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CORRELATION OF HELICOPTER NOISE LEVELS WITH PHYSICAL AND PERFOR--ETC(U)
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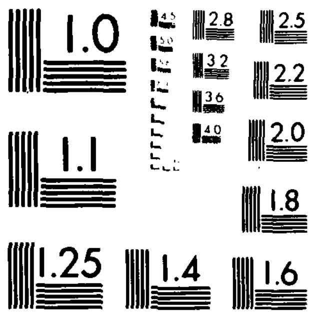

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U.S. Department of Transportation
Federal Aviation Administration

Correlations of Helicopter Noise Levels with Physical and Performance Characteristics

Office of Environment And Energy
Washington, D.C. 20591

A Preliminary Report

FAA-EE-80-42

September 1980

By J. Steven Newman

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16. Abstract

This report investigates the correlation between physical and performance characteristics of helicopters and the noise levels which they generate in various operational modes. The analysis is generally empirical although several theoretical functions described in the literature have been examined. The EPNL is the acoustical metric employed in this study. One, two, and three-step multiple regression analyses are conducted for takeoff, approach, and level flyover operations. Plots are provided for the three best single variable regression models for each mode of flight.

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1.0 INTRODUCTION

This report investigates the correlation between physical and performance characteristics of helicopters and the noise levels which the helicopters generate in various operational modes. The analysis is generally empirical although several theoretical functions described in the technical literature have been examined. The Effective Perceived Noise Level (EPNL) is the acoustical metric employed in this study. It is anticipated that subsequent analyses will examine trends for other metrics, in particular the Noise Exposure Level (single event, integrated A-Weighted Sound Level). This report has been limited to presenting statistical analyses. Parameters are tested for correlation with EPNL, a single event cumulative energy noise metric. The units of most analysis parameters are not energy. However, a limited number of variables dimensionally consistent with power, intensity or energy are tested.

1.1 Input Data Files

This study utilizes a data file assembled for analyses conducted in FAA-AEE-79-3, "Noise Levels and Flight Profiles of Eight Helicopters Using Proposed International Certification Procedures (Newman, J. S., Rickley, E. J.). This data file (Table 1.1) has been expanded to include a variety of physical parameters which may be expected to influence resulting noise levels. The legend for Table 1 is presented below:

NOTE: V_H is the speed at maximum continuous power.
V_{NE} is the never exceed speed.

LEGEND FOR CROSS CORRELATION MATRIX

TYPE - Helicopter designation

EPNL - Effective Perceived Noise Level, (level flyover) expressed in decibels

WEIGHT - Test weight, lbs.

AREA - Total main rotor blade area (square feet)

MACH - Mach number of advancing blade; sum .9 (lesser of V_H or V_{NE}) level flyover forward speed and rotational tip speed

SHP - Maximum engine shaft horsepower

M-DISC - Main disc area, square feet

BRC - Best rate of climb, feet/minute

M-FREQ - Main rotor blade frequency. Using main rotor rpm (Jane's) and number of blades (Jane's) units in Blade Passages/Sec.

T-BLADE - Total tail rotor blade area (square feet)

EPNLA - Effective Perceived Noise Level (approach), decibels

LOGW - Common logarithm of weight

LOGA - Common logarithm of area

LOGS - Common logarithm of shaft horsepower

LOGMD - Common logarithm of main disc area

DISPLO - Main disc loading, lbs/square feet

LOGTB - Common logarithm of total tail blade area

MACH6 - Mach number to sixth power

TSPEED - Rotational tip speed of tail rotor (feet/second)

MSPEED - Main rotor rotational tip speed (feet/second)

T-MACH - Tail rotor, rotational tip mach number

F1 - Log_{10} ((T-MACH x Weight)^2/T-Blade)

F2 - Log_{10} ((MACH x Weight)^2/AREA)

F3 - Log_{10} (SHP x M-DISC/MACH)

F4 - Log_{10} (MACH^6 x T-BLADE)

F5 - Log_{10} (T-MACH^6 x AREA)

2.0 CROSS CORRELATION OF ANALYSIS PARAMETERS

This section examines and discusses the interdependence between the parameters used in the regression analyses.

2.1 Cross Correlation Matrix

The matrix displayed as Table 2.1 (four pages) provides insight into the interrelationships between test variables and the relationship of each variable to EPNL for takeoff, approach and level flyover. Each entry in the matrix includes the correlation coefficient "R," the probability that the observed correlation is due merely to chance, and the number of observations. Many of the variables correlate equally well with the acoustical measures for all operational modes. Therefore, it is possible to develop a large number of single variable regression models which predict noise with similar accuracy.

The "good predictor" family of parameters includes:

- Weight: Helicopter Weight
- Area: Main Rotor Area
- SHP: Shaft Horsepower
- MDISC: Main Rotor Disc Area
- LOGW: Log Weight
- LOGA: Log Area

1.1 INPUT DATA FILES

HELICOPTER NOISE REGRESSION ANALYSIS

OBS	TYPE	EPNL	WEIGHT	AREA	MSPEED	SHP	M DISC	BRC	M FREQ	T BLADE	EPNLA	EPNLT	TSPEED
1	SA330J	91.4	15,532	188	682	3,150	1,925	1,400	17.6	15.0	95.6	95.4	669
2	BO105	88.4	5,070	116	724	840	804	1,773	20.5	3.7	91.7	89.1	730
3	B206L	85.8	4,000	37	763	840	1,075	1,550	13.1	2.2	90.3	85.9	691
4	S61	92.6	22,050	232	659	2,800	3,019	2,200	16.9	12.1	94.0	95.9	630
5	S65	97.1	37,000	475	700	7,925	4,070	2,180	18.5	19.2	99.9	95.7	663
6	B212	94.6	10,500	82	817	1,800	1,809	1,420	10.8	8.1	95.7	91.7	740
7	H500C	85.8	2,550	29	667	400	547	1,700	32.3	1.7	87.7	85.1	692
8	SA341G	86.1	3,970	51	681	590	931	1,770	18.9	1.9	89.5	89.5	696
9	SA350	87.2	4,180	47	671	641	962	1,575	18.3	3.7	91.2	89.2	653
10	SA321F	92.0	25,300	298	688	4,650	3,058	1,312	21.2	29.5	98.6	98.4	351
11	A109	90.4	5,390	80	727	840	1,023	1,620	25.7	4.4	93.0	-	728
12	MI6A	103.4	88,440	942	721	11,000	10,386	1,476	10.0	64.9	107.4	-	733
13	MI2	89.5	7,755	94	623	900	1,772	1,320	12.4	6.5	96.1	-	631
14	MI8	97.3	25,212	298	702	3,000	3,848	1,102	16.0	16.0	99.6	-	732
15	WG-13	97.7	9,350	109	699	1,500	1,385	1,200	21.2	8.6	96.9	91.6	717
16	B47G	90.3	2,728	33	720	220	1,075	800	12.4	2.4	89.6	-	659
17	H300C	80.6	1,804	23	665	190	566	750	23.7	1.7	-	-	689
18	S64	96.7	42,812	518	700	9,000	4,070	1,330	18.6	20.2	98.6	-	702
19	SA365C	89.4	7,480	83	689	1,300	1,116	1,968	23.3	9.8	94.0	-	725

1.1 INPUT DATA FILES
(Continued)

HELICOPTER NOISE REGRESSION ANALYSIS

OBS	TYPE	LOGW	LOGA	LOGTB	LOGS	LOGMD	DISLO	MACH	MACH6
1	SA330J	4.19	2.27	1.18	3.50	3.28	8.07	0.80	0.26
2	BO105	3.71	2.06	0.57	2.92	2.91	6.31	0.83	0.32
3	B206L	3.60	1.57	0.34	2.92	3.03	3.72	0.86	0.41
4	S61	4.34	2.37	1.08	3.45	3.48	7.30	0.79	0.24
5	S65	4.57	2.68	1.28	3.90	3.61	9.09	0.82	0.31
6	B212	4.02	1.91	0.91	3.26	3.26	5.80	0.87	0.45
7	H500C	3.41	1.46	0.23	2.60	2.74	4.67	0.78	0.22
8	SA341G	3.60	1.71	0.28	2.77	2.97	4.26	0.80	0.27
9	SA350	3.62	1.67	0.57	2.81	2.98	4.35	0.77	0.21
10	SA321F	4.40	2.47	1.47	3.67	3.49	8.27	0.79	0.25
11	A109	3.73	1.90	0.64	2.92	3.01	5.27	0.85	0.37
12	MI6A	4.95	2.97	1.81	4.04	4.02	8.52	0.83	0.32
13	MI2	3.89	1.97	0.81	2.95	3.25	4.38	0.67	0.09
14	MI8	4.40	2.47	1.20	3.48	3.59	6.56	0.79	0.25
15	WG-13	3.97	2.04	0.93	3.18	3.14	6.75	0.82	0.31
16	B47G	3.44	1.52	0.38	2.34	3.03	2.54	0.77	0.21
17	H300C	3.26	1.36	0.23	2.28	2.75	3.19	0.72	0.14
18	S64	4.63	2.71	1.31	3.95	3.61	10.52	0.78	0.22
19	SA365C	3.87	1.92	0.99	3.11	3.05	6.70	0.80	0.27

1.1 INPUT DATA FILES (Concluded)

HELICOPTER NOISE REGRESSION ANALYSIS

OBS	TYPE	F1	F2	F3	F4	F5
1	SA330J	6.76189	5.91467	6.87955	1.69328	0.94073
2	BO105	6.47313	5.18251	5.91106	1.57532	0.95841
3	B206L	6.44533	5.50604	6.02063	1.17856	0.31908
4	S61	7.10738	6.11200	7.03169	1.73750	0.87555
5	S65	7.40080	6.29196	7.59247	2.17344	1.31979
6	B212	6.77703	6.01214	6.57093	1.56453	0.84322
7	H500C	6.16752	5.13039	5.45019	0.80152	0.21705
8	SA341G	6.50872	5.30027	5.83467	1.13834	0.47724
9	SA350	6.20865	5.34392	5.90320	0.99310	0.27559
10	SA321F	6.33170	6.13156	7.25312	1.87283	-0.53993
11	A109	6.44866	5.41562	6.00639	1.46970	0.78989
12	MI6A	7.71593	6.75620	8.13936	2.48492	1.87869
13	MI2	6.47098	5.45619	6.37763	0.92358	0.48732
14	MI8	7.23279	6.12854	7.16259	1.87283	1.37530
15	WG-13	6.62283	5.73361	6.40284	1.52566	0.88456
16	B47G	6.03392	5.12583	5.48750	0.83649	0.14584
17	H300C	5.86313	4.86593	5.17393	0.50728	0.10506
18	S64	7.55513	6.32951	7.67348	2.05646	1.50637
19	SA365C	6.38192	5.63898	6.25648	1.34985	0.79512

TABLE 2.1

CORRELATION COEFFICIENTS / PROB > |R| UNDER HO:RHO=0 / NUMBER OF OBSERVATIONS

	EPNL	WEIGHT	AREA	MSPEED	SHP	M_DISC	BRC	M_FREQ	T_BLADE	EPNLA	EPNLT	TSPEED	LOGW
EPNL	1.00000	0.79053	0.79117	0.25695	0.77085	0.79268	0.08050	-0.43628	0.74421	0.91138	0.67551	0.09015	0.87708
	0.0000	0.0001	0.0001	0.2883	0.0001	0.0001	0.7432	0.0618	0.0003	0.0001	0.0225	0.7136	0.0001
	19	19	19	19	19	19	19	19	19	18	11	19	19
WEIGHT	0.79053	1.00000	0.99371	0.07690	0.94703	0.98737	0.10075	-0.39223	0.95648	0.87924	0.84780	-0.01080	0.87139
	0.0001	0.0000	0.0001	0.7544	0.0001	0.0001	0.6815	0.0967	0.0001	0.0001	0.0010	0.9650	0.0001
	19	19	19	19	19	19	19	19	19	18	11	19	19
AREA	0.79117	0.99371	1.00000	0.05399	0.96552	0.97105	0.12136	-0.34309	0.93830	0.88024	0.80291	-0.02204	0.88408
	0.0001	0.0001	0.0000	0.8262	0.0001	0.0001	0.6206	0.1504	0.0001	0.0001	0.0029	0.9286	0.0001
	19	19	19	19	19	19	19	19	19	18	11	19	19
MSPEED	0.25695	0.07690	0.05399	1.00000	0.07931	0.08655	-0.05065	-0.28462	0.06807	0.05264	-0.19970	0.31234	0.06854
	0.2883	0.7544	0.8262	0.0000	0.7469	0.7246	0.8369	0.2376	0.7819	0.8357	0.5560	0.1930	0.7804
	19	19	19	19	19	19	19	19	19	18	11	19	19
SHP	0.77085	0.94703	0.96552	0.07931	1.00000	0.89368	0.15580	-0.31874	0.86709	0.84641	0.76887	-0.08031	0.89840
	0.0001	0.0001	0.0001	0.7469	0.0000	0.0001	0.5242	0.1835	0.0001	0.0001	0.0057	0.7438	0.0001
	19	19	19	19	19	19	19	19	19	18	11	19	19
M_DISC	0.79268	0.98737	0.97105	0.08655	0.89368	1.00000	0.06522	-0.46733	0.95913	0.88209	0.85679	-0.00042	0.84931
	0.0001	0.0001	0.0001	0.7246	0.0001	0.0000	0.7908	0.0436	0.0001	0.0001	0.0008	0.9986	0.0001
	19	19	19	19	19	19	19	19	19	18	11	19	19
BRC	0.08050	0.10075	0.12136	-0.05065	0.15580	0.06522	1.00000	0.21970	0.03589	-0.09928	0.08042	0.06069	0.23246
	0.7432	0.6815	0.6206	0.8369	0.5242	0.7908	0.0000	0.3661	0.8840	0.6951	0.8142	0.8051	0.3382
	19	19	19	19	19	19	19	19	19	18	11	19	19
M_FREQ	-0.43628	-0.39223	-0.34309	-0.28462	-0.31874	-0.46733	0.21970	1.00000	-0.36992	-0.41936	-0.28833	-0.00522	-0.39572
	0.0618	0.0967	0.1504	0.2376	0.1835	0.0436	0.3661	0.0000	0.1190	0.0832	0.3899	0.9831	0.0935
	19	19	19	19	19	19	19	19	19	18	11	19	19
T_BLADE	0.74421	0.95648	0.93830	0.06807	0.86709	0.95913	0.03589	-0.36992	1.00000	0.88060	0.90556	-0.16209	0.82817
	0.0003	0.0001	0.0001	0.7819	0.0001	0.0001	0.8840	0.1190	0.0000	0.0001	0.0001	0.5074	0.0001
	19	19	19	19	19	19	19	19	19	18	11	19	19
EPNLA	0.91138	0.87924	0.88024	0.05264	0.84641	0.88209	-0.09928	-0.41936	0.88060	1.00000	0.85292	-0.07047	0.93104
	0.0001	0.0001	0.0001	0.8357	0.0001	0.0001	0.6951	0.0832	0.0001	0.0000	0.0008	0.7811	0.0001
	18	18	18	18	18	18	18	18	18	18	11	18	18
EPNLT	0.67551	0.84780	0.80291	-0.19970	0.76887	0.85679	0.08042	-0.28833	0.90556	0.85292	1.00000	-0.60426	0.94381
	0.0225	0.0010	0.0029	0.5560	0.0057	0.0008	0.8142	0.3899	0.0001	0.0008	0.0000	0.0490	0.0001
	11	11	11	11	11	11	11	11	11	11	11	11	11
TSPEED	0.09015	-0.01080	-0.02204	0.31234	-0.08031	-0.00042	0.06069	-0.00522	-0.16209	-0.07047	-0.60426	1.00000	-0.14994
	0.7136	0.9650	0.9286	0.1930	0.7438	0.9986	0.8051	0.9831	0.5074	0.7811	0.0490	0.0000	0.5401
	19	19	19	19	19	19	19	19	19	18	11	19	19
LOGW	0.87708	0.87139	0.88408	0.06854	0.89840	0.84931	0.23246	-0.39572	0.82817	0.93104	0.94381	-0.14994	1.00000
	0.0001	0.0001	0.0001	0.7804	0.0001	0.0001	0.3382	0.0935	0.0001	0.0001	0.0001	0.5401	0.0000
	19	19	19	19	19	19	19	19	19	18	11	19	19

TABLE 2.1 (Continued)

CORRELATION COEFFICIENTS / PROB > |R| UNDER HO:RHO=0 / NUMBER OF OBSERVATIONS

	LOGA	LOGTB	LOGS	LOGMD	DISLO	MACH	TMACH	MACH6	F1	F2	F3	F4	F5
EPNL	0.85276	0.85340	0.82731	0.87489	0.72512	0.33729	0.09015	0.30776	0.84583	0.88044	0.86046	0.86563	0.77495
	0.0001	0.0001	0.0001	0.0001	0.0004	0.1579	0.7136	0.1999	0.0001	0.0001	0.0001	0.0001	0.0001
	19	19	19	19	19	19	19	19	19	19	19	19	19
WEIGHT	0.85554	0.82667	0.81266	0.89622	0.70275	0.16211	-0.01080	0.12237	0.83365	0.84928	0.86558	0.81501	0.67820
	0.0001	0.0001	0.0001	0.0001	0.0008	0.5073	0.9650	0.6177	0.0001	0.0001	0.0001	0.0001	0.0014
	19	19	19	19	19	19	19	19	19	19	19	19	19
AREA	0.89427	0.83270	0.83315	0.89637	0.74307	0.15438	-0.02204	0.10794	0.84829	0.84584	0.87861	0.83862	0.67488
	0.0001	0.0001	0.0001	0.0001	0.0003	0.5280	0.9286	0.6600	0.0001	0.0001	0.0001	0.0001	0.0015
	19	19	19	19	19	19	19	19	19	19	19	19	19
MSPEED	0.01717	0.03924	0.11961	0.08541	0.01727	0.82387	0.31234	0.87711	0.15912	0.19667	0.08297	0.26621	0.23625
	0.9444	0.8733	0.6257	0.7281	0.9440	0.0001	0.1930	0.0001	0.5153	0.4197	0.7355	0.2706	0.3302
	19	19	19	19	19	19	19	19	19	19	19	19	19
SHP	0.88990	0.83566	0.88327	0.88437	0.82687	0.17251	-0.08031	0.12451	0.85673	0.86918	0.90433	0.84945	0.63452
	0.0001	0.0001	0.0001	0.0001	0.0001	0.4800	0.7438	0.6115	0.0001	0.0001	0.0001	0.0001	0.0035
	19	19	19	19	19	19	19	19	19	19	19	19	19
M_DISC	0.82507	0.81062	0.77031	0.90113	0.61882	0.14875	-0.00042	0.12152	0.81099	0.83452	0.84173	0.78227	0.67330
	0.0001	0.0001	0.0001	0.0001	0.0047	0.5433	0.9986	0.6202	0.0001	0.0001	0.0001	0.0001	0.0016
	19	19	19	19	19	19	19	19	19	19	19	19	19
BRC	0.24999	0.14655	0.32369	0.11520	0.34516	0.34802	0.06069	0.31324	0.31043	0.23907	0.23710	0.33174	0.18344
	0.3020	0.5494	0.1764	0.6386	0.1478	0.1443	0.8051	0.1916	0.1958	0.3243	0.3284	0.1653	0.4522
	19	19	19	19	19	19	19	19	19	19	19	19	19
M_FREQ	-0.28834	-0.36277	-0.31353	-0.56503	-0.02767	-0.03070	-0.00522	-0.11339	-0.40076	-0.47037	-0.42490	-0.26119	-0.32912
	0.2312	0.1269	0.1912	0.0117	0.9105	0.9007	0.9831	0.6439	0.0891	0.0421	0.0698	0.2801	0.1689
	19	19	19	19	19	19	19	19	19	19	19	19	19
T_BLADE	0.80852	0.84837	0.76764	0.85189	0.65043	0.16482	-0.16209	0.12653	0.69194	0.81245	0.81943	0.77375	0.56792
	0.0001	0.0001	0.0001	0.0001	0.0026	0.5001	0.5074	0.6057	0.0010	0.0001	0.0001	0.0001	0.0112
	19	19	19	19	19	19	19	19	19	19	19	19	19
EPNLA	0.91026	0.94305	0.88246	0.92922	0.73837	0.06959	-0.07047	0.07347	0.80155	0.90649	0.92477	0.84568	0.69888
	0.0001	0.0001	0.0001	0.0001	0.0005	0.7838	0.7811	0.7720	0.0001	0.0001	0.0001	0.0001	0.0013
	18	18	18	18	18	18	18	18	18	18	18	18	18
EPNLT	0.92220	0.95400	0.90912	0.90917	0.88556	-0.13522	-0.60426	-0.16689	0.57894	0.86743	0.92252	0.86066	0.19134
	0.0001	0.0001	0.0001	0.0001	0.0003	0.6918	0.0490	0.6238	0.0620	0.0005	0.0001	0.0007	0.5730
	11	11	11	11	11	11	11	11	11	11	11	11	11
TSPEED	-0.14272	-0.23415	-0.15392	-0.15240	-0.14511	0.26467	1.00000	0.29416	0.20866	-0.12001	-0.16626	-0.04759	0.58925
	0.5600	0.3346	0.5293	0.5334	0.5534	0.2735	0.0000	0.2215	0.3913	0.6246	0.4963	0.8466	0.0079
	19	19	19	19	19	19	19	19	19	19	19	19	19
LOGW	0.98145	0.96313	0.97745	0.96936	0.88872	0.21242	-0.14994	0.17339	0.90740	0.97752	0.99640	0.94254	0.68491
	0.0001	0.0001	0.0001	0.0001	0.0001	0.3826	0.5401	0.4778	0.0001	0.0001	0.0001	0.0001	0.0012
	19	19	19	19	19	19	19	19	19	19	19	19	19

TABLE 2.1 (Continued)

CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 / NUMBER OF OBSERVATIONS

	EPNL	WEIGHT	AREA	MSPEED	SHP	M_DISC	BRC	M_FREQ	T_BLADE	EPNLA	EPNLT	TSPEED	LOGW
LOGA	0.85276	0.85554	0.88427	0.01717	0.88990	0.82507	0.24999	-0.28834	0.80852	0.91026	0.92220	-0.14272	0.98145
	0.0001	0.0001	0.0001	0.9444	0.0001	0.0001	0.3020	0.2312	0.0001	0.0001	0.0001	0.5600	0.0001
	19	19	19	19	19	19	19	19	19	18	11	19	19
LOGTB	0.85340	0.82667	0.83270	0.03924	0.83566	0.81062	0.14655	-0.36277	0.84837	0.94305	0.95400	-0.23415	0.96313
	0.0001	0.0001	0.0001	0.8733	0.0001	0.0001	0.5494	0.1269	0.0001	0.0001	0.0001	0.3346	0.0001
	19	19	19	19	19	19	19	19	19	18	11	19	19
LOGS	0.82731	0.81266	0.83315	0.11961	0.88327	0.77031	0.32369	-0.31353	0.76764	0.98246	0.90912	-0.15392	0.97745
	0.0001	0.0001	0.0001	0.6257	0.0001	0.0001	0.1764	0.1912	0.0001	0.0001	0.0001	0.5293	0.0001
	19	19	19	19	19	19	19	19	19	18	11	19	19
LOGMD	0.87489	0.89622	0.89637	0.08541	0.88437	0.90113	0.11520	-0.56503	0.85189	0.92922	0.90917	-0.15240	0.96936
	0.0001	0.0001	0.0001	0.7281	0.0001	0.0001	0.6386	0.0117	0.0001	0.0001	0.0001	0.5334	0.0001
	19	19	19	19	19	19	19	19	19	18	11	19	19
DISLO	0.72512	0.70275	0.74307	0.01727	0.82687	0.61882	0.34516	-0.02767	0.65043	0.73837	0.88556	-0.14511	0.88872
	0.0004	0.0008	0.0003	0.9440	0.0001	0.0047	0.1478	0.9105	0.0026	0.0005	0.0003	0.5534	0.0001
	19	19	19	19	19	19	19	19	19	18	11	19	19
MACH	0.33729	0.16211	0.15438	0.82387	0.17251	0.14875	0.34802	-0.03070	0.16482	0.06959	-0.13522	0.26467	0.21242
	0.1579	0.5073	0.5280	0.0001	0.4800	0.5433	0.1443	0.9007	0.5001	0.7838	0.6918	0.2735	0.3826
	19	19	19	19	19	19	19	19	19	18	11	19	19
TMACH	0.09015	-0.01080	-0.02204	0.31234	-0.08031	-0.00042	0.06069	-0.00522	-0.16209	-0.07047	-0.60426	1.00000	-0.14994
	0.7136	0.9650	0.9286	0.1930	0.7438	0.9986	0.8051	0.9831	0.5074	0.7811	0.0490	0.0000	0.5401
	19	19	19	19	19	19	19	19	19	18	11	19	19
MACH6	0.30776	0.12237	0.10794	0.87711	0.12451	0.12152	0.31324	-0.11339	0.12653	0.07347	-0.16689	0.29416	0.17339
	0.1999	0.6177	0.6600	0.0001	0.6115	0.6202	0.1916	0.6439	0.6057	0.7720	0.6238	0.2215	0.4778
	19	19	19	19	19	19	19	19	19	18	11	19	19
F1	0.84583	0.83365	0.84829	0.15912	0.85673	0.81099	0.31043	-0.40076	0.69194	0.80155	0.57894	0.20866	0.90740
	0.0001	0.0001	0.0001	0.5153	0.0001	0.0001	0.1958	0.0891	0.0010	0.0001	0.0620	0.3913	0.0001
	19	19	19	19	19	19	19	19	19	18	11	19	19
F2	0.88044	0.84928	0.84584	0.19667	0.86918	0.83452	0.23907	-0.47037	0.81245	0.90649	0.86743	-0.12001	0.97752
	0.0001	0.0001	0.0001	0.4197	0.0001	0.0001	0.3243	0.0421	0.0001	0.0001	0.0005	0.6246	0.0001
	19	19	19	19	19	19	19	19	19	18	11	19	19
F3	0.86046	0.86558	0.87861	0.08299	0.90433	0.84173	0.23710	-0.42490	0.81943	0.92477	0.92252	-0.16626	0.99640
	0.0001	0.0001	0.0001	0.7355	0.0001	0.0001	0.3284	0.0698	0.0001	0.0001	0.0001	0.4963	0.0001
	19	19	19	19	19	19	19	19	19	18	11	19	19
F4	0.86563	0.81501	0.83862	0.26621	0.84945	0.78287	0.33174	-0.26119	0.77375	0.86568	0.86066	-0.04759	0.94254
	0.0001	0.0001	0.0001	0.2706	0.0001	0.0001	0.1653	0.2801	0.0001	0.0001	0.0007	0.8466	0.0001
	19	19	19	19	19	19	19	19	19	18	11	19	19
F5	0.77495	0.67820	0.67488	0.23625	0.63452	0.67330	0.18344	-0.32912	0.56792	0.69888	0.19134	0.58925	0.68491
	0.0001	0.0014	0.0015	0.3302	0.0035	0.0016	0.4522	0.1689	0.0112	0.0013	0.5730	0.0079	0.0012
	19	19	19	19	19	19	19	19	19	18	11	19	19

TABLE 2.1 (Concluded)

CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0 / NUMBER OF OBSERVATIONS

	LOGA	LOGTB	LOGS	LOGMD	DISLO	MACH	TMACH	MACH6	F1	F2	F3	F4	F5
LOGA	1.00000	0.94396	0.95947	0.93423	0.90700	0.18976	-0.14272	0.13980	0.89238	0.92411	0.97157	0.95266	0.67297
	0.0000	0.0001	0.0001	0.0001	0.0001	0.4365	0.5600	0.5681	0.0001	0.0001	0.0001	0.0001	0.0016
	19	19	19	19	19	19	19	19	19	19	19	19	19
LOGTB	0.94396	1.00000	0.93472	0.92546	0.86439	0.16785	-0.23415	0.12995	0.78322	0.93881	0.95335	0.89529	0.64393
	0.0001	0.0000	0.0001	0.0001	0.0001	0.4922	0.3346	0.5960	0.0001	0.0001	0.0001	0.0001	0.0029
	19	19	19	19	19	19	19	19	19	19	19	19	19
LOGS	0.95947	0.93472	1.00000	0.91059	0.93432	0.30681	-0.15392	0.26795	0.88978	0.96577	0.98347	0.95200	0.65489
	0.0001	0.0001	0.0000	0.0001	0.0001	0.2014	0.5293	0.2674	0.0001	0.0001	0.0001	0.0001	0.0023
	19	19	19	19	19	19	19	19	19	19	19	19	19
LOGMD	0.93423	0.92546	0.91059	1.00000	0.75781	0.14802	-0.15240	0.12578	0.88673	0.95682	0.96942	0.87958	0.65673
	0.0001	0.0001	0.0001	0.0000	0.0002	0.5453	0.5334	0.6079	0.0001	0.0001	0.0001	0.0001	0.0023
	19	19	19	19	19	19	19	19	19	19	19	19	19
DISLO	0.90700	0.86439	0.93432	0.75781	1.00000	0.25297	-0.14511	0.17839	0.79363	0.84466	0.88183	0.89103	0.60045
	0.0001	0.0001	0.0001	0.0002	0.0000	0.2961	0.5534	0.4650	0.0001	0.0001	0.0001	0.0001	0.0066
	19	19	19	19	19	19	19	19	19	19	19	19	19
MACH	0.18976	0.16785	0.30681	0.14802	0.25297	1.00000	0.26467	0.97559	0.29190	0.32545	0.21891	0.47894	0.30725
	0.4365	0.4922	0.2014	0.5453	0.2961	0.0000	0.2735	0.0001	0.2253	0.1739	0.3679	0.0380	0.2007
	19	19	19	19	19	19	19	19	19	19	19	19	19
TMACH	-0.14272	-0.23415	-0.15392	-0.15240	-0.14511	0.26467	1.00000	0.29416	0.20866	-0.12001	-0.16626	-0.04759	0.58925
	0.5600	0.3346	0.5293	0.5334	0.5534	0.2735	0.0000	0.2215	0.3913	0.6246	0.4963	0.8466	0.0079
	19	19	19	19	19	19	19	19	19	19	19	19	19
MACH6	0.13980	0.12995	0.26795	0.12578	0.17839	0.97559	0.29416	1.00000	0.26339	0.29517	0.18678	0.42367	0.29942
	0.5681	0.5960	0.2674	0.6079	0.4650	0.0001	0.2215	0.0000	0.2759	0.2199	0.4439	0.0707	0.2130
	19	19	19	19	19	19	19	19	19	19	19	19	19
F1	0.89238	0.78322	0.88978	0.88673	0.79363	0.29190	0.20866	0.26339	1.00000	0.89562	0.90565	0.88699	0.82338
	0.0001	0.0001	0.0001	0.0001	0.0001	0.2253	0.3913	0.2759	0.0000	0.0001	0.0001	0.0001	0.0001
	19	19	19	19	19	19	19	19	19	19	19	19	19
F2	0.92411	0.93881	0.96577	0.95682	0.84466	0.32545	-0.12001	0.29517	0.89562	1.00000	0.98040	0.92584	0.68536
	0.0001	0.0001	0.0001	0.0001	0.0001	0.1739	0.6246	0.2199	0.0001	0.0000	0.0001	0.0001	0.0012
	19	19	19	19	19	19	19	19	19	19	19	19	19
F3	0.97157	0.95335	0.98347	0.96942	0.88183	0.21891	-0.16626	0.18678	0.90565	0.98040	1.00000	0.93528	0.66535
	0.0001	0.0001	0.0001	0.0001	0.0001	0.3679	0.4963	0.4439	0.0001	0.0001	0.0000	0.0001	0.0019
	19	19	19	19	19	19	19	19	19	19	19	19	19
F4	0.95266	0.89529	0.95200	0.87958	0.89103	0.47894	-0.04759	0.42367	0.88699	0.92584	0.93528	1.00000	0.69477
	0.0001	0.0001	0.0001	0.0001	0.0001	0.0380	0.8466	0.0707	0.0001	0.0001	0.0001	0.0000	0.0010
	19	19	19	19	19	19	19	19	19	19	19	19	19
F5	0.67297	0.64393	0.65489	0.65673	0.60045	0.30725	0.58925	0.29942	0.82338	0.68536	0.66535	0.69477	1.00000
	0.0016	0.0029	0.0023	0.0023	0.0066	0.2007	0.0079	0.2130	0.0001	0.0012	[illegible]	[illegible]	0.0000
	19	19	19	19	19	19	19	19	19	19	19	19	19

- LOGTB: Log Tail Blade Area
- LOGS: Log Shaft Horsepower
- LOGMD: Log Main Rotor Disc Area
- DISLO: Main Rotor Disc Loading

Other quantities which are linearly independent of these parameters can be expected to play the roles of second and third variable in the multiple regression analyses. However, it is possible to see more than one of these variables appear in a multiple regression if the two variables are largely independent of each other.

2.2 Summary of Best Correlates

The table provided below identifies those single parameters which best correlate with EPNL for the various operational modes.

Level Flyover		Takeoff		Approach	
Parameter	R^2	Parameter	R^2	Parameter	R^2
				LOG TB	.889
F2	.774	LOG TB	.910	LOG W	.867
LOG W	.769	LOG W	.891	LOG MD	.863
LOG MD	.764	F3	.852	F3	.856
F4	.765	LOG A	.850	LOG A	.828
F3	.739	LOG S	.826	F2	.821
LOG TB	.727	LOG MD	.826	M DISC	.778
LOG A	.727	T BLADE	.819	LOG S	.778
				AREA	.774
				T BLADE	.774

The most apparent trend one observes is the much higher correlation for takeoff and approach EPNL values as compared with level flyover EPNL. One plausible reason for this is that the level flyovers are conducted at a higher speed than the approaches or takeoffs. It is reasonable to assume that forces generating noise in higher speed operation are subject to more variant and anomolous aerodynamic influences.

Another observation is the decline of LOG TB to "fifth place" for the higher speed level flyover. This can be attributed to the diminished tail rotor counter-torque load as the speed increased. This occurs as unbalanced airframe slip stream forces tend to counter the main rotor torque.

2.3 Plots of Best Single Variable Regression

The three best single variable regression models are plotted in Figures 2.3.1 through 2.3.3 for takeoffs, in Figures 2.3.4 through 2.3.6 for approach, and in Figures 2.3.7 through 2.3.9 for level flyover. Each plot includes identification of helicopter type and the line of regression.

3.0 STEPWISE REGRESSION ANALYSES

This analysis investigates the improvement in prediction accuracy associated with adding a second and third variable to the single parameter regression equation. For the correlation coefficient to improve the added variables (or steps) must be largely independent of previous step(s) but still related to the level of noise. Three-step models are presented below for takeoff, approach, and level flyover.

Approach

1 Step

EPNL = 10.2 log (TB) + 85.9

R^2 = .89

2 Step

EPNL = 7.1 log (TB) + .0007 (M DISC) + 86.9

R^2 = .93

3 Step

EPNL = 7.9 log (TB) + .005 (T SPEED) + .0006 (M DISC)

R^2 = .94

Level Flyover

1 Step

EPNL = 9.4 (F2) + 37.4

R^2 = .76

2 Step

EPNL = 10.4 log (MD) + 3.6 (F5) + 59.5

R^2 = .84

3 Step

EPNL = 10.7 log (MD) + 17 (MACH) + 3 (F5) + 44.9

R^2 = .85

Takeoff

1 Step

$$EPNL = 9.6 \log (TB) + 83.87$$

$R^2 = .91$

2 Step

$$EPNL = 9.55 \log (TB) - 7.3 (MACH)^6 + 86.1$$

$R^2 = .93$

3 Step

$$EPNL = 6.3 \log (TB) + 5.5 \log (MD) -9.6 (MACH)^6 + 71.97$$

$R^2 = .95$

The following table provides a summary of parameters and correlation coefficients associated with each step of the multiple regression analyses for the various operational modes:

Takeoff

Step	R^2	Parameter(s)
1	.91	Log TB
2	.93	Log TB, $(MACH)^6$
3	.95	Log TB, $(MACH)^6$, Log (MD)

Approach

Step	R^2	Parameter(s)
1	.89	Log TB
2	.93	Log TB, M DISC
3	.94	Log TB, M DISC, T SPEED

Level Flyover

Step	R^2	Parameter(s)
1	.76	F2
2	.84	F5, Log MD
3	.85	Log MD, MACH, F5

4.0 DISCUSSION

The empirical noise prediction techniques presented above provide a means to estimate single event cumulative noise exposure for helicopters whose technology and operational characteristics are similar to the helicopters used in this analysis. The obvious advantage of the strictly empirical approach (using the single event cumulative energy metric EPNL) is the averaging out of source directionality, ground interference effects, anomolous air in-flow characteristics, and speed effects. All of these considerations pose significant difficulties in the theoretical approach. On the other hand, the theoretical approach can be more successful in predicting the change in noise level associated with a design change for a specific helicopter.

The parameters appearing (or not appearing) as significant correlates to noise in this study raise some interesting questions. For example, the strength of LOG TB was not anticipated nor is "Tail Blade Area" a particularly good acoustical design parameter. On the other hand, the main rotor advancing tip mach number to the sixth power (considered an important correlate to noise) appears as a weak correlate by itself, although it does strengthen the takeoff correlation in the multiple regression analysis. Interpretation of these results and discussion of application in predicting noise of new design helicopters or reducing levels of existent machines is left for subsequent study.

TAKEOFF REGRESSION OF EPNL VERSUS LOGTB

EMPIRICAL NOISE PREDICTION ANALYSIS

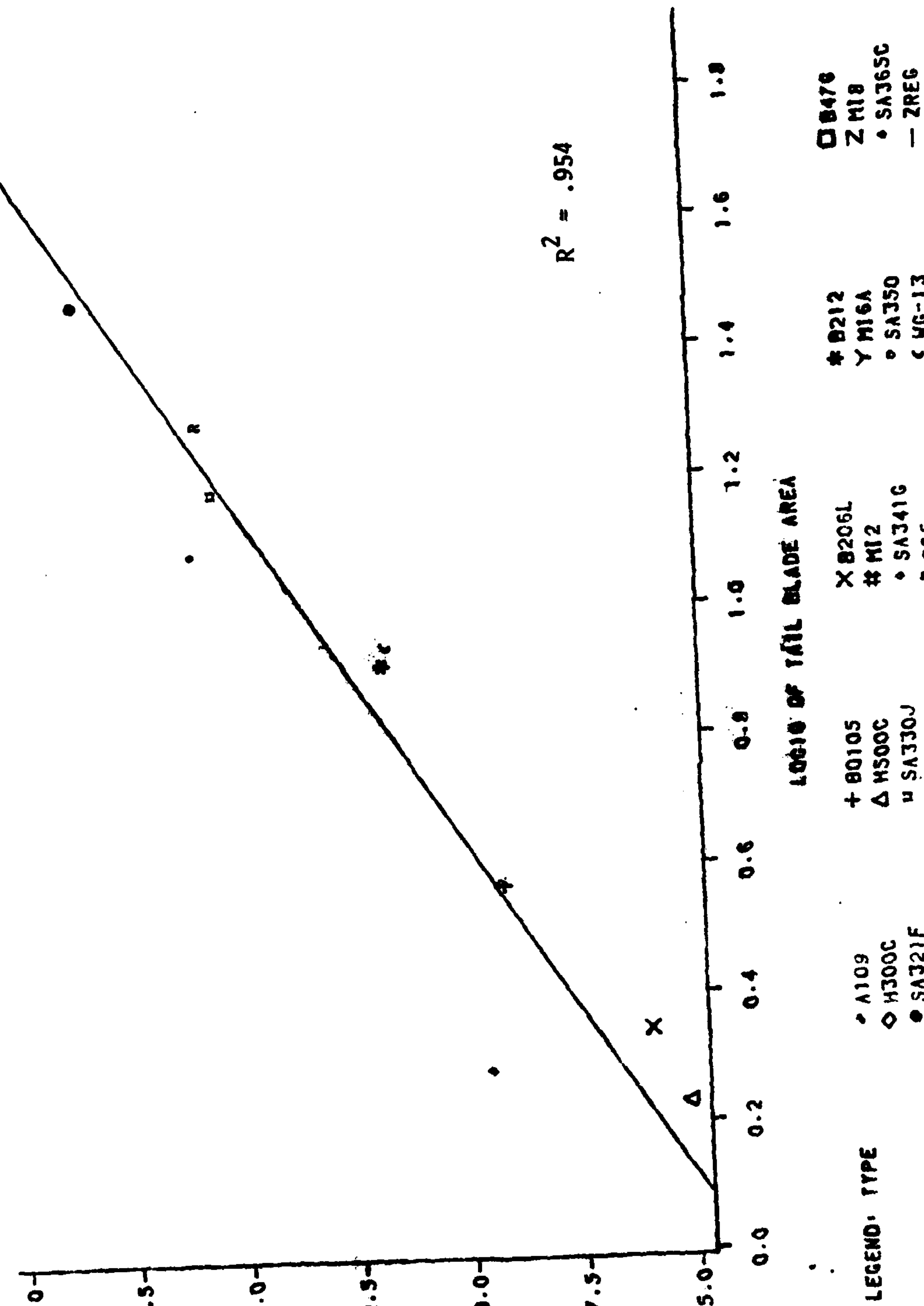


FIGURE 2.3.1

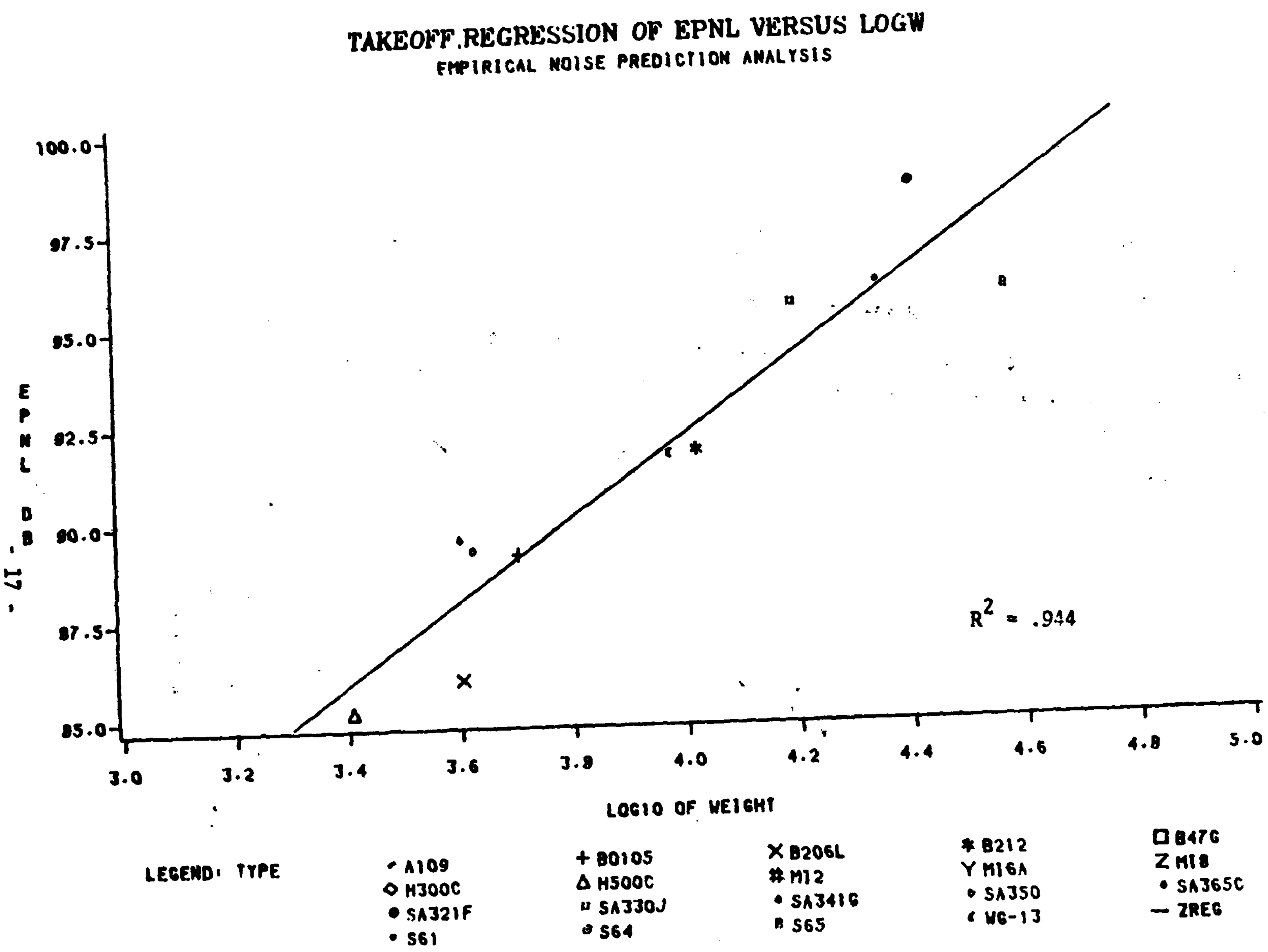
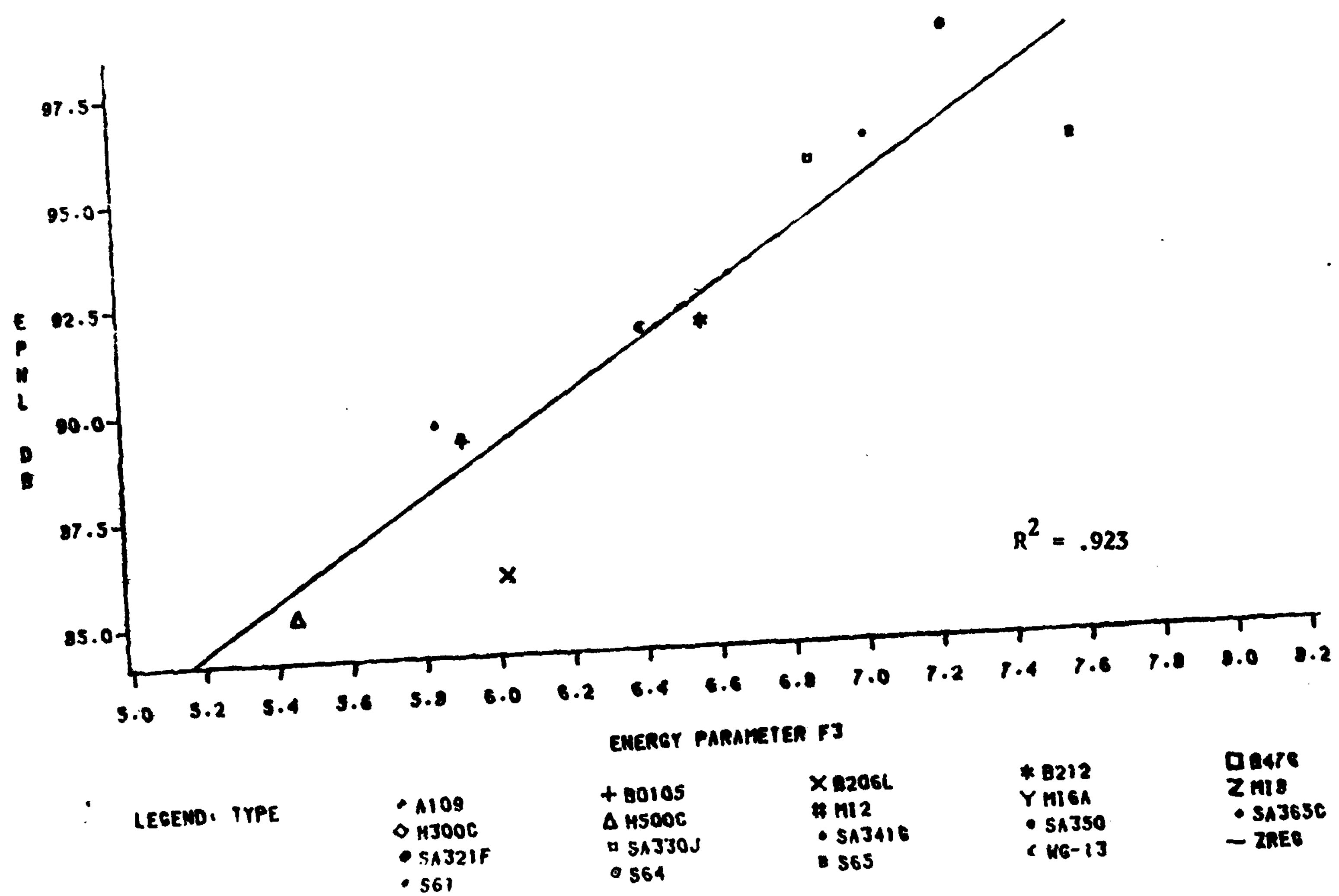

TAKEOFF REGRESSION OF EPNL VERSUS LOGW
EMPIRICAL NOISE PREDICTION ANALYSIS
EPNL DB
100.0
97.5
95.0
92.5
90.0
87.5
85.0
3.0
3.2
3.4
3.6
3.8
4.0
4.2
4.4
4.6
4.8
5.0
LOG10 OF WEIGHT
R^2 = .944
LEGEND: TYPE
A109
H300C
SA321F
S61
BO105
H500C
SA330J
S64
B206L
M12
SA341G
S65
B212
M16A
SA350
WG-13
B47G
M18
SA365C
ZREG

FIGURE 2.3.2

TAKEOFF REGRESSION OF EPNL VERSUS F3

EMPIRICAL NOISE PREDICTION ANALYSIS



F3=LOG10(SHP*MAIN DISC AREA/MACH)

FIGURE 2.3.3

LEVEL FLYOVER REGRESSION OF EPNL VERSUS F2

EMPIRICAL NOISE PREDICTION ANALYSIS

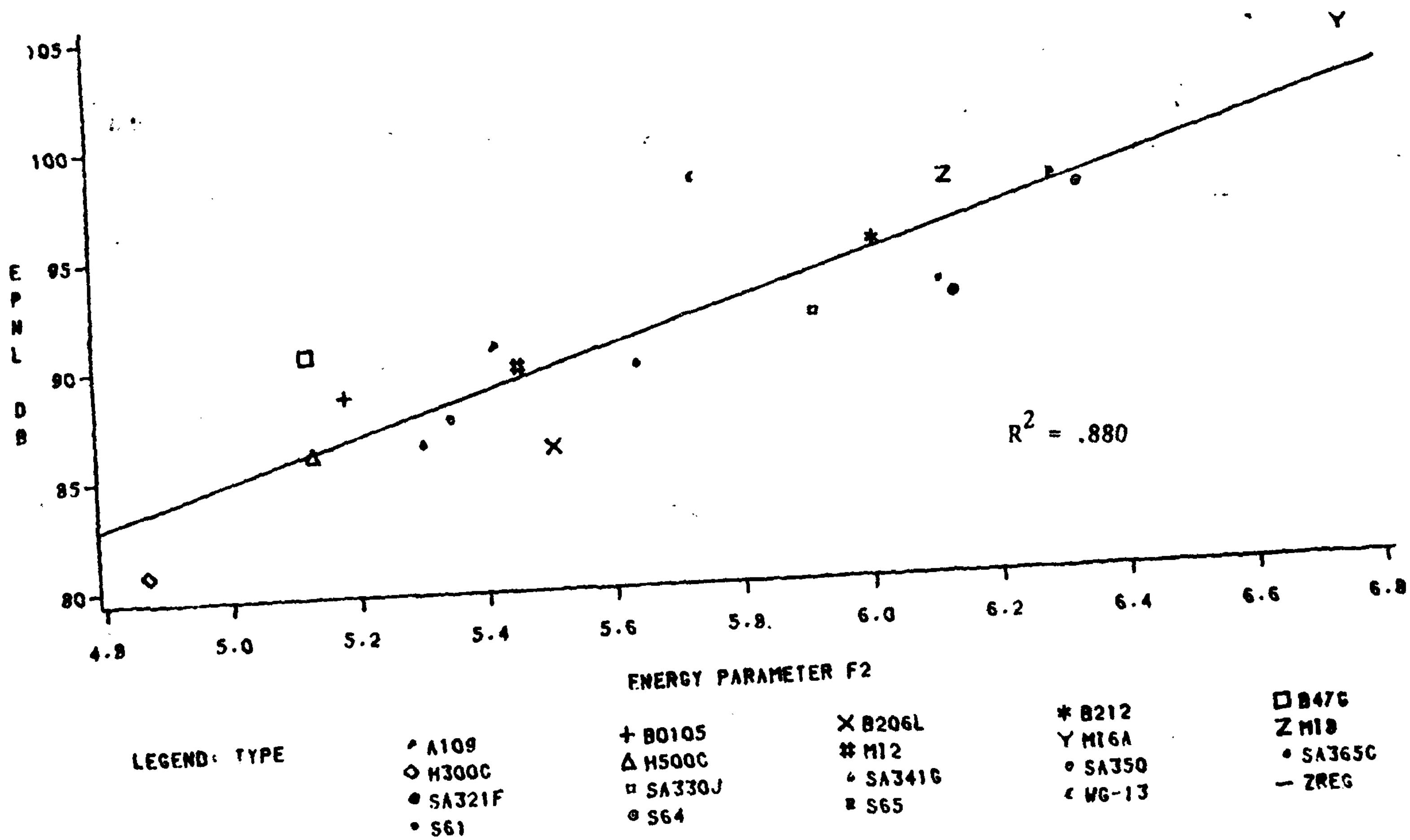


FIGURE 2.3.4

F2=LOG10((MACH*WEIGHT)**2/AREA)

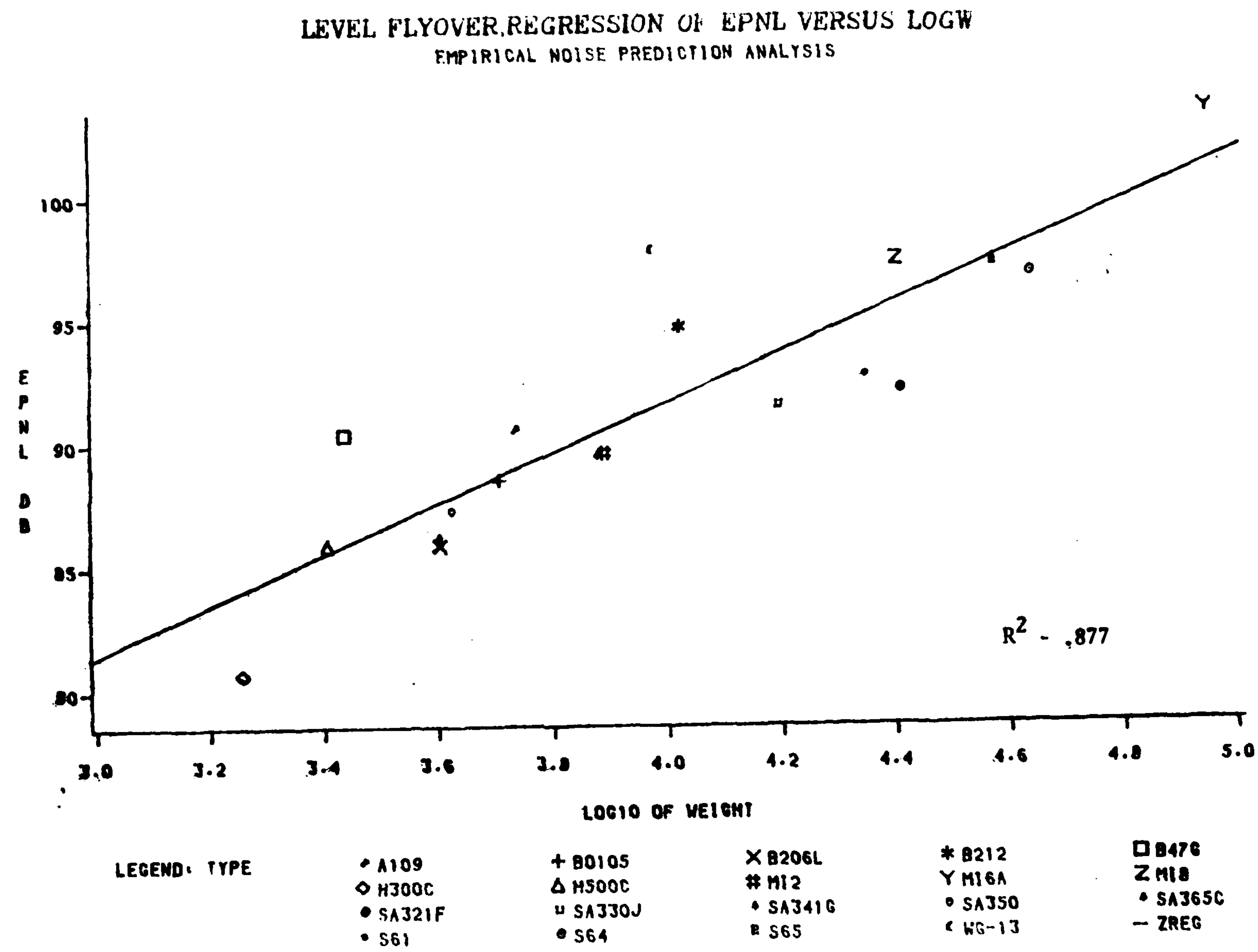

LEVEL FLYOVER,REGRESSION OF EPNL VERSUS LOGW
EMPIRICAL NOISE PREDICTION ANALYSIS
EPNL DB
100
95
90
85
80
3.0
3.2
3.4
3.6
3.8
4.0
4.2
4.4
4.6
4.8
5.0
LOG10 OF WEIGHT
R2 - .877
LEGEND: TYPE
A109
H300C
SA321F
S61
B0105
H500C
SA330J
S64
B206L
M12
SA341G
S65
B212
M16A
SA350
WG-13
B47G
M18
SA365C
ZREG

FIGURE 2.3.5

LEVEL FLYOVER REGRESSION OF EPNL VERSUS LOGMD

EMPIRICAL NOISE PREDICTION ANALYSIS

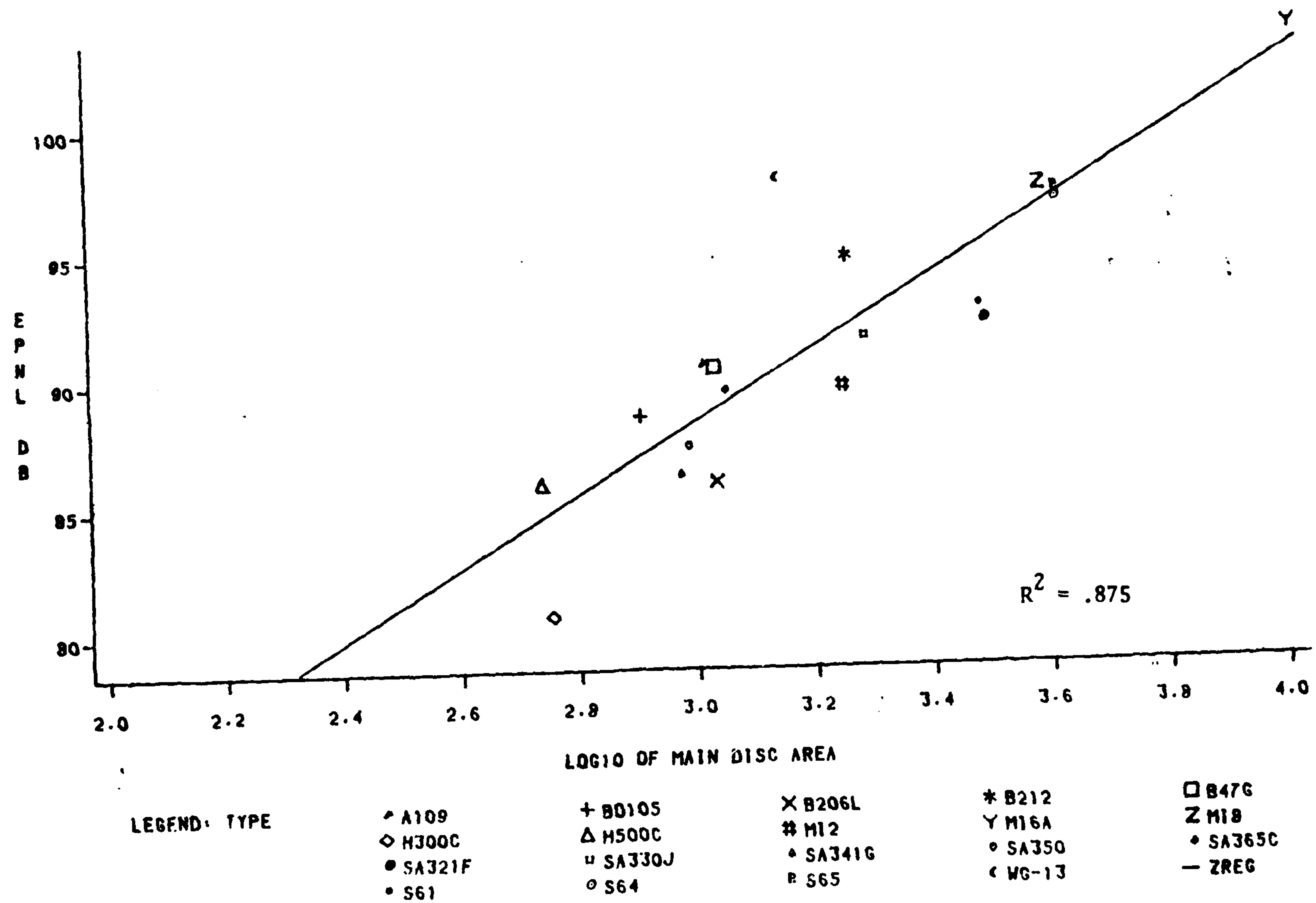


FIGURE 2.3.6

APPROACH REGRESSION OF EPNL VERSUS LOGTB

EMPIRICAL NOISE PREDICTION ANALYSIS

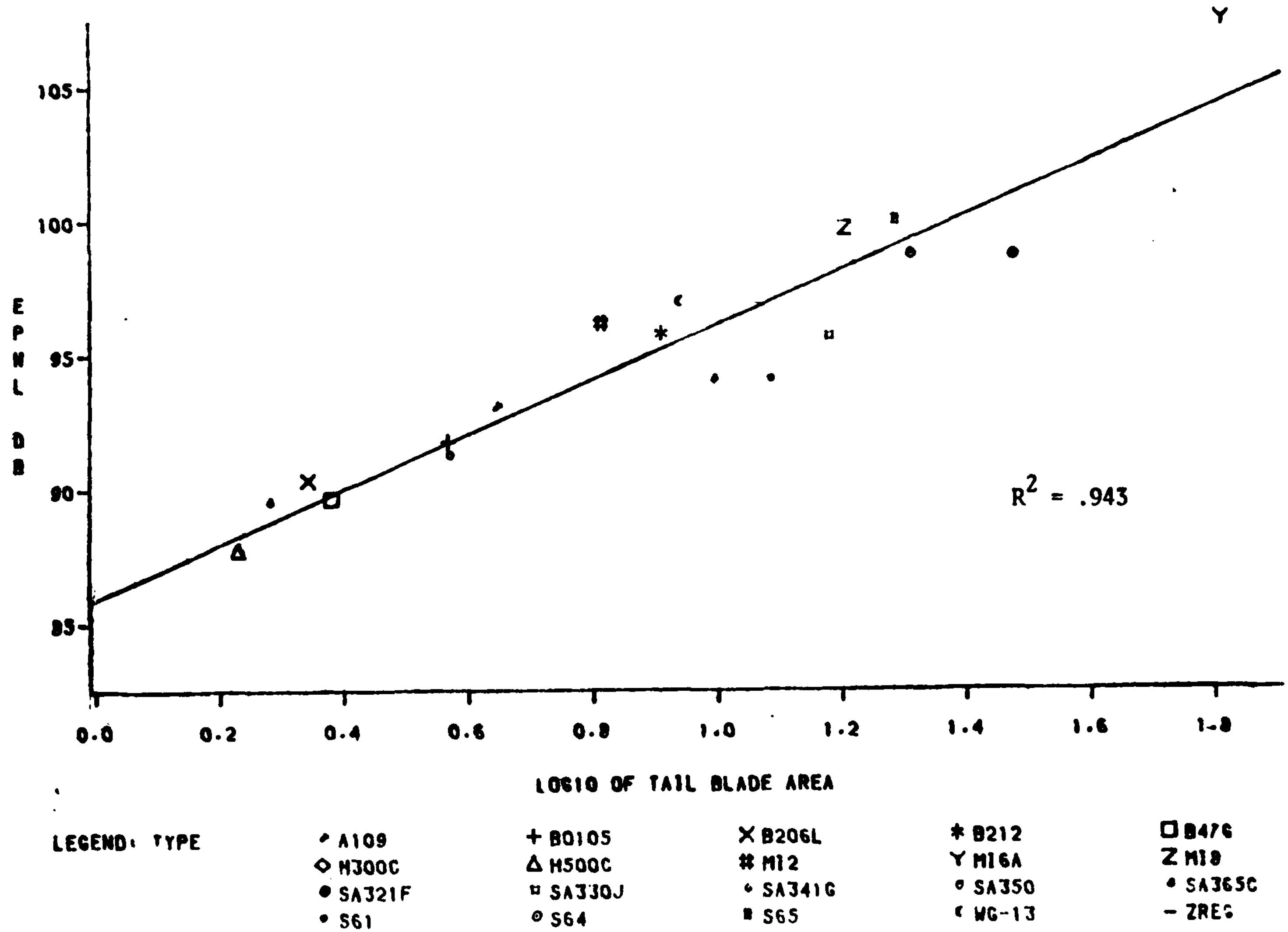


FIGURE 2.3.7

APPROACH REGRESSION OF EPNL VERSUS LOGW

EMPIRICAL NOISE PREDICTION ANALYSIS

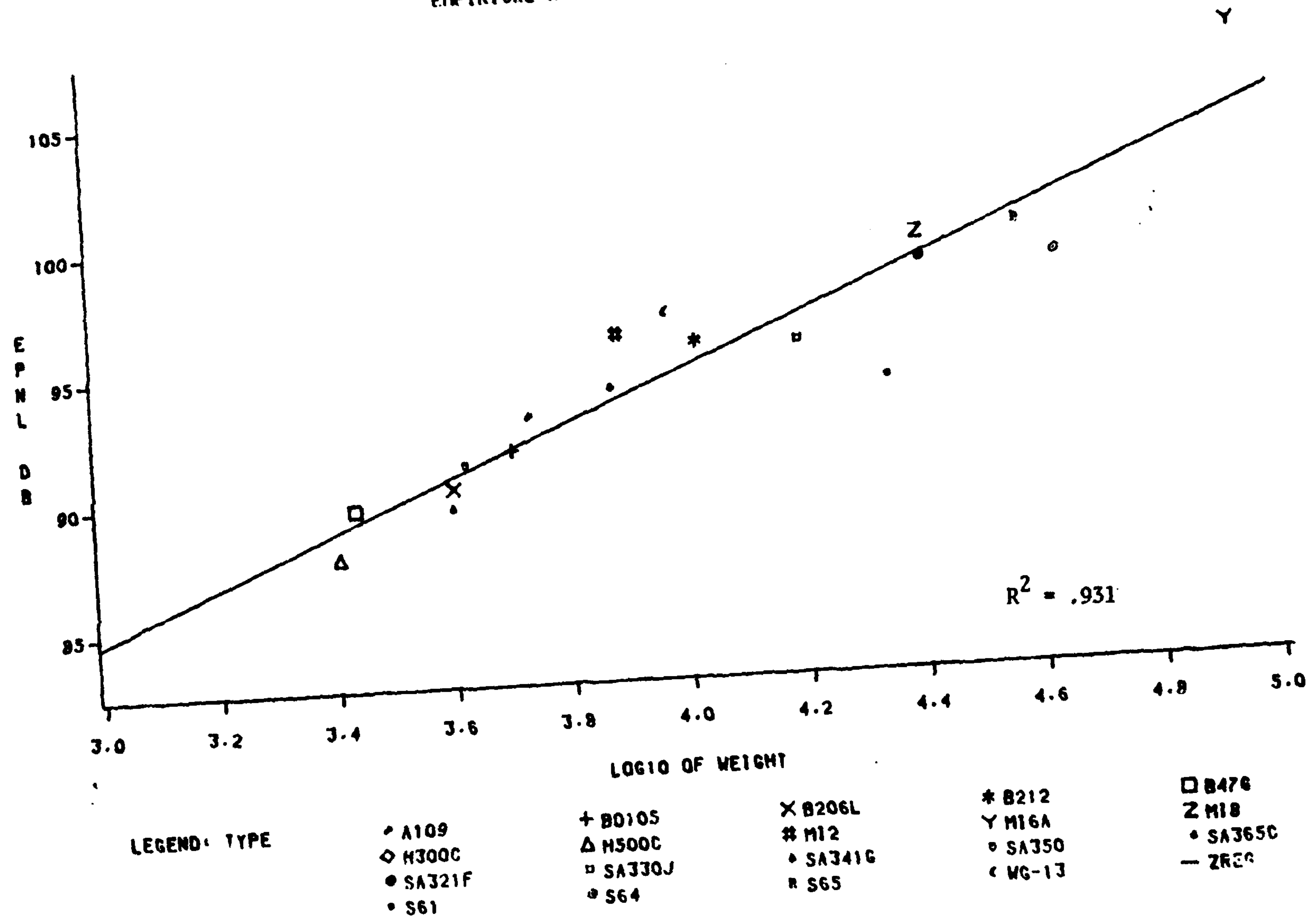


FIGURE 2.3.8

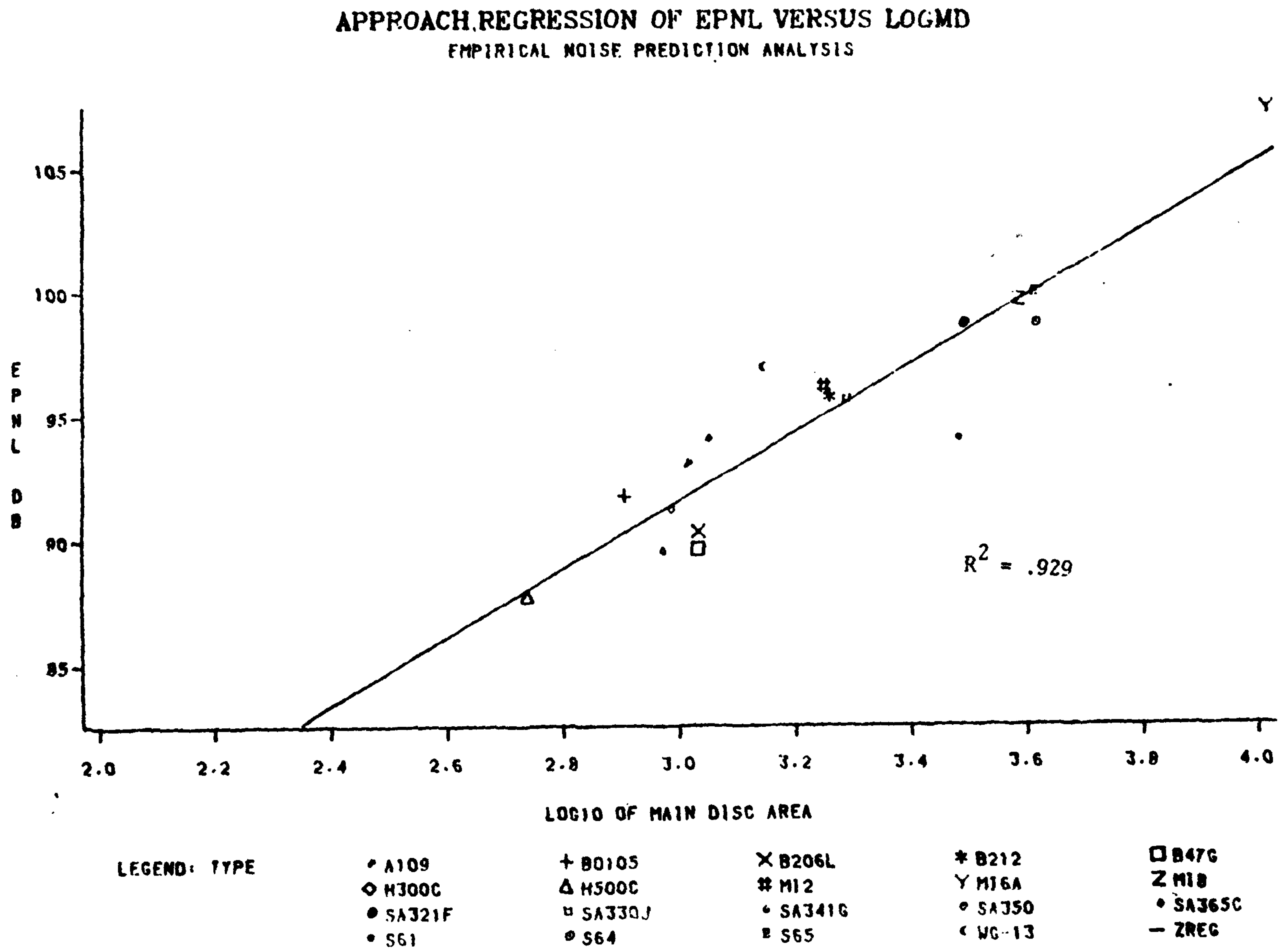

APPROACH REGRESSION OF EPNL VERSUS LOGMD
EMPIRICAL NOISE PREDICTION ANALYSIS
EPNL DB
105
100
95
90
85
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0
LOG10 OF MAIN DISC AREA
R^2 = .929
LEGEND: TYPE
A109
H300C
SA321F
S61
B0105
H500C
SA330J
S64
B206L
M12
SA341G
S65
B212
M16A
SA350
WG-13
B47G
M18
SA365C
ZREG

FIGURE 2.3.9

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