstanding extremely high degree of deep stall margin".

For this reason, reexamination of the wind tunnel test result including the result of the rear flow measurement (Fig. 6). At the same time, design characteristics of existing aircraft were also reexamined. As a result, it was concluded that the objective - to let the rear flow of the main wings and the nacelle pass in less elevation angle, to increase the effective dynamic pressure at the position of the horizontal tail wings, and finally to increase the deep stall margin - could be achieved by shifting the horizontal tail wings to the rear by 500 mm and to the lower direction by 200 mm and the position of the nacelle to the upper direction by 300 mm. The result of the wind tunnel test of the new shape revealed that the deep stall margin (Cm peak) was approximately five time that of the DC-9's. Realization of such a large margin enabled the designers of MU-300 to redesign the square measurement of the horizontal tail wings considering only the in-flight stability within the range of the ordinary flight. In addition to that, wing span could be scaled down. Fig. 7 shows the estimated figure based upon the wind tunnel test of the high angle pitching•moment characteristics according to the shape of the aircraft by the final design of MU-300. The deep stall marin has come to Cm $\approx$ -0.16.

4. FLIGHT TEST

MU-300 was given capability to recover from the condition of deep stall through the operation of the elevator. In the flight test, however, it was decided to equip the test model with a device to recover from deep stall for the safety reason until the stall characteristics were clearly identified. Said device (the device to recover from the stall condition) consists of two containers containing nitrogen gas under the pressure of 3,000 psi. A rubber hose connects the nitrogen gas containers and a jet nozzle which is paced under the fuselage. A valve is opened by the pilot, and the nitrogen gas is jet-sprayed at the time of stall lowering the nose of the aircraft. This device was demonstrated prior to the FAA's stall test. It was determined that the device was not sufficient. Accordingly, improvement of the recovery device was requested. Refuting the above decision, it was pointed out that the demonstration was conducted under the condition of the ordinary flight range above 100 kt, that the dynamic pressure was approximately twice the dynamic pressure after the stall and that the movement (response) of the aircraft in reference to the motion of the recovery device became rather small. The above refutation was not accepted, and the device had to be remodeled. The following remodeling of the device was accomplished. Two more nitrogen gas containers were added, and the position of the jet nozzle was moved as far back of the fuselage as possible. Certification of the remodeled recovery device was done under the condition most suitable to examine the actual effect of the device at below stall speed of the aircraft. The aircraft speed was reduced from 200 kt at the reduction ratio of 5 Kt/ sec., and the nitrogen gas was jet-sprayed under the following condition: 40 degrees of attitude angle; vertical acceleration of below 1 G; and the aircraft speed of 80 kt. The result of this test which confirmed the attitude angle change of 60 degrees in 5 seconds and the speed increase of 50 kt indicated that the improved device was sufficient enough.

The stall characteristics of MU-300 indicate the following. Exfoliation begins to take place from the inner side of the fence of the upper surface of the main wings as stall condition becomes near. The buffet that is generated is such a clear indication that all test pilots should be able to recognize it. As the control wheel is pulled and the elevation angle is increased, a clear pitch down is generated in response to he spread of the exfoliation domain toward the inner wings. At the same time, buffet gradually increases the intensity and finally comes to the stage which is commonly recognized as heavy buffet. At this time ordinary pilots will no longer reduce the air speed. At the internal flight test (conducted within the company) which took place at the early stage, it was discovered that the buffet at the time of lowering the flap did not have sufficient intensity. This situation was corrected by installing a stall strip, a triangle shaped object, under the front edge part of the main inner wings. Recovery from the stall condition is done by relaxing the intensity of the pulling force that is applied to the control stick. (Ref. to Fig. 8) The function of the spoiler both during the stall and during the recovery was excellent. It was possible to contain the fluctuation of the bank angle within 20 degrees under normal condition.

The evaluation method of the deep stall by FAA includes the confirmation of the characteristics by conducting the stall test through a rapid reduction of speed up to 4 kt/ set in addition to the normal stall test which is conducted by reducing the air speed by 1 kt/ sec. It was confirmed that MU-300 did not enter the stall condition at the stall test in which the air speed was reduced up to the ratio of 4 kt/ sec. It was also confirmed that the characteristics of the aircraft under the condition of one engine stall was quite mild. Overall stall characteristics of MU-300 was evaluated as excellent.

5. AN AFTERWORD

MU-300 at the early stage chose the body style characterized by the low wings, engine placement at the rear of the fuselage and the T-tail wings. The body style described above is generally believed to cause deep stall. Yet, it was given an excellent evaluation by FAA in spite of the fact that it was not equipped with a stick pusher through the design of air dynamics with consideration toward the deep stall. Stall characteristics of MU-300 were evaluated at the model certification tests in Great Britain, Canada and West Germany. MU-300 had no difficulty in obtaining the model certification from these three countries which are said to be very strict in stall characteristics. MU-300 has gone through more than 500 stall tests up to this date, and the maximum elevation angle of 30 degrees has been confirmed in these tests. As for deep stall, buffet which indicate the entrance of the stall condition as well as a clear warning by pitch down are available in addition to the warning by the shaker. In addition to that, the above listed advantages of MU-300 are further enhanced by the rapid recovery motion of the aircraft which is considered the additional characteristic of MU-300.

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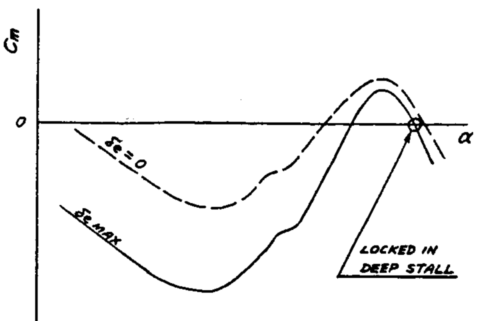
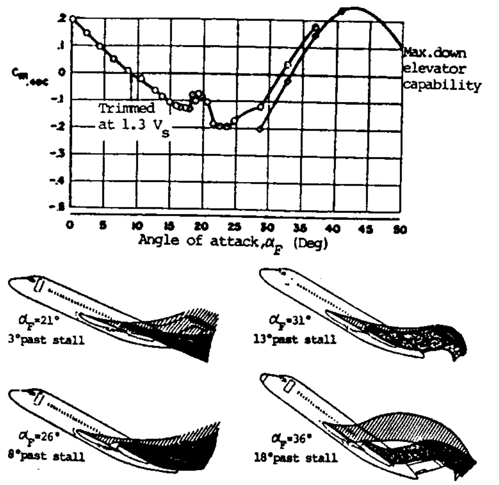
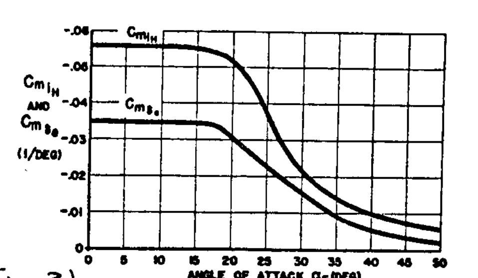


(Fig.1)

第1図 Locked in deep stall

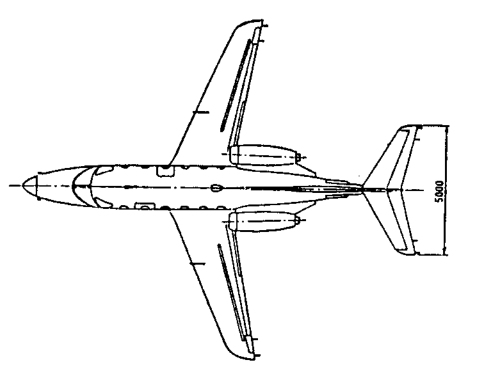


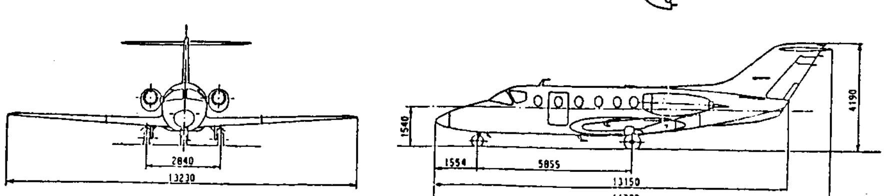
(Fig. 2) 第2図 ピッチング・モーメント特性と主翼およびナセル後流の関連[3)]



(Fig 3) 第3図 Stabilizer and elevator effectiveness[3)]

Dimension	
Overall width	13.23m
Overall length	14.73m
Overall height	4.19m
Wing area	22.43m^2
Cabin length (except cockpit)	4.77m
Cabin volume	11.3m^3
Number of seat (including 2 pilots)	9 11
Weight	
Max. takeoff weight	6,550kg
Engine	
Thrust	1,135kg x 2
Performance	
Max. operating speed	805km/h
Max. Operating altitude	12,500m
Rate of climb(2 engines)	945m/min
Stall speed	140km/h
Crusing range (45 min. reserve fuel)	2,850km
Takeoff length	1,235m





(Fig. 4) 第4図 MU-300 三 面 図

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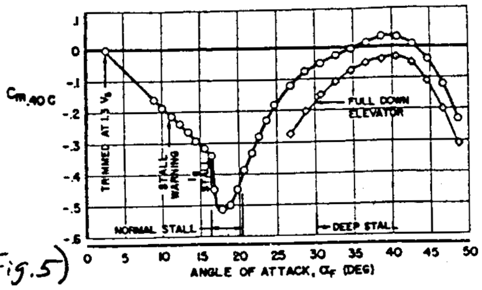
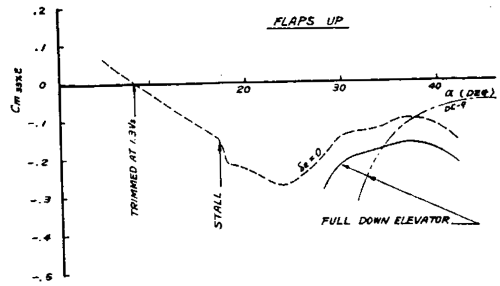
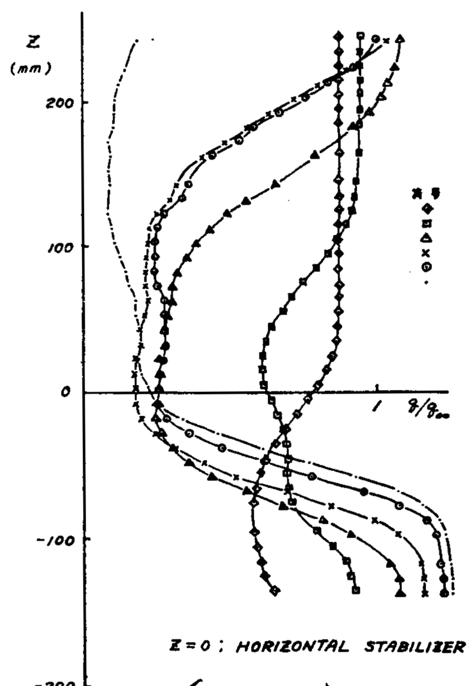


(Fig.5)

第5図 Pitching-moment coefficients for DC-9-10 configuration. Flaps 50°

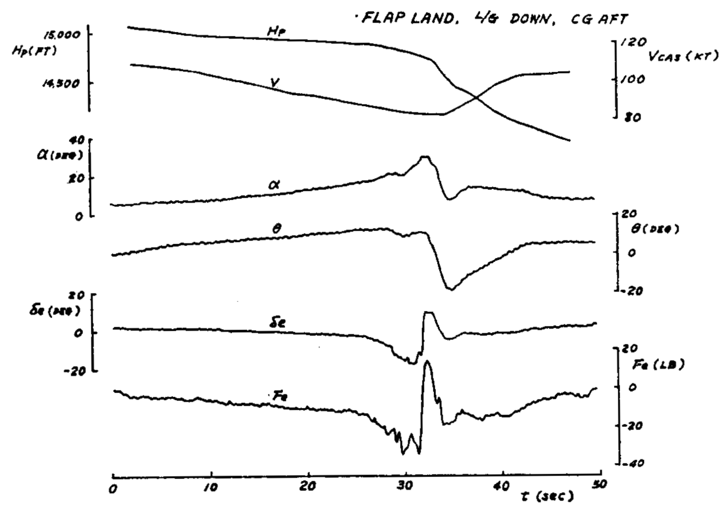


(Fig 7) 第7図 MU-300 の高迎角ピッチング・モーメント特性



(Fig.6)

第6図 水平尾翼位置での後流計測結果 (1/12.5 模型寸度)



(Fig.8) 第8図 失速特性試験タイムヒストリ