and $\Delta\alpha$ are obtained as

$$\Delta M = -\left(\frac{1}{\beta h}\right)\int_{-\infty}^{+\infty}\left\{\left[\frac{C_{pB}+C_{pH}}{2}-\left(\frac{\mu}{\pi\beta}\right)\frac{x^2-(\beta^2h^2/4)}{x^2+(\beta^2h^2/4)^2}+\left(\frac{q}{\pi\beta}\right)\frac{x}{x^2+(\beta^2h^2/4)}\right]\Big/2\cosh\left(\frac{\pi\xi}{\beta h}\right)\right\}d\xi \tag{6}$$

$$\Delta\alpha = -\left(\frac{1}{h}\right)\int_{-\infty}^{+\infty}\left\{\left[\frac{C_{pH}-C_{pB}}{2}+\left(\frac{\gamma}{2\pi}\right)\frac{\beta h}{x^2+(\beta^2h^2/4)}\right]\Big/\left[1+\exp\left(\frac{2\pi\xi}{\beta h}\right)\right]\right\}d\xi \tag{7}$$

The method consists in first evaluating the corrections for the region from x_1, the most upstream station, to x_2, the most downstream station over which the pressures on the control surface have been measured, by using Eqs. (6) and (7) and the trapezoidal integration rule. Next, the corrections for the region from x_1 to $-\infty$ and x_2 to $+\infty$ are evaluated using an exponential fit for C_p of the form

$$C_p = A\exp(-x) \tag{8}$$

for both upper and lower walls where the constant A has been determined from experimental data for the corresponding walls. It was noticed that there were practically no contributions to ΔM beyond x_1 and x_2 to $\mp\infty$, whereas the contribution from x_1 to $-\infty$ to $\Delta\alpha$ was considerable. The downstream contribution to $\Delta\alpha$ was negligible.

Results

In order to validate the method, Mokry's data[3] for a BGK-1 airfoil from the NAE 15×60-in. wind tunnel were used. The ΔM and $\Delta\alpha$ corrections obtained by the present method were −0.017 and −0.667, as compared to Mokry's values of −0.015 and −0.669. Like Mokry's method, the reference value of the flow angle at a selected reference point is needed.

Conclusion

A simple exponential fit to pressure coefficient beyond the most upstream and downstream measuring points on the control surfaces in a wind tunnel gives Mach and incidence corrections using the method of Capelier, Chevallier, and Bouniol that agree well with those obtained by other methods such as fast Fourier transforms.

Acknowledgment

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AIAA 82-4302

Existing Time Limit for Overwater Operations—Its Validity

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Nomenclature

p = probability of performance falling below the datum in the event of an engine failure
Q = incident probability per flight
t = intended duration of flight, h
γ_m = performance margin in terms of climb gradient, %
π_1 = probability of failure of one engine per flight
π_2 = probability of failure of two engines per flight
ρ = engine failure rate per engine hour
σ_r = standard deviation of single-engine climb gradients, %

Introduction

THE airworthiness and operational requirements relating to the performance of an airplane during the enroute phase are designed to ensure that the airplane can clear all obstacles by a sufficient margin in the event of one engine becoming inoperative. In addition, the airplane is required to be capable of a positive climb gradient at 1500 ft above the landing place (destination/alternate).

Under FAA requirements, no two-engine airplane may operate over a route that contains a point farther than 60 min flying time, with one engine inoperative, from an adequate airport.[1] Annex 6 of ICAO stipulates a limit of 90 min in respect to turbine engine airplanes only.[2] Air Navigation Orders, while not specifying any time limit, require safe landing capability at a given place (with the exception of performance group X airplanes).[3]

Historically, the 60/90-min rule is based on the reliability of the old piston and turbine engines. During the last decade, the reliability of turbine engines, especially that of jet engines, has improved substantially. However, this improved reliability is yet to be reflected in the performance requirements of existing airworthiness codes. A considerable gain in the operating economy and capability of airlines can be effected if the increased reliability is accounted for while establishing the time limit. This paper examines the validity, in regard to modern jet airplanes, of the 60/90-min rule.

Basis of Existing Time Limit

The desired level of safety should be achievable, during any flight stage, with one engine inoperative, by a two-engine airplane. This is ensured by specifying a minimum performance margin (γ_m) above a specified datum performance. The former is 1.1 and latter, zero, in terms of climb gradient during the enroute phase. Performance margin depends on the following: 1) selected incident probability—defined as the probability of performance falling below the datum performance (the ICAO stipulated, during the early 1950s, a value ranging from 2×10^{-6} to 7×10^{-6} per flight; this probability also determines the desired level of safety); 2) engine failure rate per engine hour; 3) standard deviation of climb gradients; and 4) duration of flight.

Methodology Used

The variance of enroute climb gradients with one engine inoperative has been determined here by using the

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methodology given in Ref. 4. Effects of sideslip and turbulence on the variance have been incorporated by applying the necessary correction.[5] The climb gradient distribution is taken as normal; hence a knowledge of variance and datum performance is sufficient to determine the incident probability.

Assuming each engine to be independent of the other, the probability of an engine failure per flight (π_1) is $2\rho t$ and that of both engines failing (π_2) is $\rho^2 t^2$. Further, the resultant incident probability is given by

$$Q = 2p\rho t + \rho^2 t^2$$

In Table 1, some representative values of Q have been shown for a range of γ_m and π_1 at $\sigma_r = 0.3535$. The following useful expressions can be derived with a little underestimation of Q at lower values of π_1 and a slight overestimation at higher values of π_1:

$$\pi_1 = 176.0 \times Q^{0.942} \quad \text{for} \quad \gamma_m = 1.0$$

$$= 157.0 \times Q^{0.880} \quad \text{for} \quad \gamma_m = 1.1$$

$$= 70.4 \times Q^{0.784} \quad \text{for} \quad \gamma_m = 1.2$$

$$= 19.0 \times Q^{0.669} \quad \text{for} \quad \gamma_m = 1.3$$

Thus the permissible duration of flight can be determined for a given value of Q, γ_m, and ρ. Figure 1 shows the relationship between γ_m and Q at constant values of π_1 and $\sigma_r = 0.3535$.

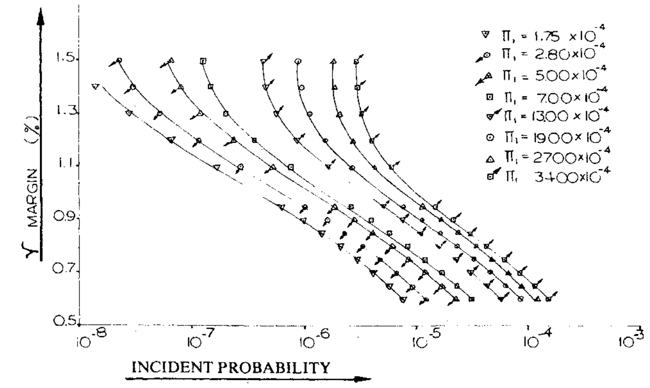

Fig. 1 Incident probability vs performance margin (σ_r = 0.3535%).

Analysis

The permissible duration of flight is 2h at $\gamma_m = 1.1$, $Q = 2 \times 10^{-6}$, $\rho = 3.5 \times 10^{-4}$, and $\sigma_r = 0.3535$. This gives an insight into the 60-min rule. It was also found that the contribution of π_2 in Q was about 30% at $Q = 2 \times 10^{-6}$ and $\gamma_m = 1.1$.

The average in-flight shutdown rates of jet engines used by U.S. airlines decreased from 1.4×10^{-4} to 0.8×10^{-4} per engine hour during the period 1973-1979.[6,7] The corresponding figure in respect to turboprops was 3.5×10^{-4}, the rate used in establishing the 60-min rule. Thus a value of $\rho = 1 \times 10^{-4}$ for modern jet engines would be in order. Regarding σ_r, very little published data are available. However, a σ_r of 0.3535 is considered too high for jet engines. A value of 0.3000 seems more realistic, yet has some built-in conservatism.

It can be seen from Fig. 2 that the permissible duration of flight is 8.0 h at $Q = 2 \times 10^{-6}$, $\gamma_m = 1.1$, $\sigma_r = 0.3535$, and $\rho = 1 \times 10^{-4}$, thus implying a rule of 4.0 h as against the existing 60/90-min rule. At lower values of σ_r the permissible duration of flight will be further enhanced beyond 8.0 h; in

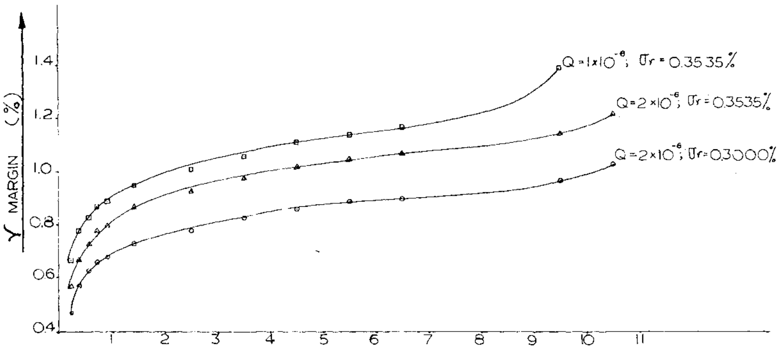

Fig. 2 Duration of flight (h) vs performance margin ($\rho = 1 \times 10^{-4}$).

Table 1 Incident probabilities as a function of performance margin. σ_r = 0.3535%; all figures of Q are to be multiplied by 10^{-6}

γ_m, %	Q_1	Q_2	Q_3	Q_4	Q_5	Q_6	Q_7	Q_8	Q_9	Q_{10}
1.5	0.0096	0.0227	0.0672	0.1300	0.2110	0.3140	0.4390	0.9210	1.8500	2.9300
1.4	0.0142	0.0301	0.0803	0.1480	0.2350	0.3430	0.4720	0.9710	1.9200	3.0200
1.3	0.0281	0.0522	0.1200	0.2040	0.3060	0.4300	0.5760	1.1200	2.1300	3.2900
1.2	0.0687	0.1180	0.2370	0.3670	0.5150	0.6860	0.8780	1.5600	2.7600	4.0800
1.1	0.1710	0.2820	0.5300	0.7770	1.0400	1.3300	1.6400	2.6800	4.3400	6.0700
0.95	0.6330	1.0200	1.8500	2.6200	3.4100	4.2300	5.0600	7.6900	11.5000	15.0000
0.90	0.9780	1.6100	2.8300	4.0000	5.1900	6.4000	7.6200	11.4000	16.8000	21.7000
0.85	1.4400	2.3200	4.1600	5.8600	7.5800	9.3200	11.0000	16.5000	23.9000	30.8000
0.80	2.0900	3.3600	6.0100	8.4900	10.9000	13.4000	15.9000	23.5000	34.0000	43.4000
0.75	2.9800	4.7800	8.5600	12.0000	15.5000	19.0000	22.5000	33.2000	47.7000	60.7000
0.70	4.1800	6.7000	12.0000	16.8000	21.7000	26.5000	31.4000	45.9000	66.2000	84.0000
0.65	5.7600	9.2200	16.5000	23.1000	29.8000	36.5000	43.1000	63.4000	87.3000	115.0000
0.60	7.8100	12.5000	22.4000	31.3000	40.3000	49.3000	58.3000	85.7000	122.0000	154.0000
$\pi_1 \times 10^{-4}$	1.75	2.80	5.00	7.00	9.00	11.00	13.00	19.00	27.00	34.00

addition, the contribution of π_2 in Q will be lower than 30%. These findings thus indicate that there is a strong case for revising the 60/90-min limit in respect to large jet airplanes.

Discussions

There is a high degree of conservatism built into the present airworthiness and operational codes in respect to modern jet airplanes. This is partially reflected in improved safety records. However, this unattended conservatism is penalizing for twin-jet airplanes in terms of operating economy and capability. In view of increasing fuel prices, overconservatism cannot be said to be very healthy.

A γ_m of 1.1%, although overconservative for modern jet airplanes, cannot be revised in isolation as it also affects the landing climb and baulked landing requirements. A long-term view is necessary in the light of the new evidence. However, the 60/90-min rule can be easily revised.

The present 60/90-min ruling may act as a deterrent to the development of two-engine high-capacity jets like the B757 and B767 airbus, etc. While the present approach is to group turboprops, turbofans, and turbojets under the single head of turbine engines for the purpose of formulating airworthiness requirements, operational experience has established beyond doubt that jet engines are more reliable than turboprops. It may be worthwhile to treat turboprops and jet engines separately for this purpose and so enhance the operational capability and economy of jet airplanes.

Within the jet engine population, also, engine failure rates vary considerably with the type of engine. For the purpose of requirements like the 60/90-min one, each type of jet-engine airplane may be assessed on its own merit rather than assessing all types against a common rule.

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Laser Velocimeter for Large Wind Tunnels

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Introduction

THE measurement of velocity in large wind tunnels is normally performed using mechanical probes. This practice, although a basic, dependable method of making such measurements, can entail considerable complexity owing to the structure often required for probe support. Support structures can be bulky, complex, and costly, especially if probe translation is desired over long distances in a large wind tunnel test section.

The use of laser velocimetry for the flowfield measurements in large wind tunnels is far more desirable since it can be implemented with minimal mechanical complexity and with minimal modifications to the test section structure. By incorporating a variable-focus capability, a velocimeter can be used for surveying large regions within a wind tunnel test section without introducing objectionable support structures in the immediate vicinity of the model as would be required when mechanical probes are used. Accordingly, the velocimeter described herein is intended to be used in investigations that include V/STOL vehicle flowfield mapping for location and sizing of wakes and plumes,[1] wing-loading distribution determination without the need for pressure taps,[2] the aerodynamics of high-lift airfoils as well as rotating rotor blades,[3] and vehicle wake studies.

The laser velocimeter described herein has been designed to fill the need for a long-range system that can operate in a large wind tunnel. The instrument has undergone preliminary testing and is now in the final stages of development. It is a single-color dual-beam backscatter system that is capable of sensing two orthogonal components of velocity. The system will be installed within the test section of the NASA Ames 40- × 80-ft Wind Tunnel. Flow surveys will be accomplished through a combination of mechanical translation and rotation and optical focusing. A dedicated stand-alone microprocessor-based interface unit will be used for test-point position control, data acquisition, and display.

Velocimeter Description

An argon-ion laser capable of producing 9 W of continuous power at a wavelength of 514.5 nm is the source of laser light. A unique arrangement of two acousto-optic cells is used to accomplish beam splitting as well as frequency shifting (to eliminate flow direction ambiguity) functions. In this manner, a frequency difference between the two parallel output beams of 20 MHz is ultimately obtained. The optical system that focuses the beam pair to a particular point in the wind tunnel comprises three lens modules and a large folding mirror. The output lens module is a stationary singlet and has a clear aperture diameter of 33 cm; the intermediate module is also a stationary singlet element; and the module that first intercepts the parallel output beams is a movable triplet assembly. The folding mirror is 38 cm wide, 51 cm long, and 6.4 cm thick and is coated for 99.94% reflectance at the laser wavelength when the incidence angle is 45 deg.

A sketch of the installation and associated positioning hardware is shown in Fig. 1. Three scanning motions control the position of the velocimeter test point. The laser and optical components are mounted within a cylindrical aluminum housing 76 cm in diameter and 4.3 in length that can be rotated about its longitudinal axis (see Fig. 1) so that the test point can be positioned at any point along an arc of 45 deg to either side of the vertical. The package is mounted on linear bearings that attach to a rail support system to provide lateral positioning capability, and range control (optical focusing) is accomplished by translation of the movable lens module. Longitudinal positioning, on the other hand, is accomplished by repositioning the rail system, which is only temporarily attached to the tunnel floor. Each of the three scanning motions is made with a stepping motor through computer control; absolute optical shaft-angle encoders provide positive position readback.

A stand-alone microprocessor-based interface unit has been designed and fabricated in order to monitor encoder positions, provide motor control, and buffer the velocity

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