10 IN-FLIGHT ROTORCRAFT ACOUSTICS PROGRAM TESTING

Flight data were obtained in formation flight with a YO–3A airplane acoustic platform under a joint test that was part of the In-Flight Rotorcraft Acoustics Program (IRAP). The flight data are discussed in this section. The corresponding acoustic measurements obtained using the YO–3A are in a separate data base and are not discussed here. A history of the IRAP project is given in Ref. 18. The basic flight test procedures used during IRAP testing are discussed in Section 2.

A nominal C_W/σ of 0.071 was selected to match wind tunnel test conditions at the DNW of a 1/5.73-scaled model rotor (Ref. 35). Test data were obtained at indicated airspeeds of 65, 75, and 95 KIASB and rates of descent from zero to –1000 ft/min. An additional test condition of $C_W/\sigma = 0.086$ and an airspeed of 68 KIASB was selected to examine the effects of thrust on the BVI signatures. In addition, two cases of accelerated flight were examined. Accuracy of rate of descent based on boom pressure altitude measurements is discussed first, then the data obtained in steady descending flight. Finally, the two accelerating flight cases are mentioned.

Rate of Descent Measurement

Rate of descent was calculated for the IRAP flight tests using the measurement of boom pressure altitude (HPB) and advance ratio (AMU). During ground-acoustic testing (see Section 7), data for 86 ascent, level flight, and descent conditions were obtained where rate of descent (or rate of climb) was measured using both the boom pressure altitude and a ground-mounted laser tracker. This data base of measurements provides a useful means of assessing the accuracy of the boom pressure altitude measurement.

Figure 91 compares the pressure altitude measured by the boom (HPB) and the laser tracker (ZLASER) for Counter 9115. The data for this case were extracted from TRENDS using the PRINT command in TIMEHIST. For both measurements, a linear regression fit of altitude with time has been calculated. These fits are shown in Fig. 91 by a dashed line, however, there is so little variance in the laser tracker data that the data and regression fit are coincident. From this figure it can be seen that there is an offset between the boom measurement and the laser tracker of about 100 feet and the boom measurement is much noiser than the laser tracker. Nonetheless, the computed flight path angles are quite similar, with $\gamma_{HPB} = –5.27$ deg and $\gamma_{LASER} = –5.38$ deg. The variance in the boom measurement, however, is 15X greater than the laser measurement. Note that the offset in the two measurements has no effect on the determination of rate of descent.

As discussed in Section 7, all of the laser tracking data were extracted from the TRENDS BH2 database using the OUTDATA utility as a batch process under GATEWAY in the TRENDS menu. At the same time, the HPB and AMU data were also obtained and all data were post-processed to compute average values over each revolution. Flight path angles were computed for both the boom and laser tracker by fitting a first-order regression curve to the mean values calculated for each revolution. The calculated flight path angles based on the laser tracker were previously shown in Fig. 43. Of 89 ascent, level flight, and descent conditions, three were excluded because the variance was excessive, indicating either measurement or flight motion problems. The calculated flight path angles for the remaining 86 points are shown in Fig. 92, where the boom measurement is shown as a function of the laser tracker. A linear regression curve is also shown in the figure ($r^2 = 0.9927$) and the slope is 1.034, indicating that the flight path angle calculated from the boom pressure altitude is 3.4% high.

Based on the comparison of flight path angles calculated with the boom pressure altitude and laser tracker during ground-acoustic testing, it appears that the boom pressure altitude measurement provides a reasonably accurate measure of vertical rate. The laser tracker is believed to be a more accurate measurement of aircraft altitude and vertical rate than the boom pressure altitude measurement, however, no modification has been made to the vertical rate measurements in this section based on the 3.4% difference.

IRAP Steady Descents

For the test flights at a nominal weight coefficient of $C_W/\sigma = 0.071$, no ballast was placed in the ballast cart and no attempt was made to keep the aircraft c.g. constant. Test data were obtained in formation flight with the YO–3A acoustic measurement platform for a range of descent conditions at three advance ratios: 0.17, 0.20, and 0.25. Thirty-four counters were obtained for $\mu = 0.17$ and are listed in Table 129. The flight path angles based on the boom pressure measurement (HPB) and the tip-path-plane angles are shown in Table 130 along with measures of variance. Twelve counters were obtained for $\mu = 0.20$ at the nominal weight coefficient and these are listed in Table 130. The flight path and tip-path-plane angles are shown in Table 131. Only three counters were obtained at $\mu = 0.25$ and these are listed in Table 132. The flight path and tip-path-plane angles are in Table 133.

On Flight 113, 1500 lbs of ballast was added to the ballast cart to obtain a nominal weight coefficient of $C_W/\sigma = 0.086$. The ballast cart was kept in a fixed condition for these test cases. Fifteen counters were obtained for a range of rates of descent at an advance ratio of 0.17 and are shown in Table 134. The flight path and tip-path-plane angles for this weight coefficient are shown in Table 135.

Figure 93 shows the flight path angles computed using the boom pressure measurements for all of the IRAP descent flight cases and these are compared with the flight path angles obtained during ground-acoustic testing (see Section 7). The IRAP test conditions cover a smaller range of flight path angles and advance ratios than were obtained during ground-acoustic testing.

The rates of descent and advance ratios for testing at $C_W/\sigma = 0.071$ were selected to match as closely as possible conditions with a 1/5.73-scaled model rotor tested at the DNW. The flight path angles and advance ratios for these cases are compared in Fig. 94 with data from Table 13 of Ref. 35. The wind tunnel was able to set the advance ratio and shaft angle (rate of descent) accurately, but as is seen in Fig. 94, it was more difficult to achieve precise values during formation flight under the IRAP program.

The IRAP test counters provide good resolution in terms of flight path or tip-path-plane angle. From the counters listed in Table 130, ten cases have been selected where the tip-path-plane angle varies from –2.65 deg (approximately level flight) to 5.46 deg (8 deg descent angle). The pressure data were extracted from TRENDS using the OUTDATA utility and these data were converted to the Plot/Data Base format using post-processing routines. Figure 95 shows the normal force computed at $0.865R$ for the ten cases, where only harmonics above the 16th are retained to show the BVI on the rotor at this radial station. The BVI signatures should be compared with a comparable data from ground-acoustic testing in Sect. 9, see Fig. 84, but note the increased resolution in the tip-path-plane angle. As the tip-path-plane angle increase (increasing rate of descent), the advancing side BVI remains fairly constant, but occurs earlier in the first quadrant of the rotor. In level flight conditions, no BVI is seen on the retreating side, but the BVI starts to appear at $\alpha_{TPP} = -0.23$ deg and occurs later in the fourth quadrant as the descent angle becomes more negative.

IRAP Level Flight Acceleration

During the IRAP program one test point was obtained where the UH–60A and the YO–3A accelerated in formation flight from an advance ratio of about 0.15 to 0.22. The duration of the accelerating flight case was a little over 52 sec. This record was split in thedata base into the original counter, Counter 10305, and a pseudo-counter, Counter 10321. These counters are listed in Table 137. Over the duration of the accelerating flight condition, the two aircraft climbed slightly, starting from about 2490 feet and ending at 2640 feet. The average rate of climb was about 179 ft/min and the average flight path angle was about 1.3 deg.

Table 129. – IRAP testing, $C_W/\sigma = 0.071$, $\mu = 0.17$.

FLIGHT	COUNTER	DESCRIPTION	DURATION
100	10006	LEVEL,65 KIASB, PT C	13.99 Seconds
100	10007	LEVEL,65 KIASB, PT C	13.99 Seconds
100	10008	DESCENT,300FPM,65 KIASB,PT D	13.99 Seconds
100	10009	DESCENT,300FPM,65 KIASB,PT D	14.00 Seconds
100	10010	DESCENT,400FPM,65 KIASB,PT E	13.99 Seconds
100	10011	DESCENT,400FPM,65 KIASB,PT E	13.99 Seconds
100	10013	DESCENT,500FPM,65 KIASB,PT F	13.99 Seconds
100	10014	DESCENT,500FPM,65 KIASB,PT F	12.00 Seconds
100	10015	DESCENT,600FPM,65 KIASB,PT G	13.99 Seconds
101	10106	DESCENT,600FPM,65 KIASB,PT G	13.99 Seconds
101	10107	DESCEMT,600FMP,65 KIASB,PT G	13.99 Seconds
101	10110	DESCENT,700FPM,65 KIASB,PT H	13.99 Seconds
101	10111	DESCENT,700FPM,65 KIASB,PT H	13.99 Seconds
101	10112	DESCENT,800FPM,65 KIASB,PT I	13.99 Seconds
101	10113	DESCENT,800FPM,65 KIASB,PT I	14.00 Seconds
101	10114	DESCENT,900FPM,65 KIASB,PT J	13.99 Seconds
101	10115	DESCENT,900FPM,65 KIASB,PT J	13.99 Seconds
114	11409	DESCENT,200FPM,68KIASB,PT C	13.99 Seconds
114	11410	DESCENT,200FPM,68KIASB,PT C	13.99 Seconds
114	11411	DESCENT,300FPM,68KIASB,PT D	13.99 Seconds
114	11412	DESCENT,300FPM,68KIASB,PT D	13.99 Seconds
114	11413	DESCENT,400FPM,68KIASB,PT E	13.99 Seconds
114	11414	DESCENT,400FPM,68KIASB,PT E	13.99 Seconds
114	11415	DESCENT,500FPM,68KIASB,PT F	13.99 Seconds
114	11416	DESCENT,500FPM,68KIASB,PT F	13.99 Seconds
114	11417	DESCENT,600FPM,68KIASB,PT G	6.82 Seconds
114	11418	DESCENT,600FPM,68KIASB,PT G	13.99 Seconds
114	11419	DESCENT,700FPM,68KIASB,PT H	13.99 Seconds
114	11420	DESCENT,700FPM,68KIASB,PT H	13.99 Seconds
114	11421	DESCENT,800FPM,68KIASB,PT I	13.99 Seconds
114	11422	DESCENT,800FPM,68KIASB,PT I	13.99 Seconds
114	11423	DESCENT,900FPM,68KIASB,PT J	13.99 Seconds
114	11424	DESCENT,900FPM,68KIASB,PT J	13.99 Seconds
114	11425	DESCENT,1000FPM,68KIASB,PT K	13.99 Seconds

Table 130. – Flight path and tip-path-plane angles for IRAP testing; $C_W/\sigma = 0.071$, $\mu = 0.17$.

COUNTER	DESCRIPTION	γ_{HPB} deg	$S_e(\gamma_{HPB})$ deg	α_{TPP} deg	$\sigma(\alpha_{TPP})$, deg
10006	LEVEL,65 KIASB, PT C	0.25	1.96	−2.65	0.17
10007	LEVEL,65 KIASB, PT C	0.16	2.00	−2.25	0.74
10008	DESCENT,300FPM,65 KIASB,PT D	−0.55	3.53	−1.84	0.84
10009	DESCENT,300FPM,65 KIASB,PT D	−3.05	1.10	0.37	0.87
10010	DESCENT,400FPM,65 KIASB,PT E	−4.43	1.75	1.70	1.18
10011	DESCENT,400FPM,65 KIASB,PT E	−2.91	1.24	0.36	1.38
10013	DESCENT,500FPM,65 KIASB,PT F	−3.99	0.99	1.70	0.16
10014	DESCENT,500FPM,65 KIASB,PT F	−3.46	2.81	0.13	1.01
10015	DESCENT,600FPM,65 KIASB,PT G	−4.32	1.97	2.40	0.31
10106	DESCENT,600FPM,65 KIASB,PT G	−4.39	1.79	1.54	0.58
10107	DESCEMT,600FMP,65 KIASB,PT G	−5.56	1.27	3.25	0.54
10110	DESCENT,700FPM,65 KIASB,PT H	−5.50	1.36	3.53	0.31
10111	DESCENT,700FPM,65 KIASB,PT H	−5.71	1.12	3.31	0.46
10112	DESCENT,800FPM,65 KIASB,PT I	−6.06	1.58	3.92	0.64
10113	DESCENT,800FPM,65 KIASB,PT I	−6.58	1.35	3.87	0.29
10114	DESCENT,900FPM,65 KIASB,PT J	−7.94	1.59	5.46	0.55
10115	DESCENT,900FPM,65 KIASB,PT J	−7.32	1.49	4.60	0.52
11409	DESCENT,200FPM,68KIASB,PT C	−1.89	1.24	−0.28	0.56
11410	DESCENT,200FPM,68KIASB,PT C	−1.58	1.60	−0.98	0.40
11411	DESCENT,300FPM,68KIASB,PT D	−2.14	1.25	−0.23	0.62
11412	DESCENT,300FPM,68KIASB,PT D	−2.58	1.62	0.56	0.82
11413	DESCENT,400FPM,68KIASB,PT E	−2.40	1.40	0.57	0.95
11414	DESCENT,400FPM,68KIASB,PT E	−3.40	1.37	1.31	0.33
11415	DESCENT,500FPM,68KIASB,PT F	−4.50	1.34	1.85	1.13
11416	DESCENT,500FPM,68KIASB,PT F	−4.29	1.28	2.72	0.44
11417	DESCENT,600FPM,68KIASB,PT G	−4.51	1.32	2.49	0.36
11418	DESCENT,600FPM,68KIASB,PT G	−5.07	1.29	2.69	0.74
11419	DESCENT,700FPM,68KIASB,PT H	−6.02	1.99	3.53	0.91
11420	DESCENT,700FPM,68KIASB,PT H	−5.96	1.28	3.40	0.44
11421	DESCENT,800FPM,68KIASB,PT I	−6.63	1.84	4.48	1.01
11422	DESCENT,800FPM,68KIASB,PT I	−6.48	1.56	3.90	0.59
11423	DESCENT,900FPM,68KIASB,PT J	−7.53	1.37	5.10	0.48
11424	DESCENT,900FPM,68KIASB,PT J	−7.07	2.28	5.07	0.91
11425	DESCENT,1000FPM,68KIASB,PT K	−7.00	1.84	5.20	0.66

Table 131. – IRAP testing, $C_W/\sigma = 0.071$, $\mu = 0.20$.

FLIGHT	COUNTER	DESCRIPTION	DURATION
101	10117	DESCENT,400FPM,75 KIASB,PT E	13.99 Seconds
102	10208	DESCENT,400FPM,75 KIASB,PT E	13.99 Seconds
102	10209	DESCENT,400FPM,75 KIASB,PT E	13.99 Seconds
102	10210	DESCENT,500FPM,75 KIASB,PT F	13.99 Seconds
102	10211	DESCENT,500FPM,75 KIASB,PT F	14.04 Seconds
102	10213	DESCENT,600FPM,75 KIASB,PT G	14.00 Seconds
102	10214	DESCENT,600FPM,75 KIASB,PT G	14.00 Seconds
102	10216	DESCENT,700FPM,75 KIASB,PT H	13.99 Seconds
102	10217	DESCENT,700FPM,75 KIASB,PT H	13.99 Seconds
102	10218	DESCENT,800FPM,75 KIASB,PT I	13.99 Seconds
102	10219	DESCENT,800FPM,75 KIASB,PT I	13.99 Seconds
102	10220	DESCENT,900FPM,75 KIASB,PT J	13.99 Seconds

Table 132. – Flight path and tip-path-plane angles for IRAP testing; $C_W/\sigma = 0.071$; $\mu = 0.20$.

COUNTER	DESCRIPTION	γ_{HPB} deg	S_e (γ_{HPB}) deg	α_{TPP} deg	σ (α_{TPP}), deg
10117	DESCENT,400FPM,75 KIASB,PT E	–2.00	1.58	–0.80	1.23
10208	DESCENT,400FPM,75 KIASB,PT E	–3.29	1.45	0.02	1.41
10209	DESCENT,400FPM,75 KIASB,PT E	–2.61	1.22	–0.78	0.35
10210	DESCENT,500FPM,75 KIASB,PT F	–3.15	1.39	0.22	0.29
10211	DESCENT,500FPM,75 KIASB,PT F	–3.24	1.93	0.68	0.83
10213	DESCENT,600FPM,75 KIASB,PT G	–4.50	1.48	1.46	0.94
10214	DESCENT,600FPM,75 KIASB,PT G	–4.32	1.28	1.45	0.69
10216	DESCENT,700FPM,75 KIASB,PT H	–6.19	1.46	2.32	0.80
10217	DESCENT,700FPM,75 KIASB,PT H	–5.38	2.97	2.51	0.25
10218	DESCENT,800FPM,75 KIASB,PT I	–5.81	1.42	2.80	0.50
10219	DESCENT,800FPM,75 KIASB,PT I	–5.31	1.27	2.49	0.67
10220	DESCENT,900FPM,75 KIASB,PT J	–5.59	1.18	3.23	0.92

Table 133. – IRAP testing, $C_W/\sigma = 0.071$, $\mu = 0.25$.

FLIGHT	COUNTER	DESCRIPTION	DURATION
103	10306	DESCENT,300FPM,95 KIASB,PT D	13.9 Seconds
103	10309	DESCENT,400FPM,95 KIASB,PT E	14.00 Seconds
103	10311	DESCENT,400FPM,95 KIASB,PT E	14.00 Seconds

Table 134. – Flight path and tip-path-plane angles for IRAP testing; $C_W/\sigma = 0.071$, $\mu = 0.25$.

COUNTER	DESCRIPTION	γ_{HPB} deg	$S_e(\gamma_{HPB})$ deg	α_{TPP} deg	$\sigma(\alpha_{TPP})$, deg
10306	DESCENT,300FPM,95 KIASB,PT D	–2.10	1.19	–2.99	0.54
10309	DESCENT,400FPM,95 KIASB,PT E	–2.34	0.93	–2.12	0.85
10311	DESCENT,400FPM,95 KIASB,PT E	–2.25	1.15	–2.91	0.71

Table 135. – IRAP testing, $C_W/\sigma = 0.086$, $\mu = 0.17$.

FLIGHT	COUNTER	DESCRIPTION	DURATION
113	11306	DESCENT,200FPM,65KIASB,PT C	13.99 Seconds
113	11307	DESCENT,200FPM,65KIASB,PT C	10.99 Seconds
113	11308	DESCENT,300FPM,65KIASB,PT D	13.99 Seconds
113	11309	DESCENT,300FPM,65KIASB,PT D	13.99 Seconds
113	11310	DESCENT,400FPM,65KIASB,PT E	13.99 Seconds
113	11311	DESCENT,400FPM,65KIASB,PT E	13.99 Seconds
113	11312	DESCENT,500FPM,65KIASB,PT F	13.99 Seconds
113	11313	DESCENT,500FPM,65KIASB,PT F	13.99 Seconds
113	11314	DESCENT,600FPM,65KIASB,PT G	13.99 Seconds
113	11315	DESCENT,600FPM,65KIASB,PT G	10.61 Seconds
113	11317	DESCENT,700FPM,65KIASB,PT H	13.99 Seconds
113	11319	DESCENT,800FPM,65KIASB,PT I	14.00 Seconds
113	11320	DESCENT,800FPM,65KIASB,PT I	13.99 Seconds
113	11321	DESCENT,900FPM,65KIASB,PT J	13.99 Seconds
113	11322	DESCENT,900FPM,65KIASB,PT J	13.99 Seconds

Table 136. – Flight path and tip-path-plane angles for IRAP testing; $C_W/\sigma = 0.086$, $\mu = 0.17$.

COUNTER	DESCRIPTION	γ_{HPB} deg	$S_e\ (\gamma_{HPB})$ deg	α_{TPP} deg	$\sigma\ (\alpha_{TPP})$, deg
11306	DESCENT,200FPM,65KIASB,PT C	–1.24	2.20	–0.56	1.05
11307	DESCENT,200FPM,65KIASB,PT C	–1.56	1.61	–0.63	0.72
11308	DESCENT,300FPM,65KIASB,PT D	–2.90	1.54	0.89	0.24
11309	DESCENT,300FPM,65KIASB,PT D	–2.33	1.53	0.18	0.59
11310	DESCENT,400FPM,65KIASB,PT E	–1.97	1.91	–0.80	1.09
11311	DESCENT,400FPM,65KIASB,PT E	–2.77	1.69	0.22	0.83
11312	DESCENT,500FPM,65KIASB,PT F	–4.50	1.56	2.43	0.85
11313	DESCENT,500FPM,65KIASB,PT F	–4.53	1.51	2.05	0.65
11314	DESCENT,600FPM,65KIASB,PT G	–4.66	1.53	2.60	0.45
11315	DESCENT,600FPM,65KIASB,PT G	–4.65	1.27	2.48	0.76
11317	DESCENT,700FPM,65KIASB,PT H	–5.74	2.46	3.17	1.11
11319	DESCENT,800FPM,65KIASB,PT I	–6.41	1.63	4.53	0.78
11320	DESCENT,800FPM,65KIASB,PT I	–6.34	1.64	3.86	0.56
11321	DESCENT,900FPM,65KIASB,PT J	–7.03	1.27	4.28	0.80
11322	DESCENT,900FPM,65KIASB,PT J	–7.90	2.02	4.93	0.52

Table 137. – IRAP level acceleration.

FLIGHT	COUNTER	DESCRIPTION	DURATION
103	10305	LEVEL ACCEL, 60 - 90 KIASB	32.90 Seconds
103	10321	LEVEL ACCEL, 60 - 90 KIASB*	19.24 Seconds

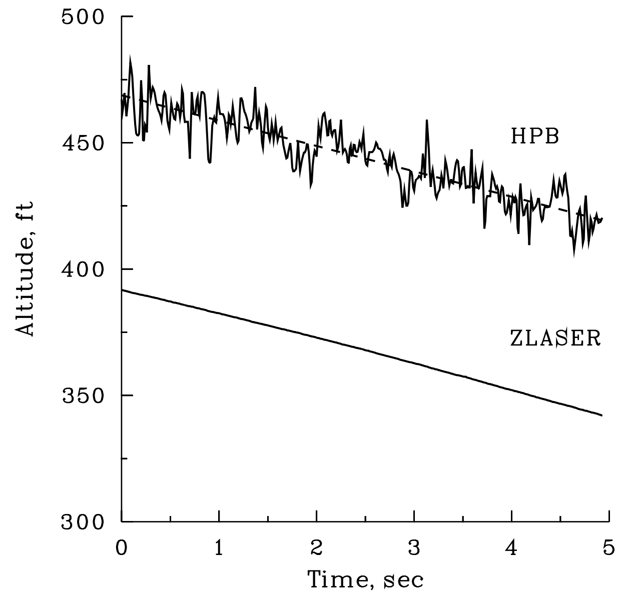

Figure 91. – Comparison of altitude measured with the test boom pressure and a laser tracker for Counter 9115 during ground-acoustics testing. A linear regression fit of both measurements is also shown.

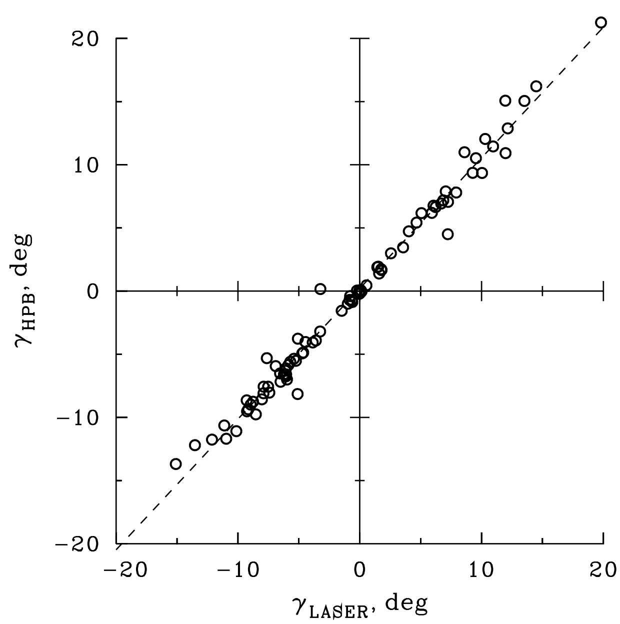

Figure 92. – Flight path angle as calculated with boom pressure altitude shown as a function of the flight path angle calculated with the laser tracker; all ground-acoustic test cases. Dashed line shows a linear regression fit of the data.

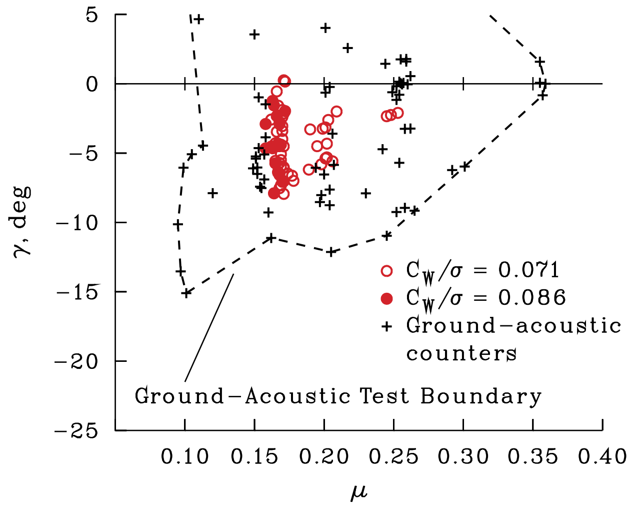

Figure 93. – IRAP flight path angles as a function of advance ratio compared with flight path angles obtained during ground-acoustic testing.

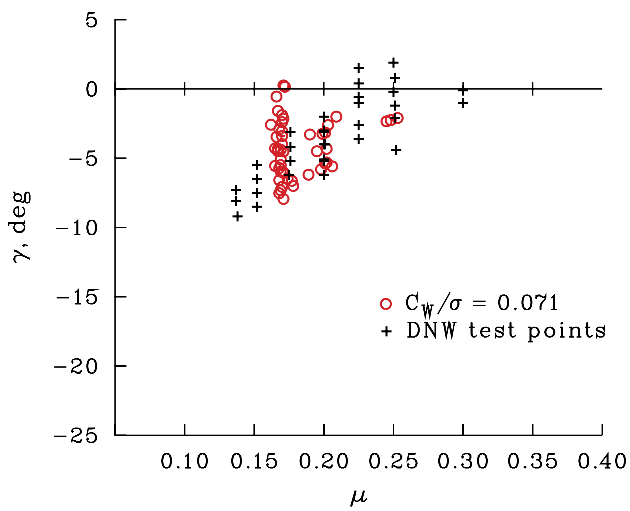

Figure 94. – IRAP flight path angles as a function of advance ratio compared with flight path angles from testing of a model-scale rotor in the DNW (Ref. 35).

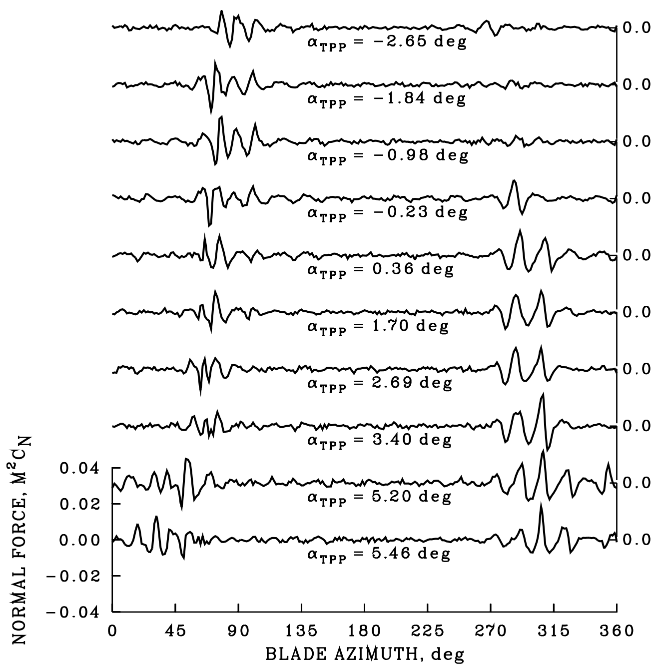

Figure 95. – Filtered time histories of normal force at 0.865*R* at an advance ratio of 0.17 shown as a function of tip-path-plane angle; 17–120 harmonics.