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8.2 Learjet Model 25

Drag Analysis

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Drag Analysis

The procedures and data for estimating drag at Gates Learjet are contained in the Learjet Aerodynamics Handbook and were used to calculate the drag characteristics of the Model 25 airplane. Based on cruise flight test data obtained on the Model 25, these methods generally predicted the total drag characteristics within current acceptable and reasonable engineering accuracy.

The use of wind tunnel model results will not guarantee absolute accuracy because of the many corrections and interpretations that must be applied to the data. However, small scale tunnel tests can provide the technique for minimizing configuration drag as well as identifying the aerodynamic contributions of each individual component.

Flight testing, when carefully executed, will provide the complete trimmed drag of the airplane. Such a program requires extensive testing since it is necessary to define the characteristics throughout the operating envelope of the airplane. What a flight program does not do and cannot do (within practical limitations) is to isolate and identify drag characteristics for each of the major components of the total vehicle. Without knowing the drag build-up for the airplane it is difficult and costly, from flight test data alone, to identify drag problems and then through the continued use of flight tests to arrive at a solution to the problem.

Only by integration of the results of all the available techniques can confidence in drag prediction and eventual control of drag levels be developed.

The total airplane drag is produced by several separate contributions that are identified as:

- profile drag (skin friction)
- interference drag
- roughness and gap drag
- induced drag
- compressibility drag
- profile drag variation with lift
- trim drag

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Estimated data, flight test data and small scale and full-scale wind tunnel tests are available for the Learjet. It is then reasoned that from these sources an assessment of the individual magnitudes can be determined. The following comments provide the reasoning and analysis for using these data to determine the drag for the Model 25. For purposes of evaluation and comparison a mid-cruise weight of 12,000 pounds, an altitude of 40,000 feet and a cruise Mach number of 0.75 will be used.

Figure 1 presents the trimmed, level flight drag characteristics for the Model 25 at cruise Mach numbers of 0.60, 0.70, 0.75 and 0.80. For a weight of 12,000 pounds and a cruise Mach number of 0.75 the lift coefficient is 0.336 and the corresponding total drag coefficient is 0.0338.

Profile, Interference, and Roughness Drag

The estimated skin friction drag is 0.0186, interference drag is 0.0032, and roughness and gap drag is 0.0016. The total zero lift drag is then estimated to be 0.0234 or 69.23 percent of the flight test cruise drag. Therefore, if the zero lift drag estimate is correct, the balance of the drag, 0.0104 may be attributed to:

- induced drag
- compressibility drag
- profile drag variation with lift
- trim drag

Induced Drag

One accounting technique that can be used in evaluating the drag contribution due to induced drag is to evaluate the induced drag term with the span efficiency factor equal to 1.0. By using this procedure all of the losses due to non-elliptical spanwise loading and wing-tip tank effects will be included in the profile drag variation with lift. Using this technique the induced drag at the cruise condition is 0.0072 or 21.30 percent of the total cruise drag. For reference purposes, Figure 2 presents a plot of induced drag based on $e = 1.0$.

At this point the contribution due to zero lift drag and induced drag is 0.0306. The remainder of the cruise drag 0.0032 or 9.47 percent should be accounted for by

- compressibility drag
- profile drag variation with lift
- trim drag

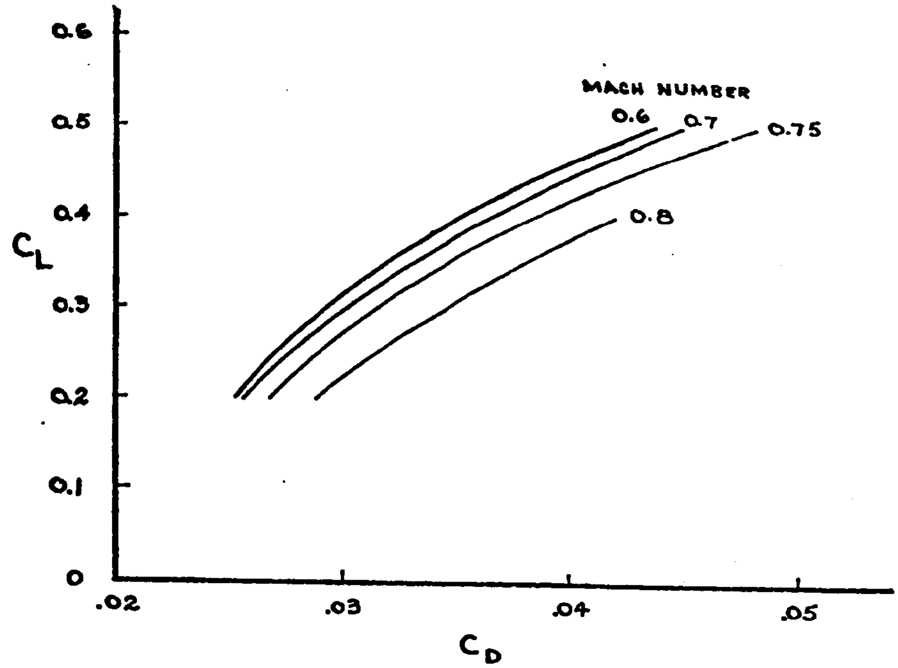

Figure 1. Learjet Model 25 Drag

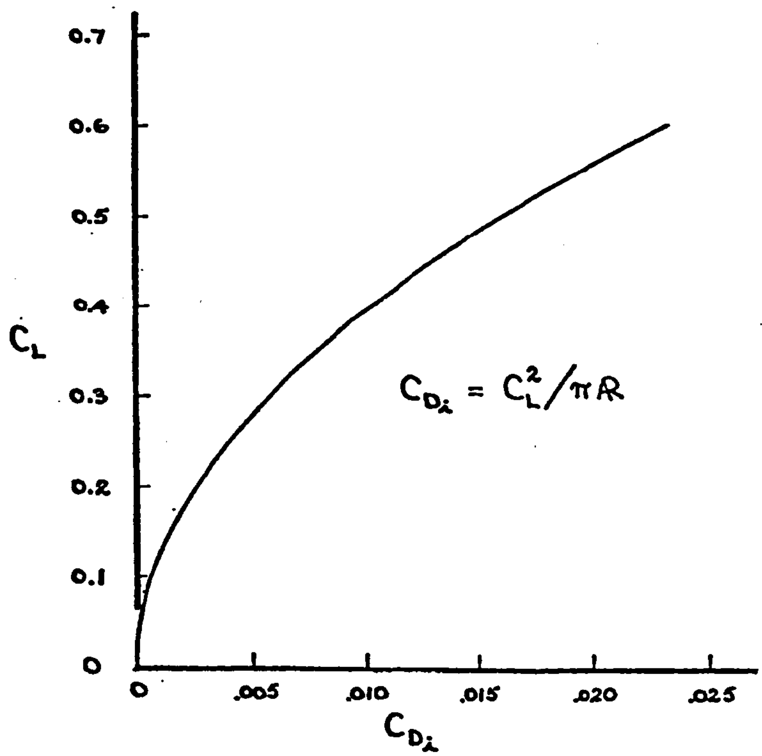

Figure 2. Learjet Model 25 Induced Drag

Compressibility Drag

Based on flight test data, Figure 3 presents the compressibility drag increments for the Model 25. Using these data the compressibility drag coefficient for a Mach number of 0.75 and a lift coefficient of 0.336, is determined to be 0.0028. The remaining drag increment of 0.0004 should be the sum of the

- profile drag variation with lift
- trim drag

In comparing the actual flight test compressibility drag increments to the original estimated curves it was noted that the flight values were higher than the predicted values. The difference between the actual and the estimated increases with Mach number and lift coefficient which is not unexpected. The reason for this difference may be better rationalized if the prediction procedures are reviewed.

As previously noted the total drag of the airplane may be attributed to profile drag (skin friction), profile drag variation with lift, interference drag, roughness and gap drag, induced drag, compressibility drag and trim drag. At zero lift the induced drag contribution is zero and the remainder of the zero lift drag should be accounted for by the other contributions.

Considering the data presented in Figure 4 and similar data for $M = 0.6$, the increment between the zero lift drag coefficient values for $M = 0.6$ and $M = 0.75$ should then be equal to the compressibility drag and the trim drag contributions. The difference between trim drag at zero lift for these two Mach numbers will be considered as being insignificant. The reason for this assumption is that between these speeds the stability values that determine trim drag should not be significantly different. Therefore, the increment between the zero lift drag coefficients should represent compressibility drag alone.

At zero lift for $M = 0.6$, $C_D = 0.0210$ and for $M = 0.75$, $C_D = 0.0226$ with $\Delta C_D = 0.0016$. From the data of Figure 3, the compressibility drag increment at $C_L = 0.2$ is determined to be 0.0015 which is in good agreement with the sixteen count increment at zero lift. This correlation would then indicate that from $M = 0.6$ to 0.75 the compressibility drag increment is the same for all lift coefficients in the range from 0.0 to 0.2. Such results are not unexpected with similar trends being shown in available literature. At Mach numbers greater than 0.75 the compressibility drag increments for lift coefficients of 0.0 and 0.2 should deviate as shown.

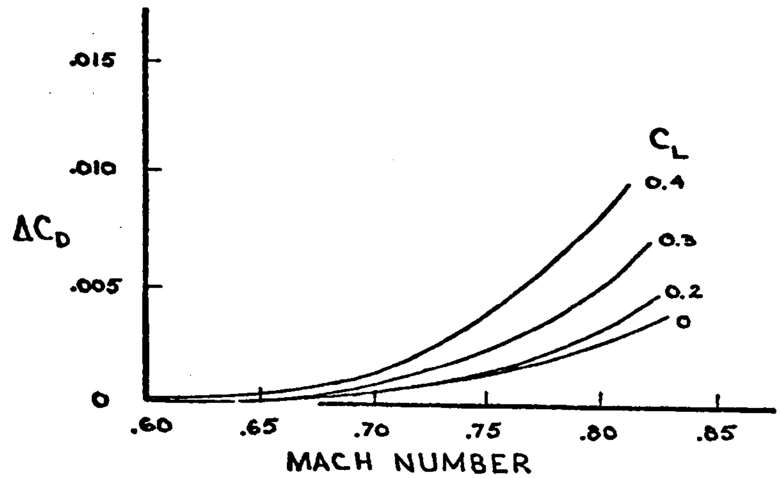

Figure 3. Learjet Model 25 Compressibility Drag

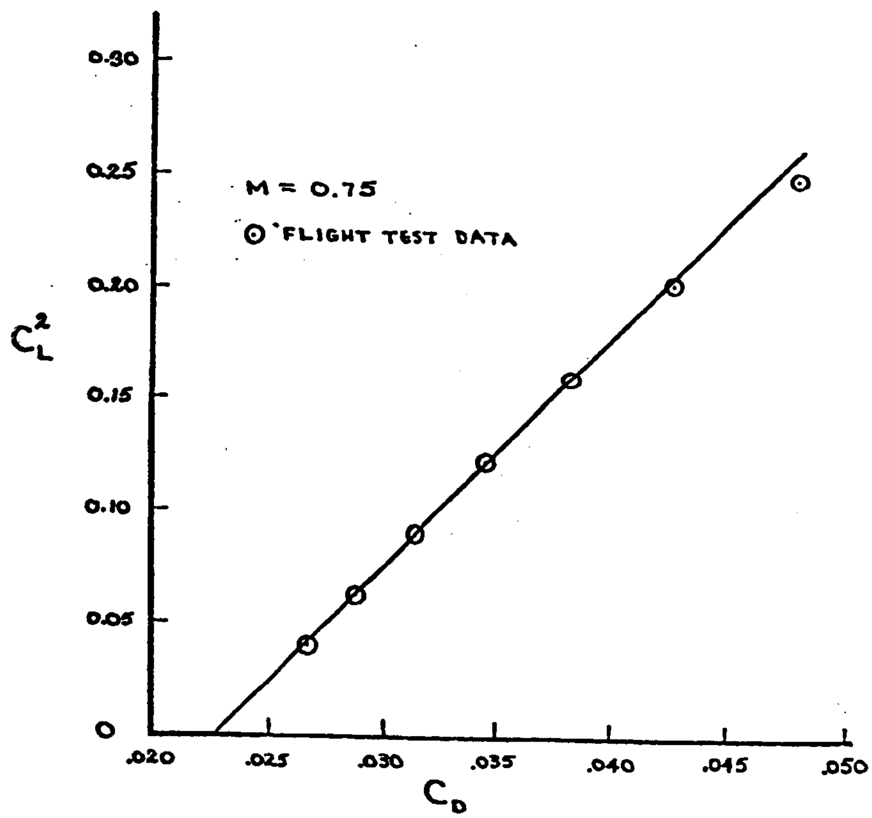

Figure 4. Learjet Model 25 Drag

Profile Drag Variation With Lift

Using the full scale wind tunnel test results and letting e = 1.0 for evaluating induced drag the profile drag variation with lift is determined from $C_{D_P} = C_D - C_{D_i}$ with the results being presented in Figure 5.

Using the data of Figure 5 the profile drag increment due to lift for a $C_L = 0.336$ is $\Delta C_{D_P} = 0.0007$ or 2.07 percent of the total cruise drag. However, this value is 0.0003 more than the total drag increment allowed for both profile drag variation with lift and trim drag.

Trim Drag

In considering the trim drag increment it is noted that the basic skin friction drag of the horizontal tail has already been included in the basic profile drag of the airplane. A profile drag variation with lift will exist for the horizontal stabilizer. However, this contribution is probably so small as to be negligible. Thus, the horizontal stabilizer trim drag increment will be considered to consist only of the induced drag contribution of the tail.

Low speed wind tunnel test data are used to show that the tail induced drag or trim drag increment is 0.0005. Compared to the total cruise drag of 0.0338 the trim drag amounts to 1.48 percent.

It is noted the sum of the estimated profile drag due to lift, 0.0007, and the trim drag, 0.0005, is 0.0008 more than the total drag increment allowed for them.

Discussion of Drag Analysis

By using the reasoning and procedures given in the preceding analysis, all of the drag, except for a drag increment of 0.0008 can be accounted for in the analysis. Balance of the total drag picture can be obtained by slight revisions in the estimates of any of the individual sources. However, the more likely and suspect areas for reassessment are the contributions due to profile drag (skin friction), interference drag, and roughness and gap drag. These items are open to question because they represent the estimated portion of the previous analysis, whereas all of the other items have a firmer basis for conviction. The eight drag count increment represents 2.37 percent of the cruise drag. In order for the individual drag contributions to balance it is reasoned that this drag reduction may be distributed between profile, interference and roughness so that the total for these three sources is 0.226 instead of the original estimate of 0.0234.

If the zero lift drag is 0.0226 it should then be possible to take the flight test drag polar at M = 0.75 (Figure 1), plot these data as C_L^2 versus C_D and extrapolate this curve to zero lift and verify the 0.0226 value. Figure 4 presents a plot of C_L^2 versus C_D with the symboled points being taken directly from Figure 1. The zero lift drag, as determined from this plot is 0.0226 which then substantiates this zero lift drag value as determined from the previous analysis.

Distributing the eight drag count reduction between the three sources so that the total zero lift is 0.0226, the breakdown of total airplane cruise drag is then given in Figure 6.

Based on a total profile drag of 0.0180 and on the original estimated profile drag contribution of each individual component the profile drag (skin friction) may be summarized as shown in Figure 7.

The total profile drag accounts for 53.25 percent of the total cruise drag of the airplane.

Drag Distribution

Figure 8 presents the drag distribution for the airplane as a function of Mach number with the data being extended to Mach 0.85. This plot provides a summary presentation of the drag contributions of the various drag sources discussed in this report. Throughout the flight range the drag contribution due to profile drag continues to be the major source of drag representing 61 to 66 percent of the total cruise drag. With increasing cruise speed the induced drag decreases, varying from 24 to 11 percent of the total. The compressibility drag increases with increasing Mach number, varying from 4 to 24 percent. The contribution due to trim drag and profile variation with lift represents the smallest source for a range of 8 to 2 percent of the total cruise drag.

A comparison of high Mach number estimated drag with flight test determined drag is presented in Figure 9.

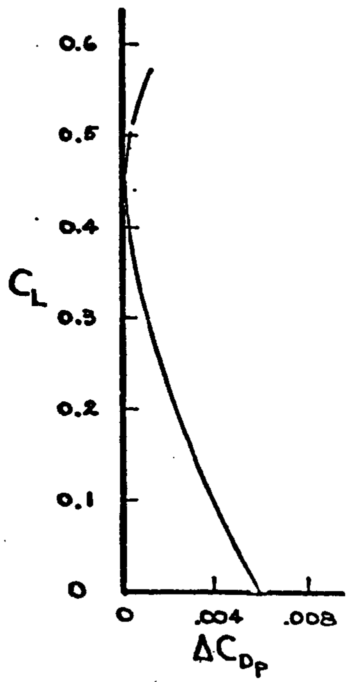

Figure 5. Learjet Model 25 Profile Drag Variation with Lift

$M = 0.75$ $C_L = 0.336$ $C_D = 0.0338$

Source	ΔC_D	% of Total
Profile drag (skin friction)	.0180	53.25
Profile drag variation with lift	.0007	2.07
Interference drag	.0031	9.17
Roughness and gap drag	.0015	4.44
Induced drag	.0072	21.30
Compressibility drag	.0028	8.28
Trim drag	.0005	1.48
TOTAL	0.0338	100.00

Figure 6. Cruise Drag Breakdown

C_{Dp}, Profile Drag = 0.0180

Item		% of ΔC_{Dp}	ΔC_{Dp}
Wing		29.57	.0053
Fuselage		34.95	.0063
Tip Tanks		11.83	.0021
Tip Tank Fins		0.54	.0001
Nacelles		6.45	.0012
Pylons		1.61	.0003
Horizontal		9.14	.0016
Vertical		5.91	.0011
	TOTAL	100.00%	0.0180

Figure 7. Profile Drag (Skin Friction) Breakdown

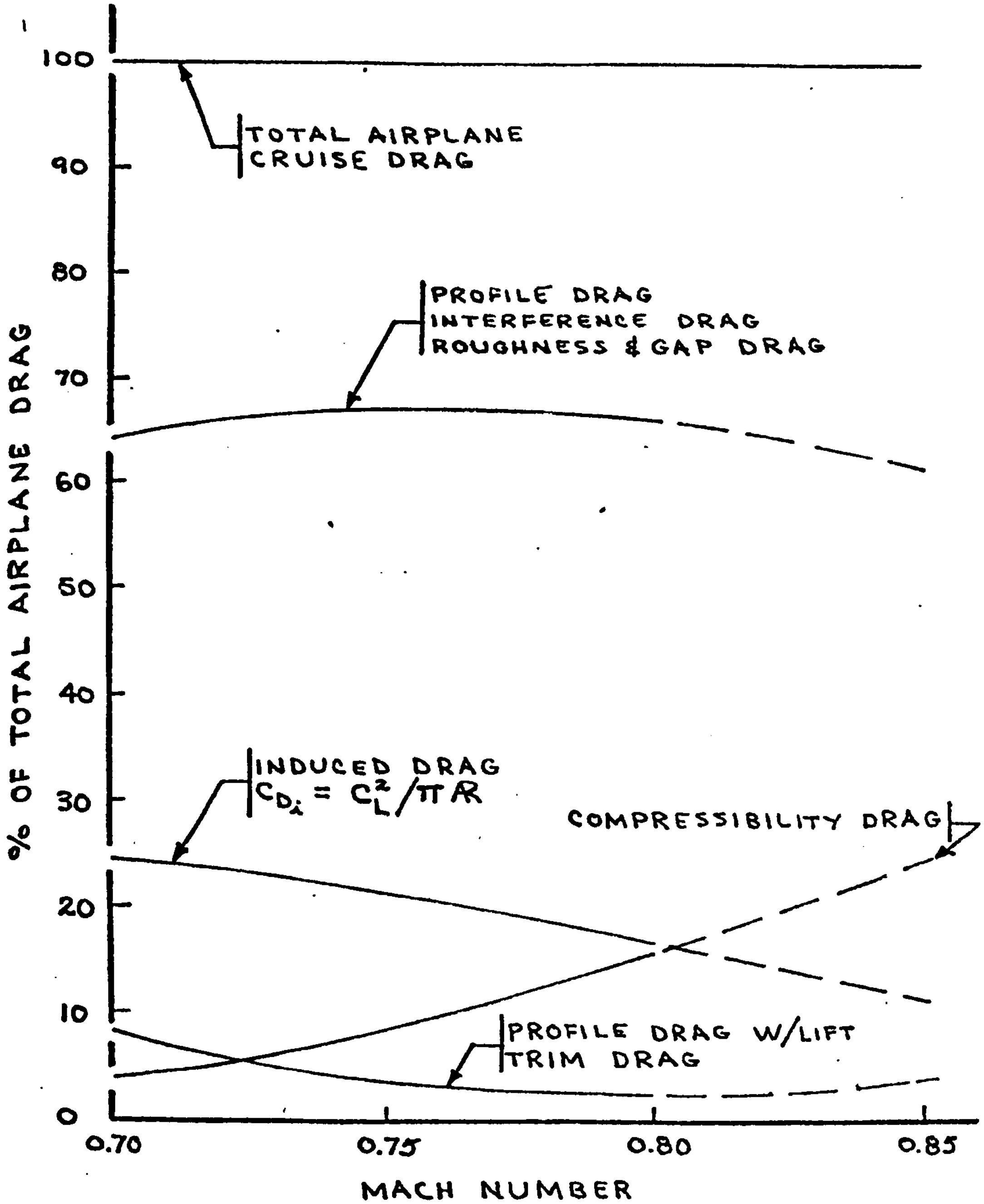

Figure 8. Learjet Model 25 Drag Distribution

EXAMPLE @ MID-CRUISE WT.
40,000 FT.

M	C_L	C_D (Actual)	C_D (Estimated)	ΔC_D	% DIFF.
.70	.385	.0353	.0353	0	0
.75	.336	.0338	.0335	.0003	0.9
.77	.318	.0338	.0331	.0007	2.1
.80	.295	.0341	.0326	.0015	4.6

Figure 9. Comparison of Flight Test Drag and Estimated Drag