CONF-960912--35

BNL-63259

RELATING AVIATION SERVICE DIFFICULTY REPORTS TO ACCIDENT DATA FOR SAFETY TREND PREDICTION[a]

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ABSTRACT

A synthetic model[1] of scheduled-commercial U.S. aviation fatalities was constructed from linear combinations of the time-spectra of critical systems reporting using 5.5 years of Service Difficulty Reports (SDR)[2] and Accident Incident Data System (AIDS) records[3]. This model, used to predict near-future trends in aviation accidents, was tested by using the first 36 months of data to construct the synthetic model which was used to predict fatalities during the following eight months. These predictions were tested by comparison with the fatality data. A reliability block diagram (RBD) and third-order extrapolations also were used as predictive models and compared with actuality. The synthetic model was the best predictor because of its use of systems data.

Other results of the study are a database of service difficulties for major aviation systems, and arank ordering of systems according to their contribution to the synthesis.

I. INTRODUCTION

The U.S. Federal Aviation Administration (FAA) is responsible for the safety of 7,300 scheduled-commercial, 11,100 charters, 184,400 general aircraft. Scheduled-commercial aircraft, the subject of this study, fly under the most stringent Federal Air Regulation: FAR 121. This study used two of FAA's data bases: SDRs containing service incidents related to safety, and AIDS containing accidents, fatalities and damage reports. The data encompassed January 1990 to August 1995, and consisted of 224,000 SDR records in 90 fields and 31,872 AIDS records in 181 fields.

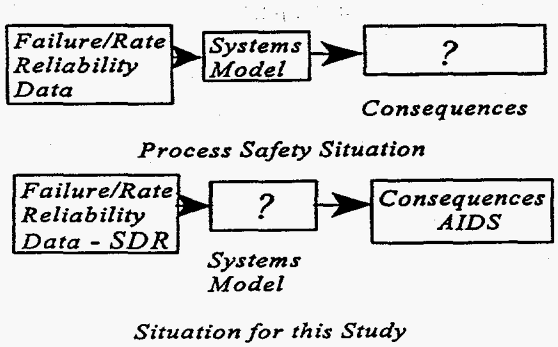

Fig. 1 Comparing Typical Process Safety with this Study Situation

Process industry safety studies (Figure 1) use a failure rate data base for systems and components to quantify a system model to estimate the likelihood of consequences of failure. This study had failure rate and consequence data but needed to determine a system model to connect them.

This was done by envisioning a matrix $|R|$ composed of linear combinations of service data matrices $|D|$, where the weighting coefficients are matrix $|W|$ (Eq. 1). If $|R|$and $|D|$ are square, the equation can be solved to find $|W|$ (Eq. 2). With concerns for stability, this was not done; the w's were found by least-squares fitting of the system difficulty curves to the reference data curve (Eq. 3). Thus the assumption is made that service difficulties are related to the accidents and there is little time lag (phase shift).

$$|R| = |D| * |W| \qquad 1)$$

$$|W| = |D^{-1}| * |R| \qquad 2)$$

$$\sum_{t=1}^{T} \left(\sum_{n=1}^{N} w_n * d_{n,t} - r_t \right)^2 \rightarrow \min of\, w_1, \ldots w_N \qquad 3)$$

II. REFERENCE DATA

Figure 2 shows the structure of the reference to which the structure of selected systems is fitted.

[a]Work was done under FAA Grant 95-p-0056

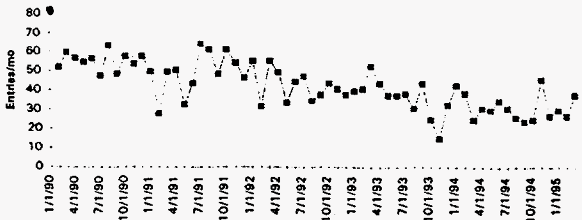

Figure 2 Reference Data
Fatalities Experienced by Carriers Flying under Part 121

III. SYSTEMS DATA

Figure 3 shows, for example, the data patterns for the Wing Structure system that is one of the systems fitted to the reference data.

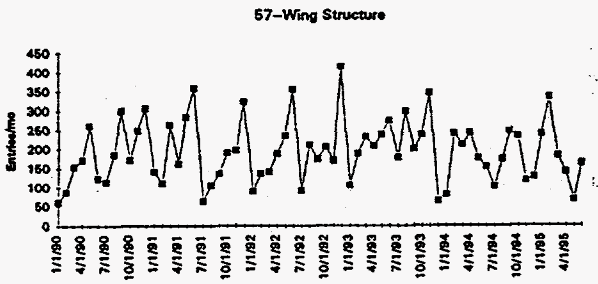

Figure 3 Example of Systems Data

IV. SYSTEM GROUPS

The SDR uses the Aviation Transportation Association's (ATA) 48 major systems classifications with subsystems. For each subsystem there is a code with one digit signifying the criticality. Many systems have little direct relevance to safety and including them in the fitting may obscure safety systems. Two types of system groups were used: subsystems having criticality rating of four or five (Table 1) and the BNL group based on engineering reasoning regarding envelope, propulsion, flight surfaces and control (Table 2).

Table 1 Rank-Ordering Critical 45 Systems

No.	Description	Weight (w_n)
28	Fuel	0.323
73	Fuel Control	0.314
76	Mixture and Power	0.287
74	Ignition	0.199
32	Landing Gear	0.194
67	Rotorcraft Flight Control	0.104
64	Tail Rotor	0.009
63	Main Rotor Drive	-0.018
57	Air Frame	-0.031
72	Engine	-0.084
71	Engine Cowling	-0.164
65	Tail Rotor Drive	-0.192

Table 2 Judgement-Based System Group

ATA No.	System Title	Reason
21	Air Conditioning	Cabin pressurization
22	Auto Pilot	Navigational error
23	Communi-cation	Navigational error
24	Electrical	Power
26	Fire Protect.	Fire hazard
27	Flight control	Aircraft control
28	Fuel	Engine fuel
29	Hydraulic	Controls
30	Anti-Ice	Ice removal
32	Landing Gear	Safe landing
34	Navigation	Navigation
35, 36, 37	O_2 Pneu.Vac.	Atmosphere
52,53,56	Cabin Windows	Pressure envelope
55, 57	Empennage, Wings	Stabilization and lift
72-79	Eng., Fuel, Oil Ignit., Cntrl, Indic. Exhaust	Propulsion

V. PREDICTION BASED ON SYNTHESIZED SPECTRA

Synthetic reference (consequence) data were constructed by linearly combining system's spectra components of each of the systems groups by least-squares linear regression fitting of the system spectra to the reference spectrum. Several fitting techniques were tried: representing both the reference spectrum and the system spectra as power-series, the reference spectrum as a power series and the system spectra as histograms, and freeform fitting with the reference and system spectra as histograms. The last one seemed to be the best because it eliminates the distortion caused by power series. The fitting coefficients are given in the right column of Table 1 for the Critical 45 systems.

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The fit using the BNL-judged systems was similar. Figure 4 compares the fitted system's spectra to the reference spectra.

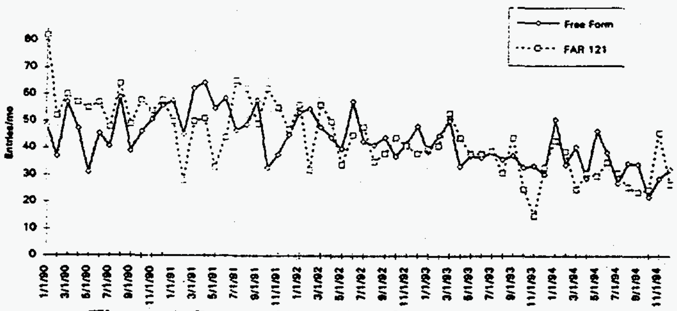

Figure 4 Comparison of Reference and Synthetic Spectra

VI. RELIABILITY MODEL-BASED PREDICTION

A. Entry Data

The SDR data base was searched to compile the number of system entries for aircraft flying under FAR 121. The results are presented in Table 3 in terms of ATA system designation, description and entries per flight. These results may be converted to entries/flight hours by multiplying by 0.645 or entries per year by multiplying by 8.e+6.

Table 3 Incident Data

ATA No.	Description	Entries/ flight
1200	Servicing	1.24e-05
1800	Helicopter Vibration	0.00e+00
2100	Air-conditioning	8.04e-05
2200	Auto pilot	5.29e-06
2300	Communications System	1.16e-05
2400	Electrical Power System	5.63e-05
2500	Interior Equipment	5.72e-05
2600	Fire Protection	7.18e-05
2700	Flight Control System	1.31e-04
2800	Fuel System	1.97e-05
2900	Hydraulic System	5.72e-05
3000	Anti-ice System	2.30e-05
3100	Instruments	1.22e-05
3200	Landing Gear	4.16e-04
3300	Lighting System	4.31e-04
3400	Navigation System	6.51e-05
3500	Oxygen System	1.64e-05
3600	Pneumatic System	2.44e-05
3700	Vacuum System	3.88e-07
3800	Water and Waste System	2.39e-06
4500	Central Maintenance Computer	0.00e+00
4900	Airborne APU System	1.51e-05
5100	Practices/structures Balloons	0.00e+00
5200	Doors	1.51e-04
5300	Fuselage	1.20e-03
5400	Nacelles/pylons Structure	4.45e-05
5500	Empennage Structure	7.56e-05
5600	Windows Windshield System	1.50e-05
5700	Wing Structure	2.96e-04
6100	Propeller System	4.99e-05
6200	Main Rotor System	1.25e-06
6300	Main Rotor Drive	1.03e-06
6400	Tail Rotor	9.57e-07
6500	Tail Rotor Drive System	9.12e-08
6700	Rotorcraft flight control	5.47e-07
7100	Power Plant	2.71e-05
7200	Engine (Turbine/turboprop)	1.15e-04
7300	Engine Fuel and Control	5.50e-05
7400	Ignition System	2.48e-06
7500	Engine Bleed Air System	1.45e-05
7600	Engine Controls	1.11e-05
7700	Engine Indicating System	3.43e-05
7800	Engine Exhaust	1.31e-05
7900	Engine Oil System	2.50e-05
8C00	Engine Starting	4.40e-06
8100	Turbine System (Recip. Only)	1.82e-07
8200	Water Injection	7.98e-07
8300	Accessory Gearboxes	5.47e-07
8500	Engine Reciprocating	7.16e-06

B. Reliability Block Diagram

For more conventional system modeling, the reliability block diagram shown in Figure 5 was used using the systems group from Table 2. This diagram indicates that each of these 19 systems must function properly for successful operation. The failure rate of this aircraft model is found by using the failure rates of each system from Table 3 as summarized in Table 4. The result (corresponding to logical "OR"ing) of the system failure rates is a frequency of 2.76E-3/flight.

The AIDS data shows 2851 total (passengers, crew and ancillaries) fatalities over a 5.5 year period which is equivalent to 6.5E-5 fatalities/flight[4]. The ratio of the entry rate/flight to the fatality rate/flight is 42.5.

VII. ANALYTIC CONTINUATION-BASED PREDICTION

Fitting the reference spectrum to a power series in time may also be used to predict future trends by specifying time into the future from the time of the fitting. Figure 6 compares the reference spectrum to the fit based on the equation: fatalities/month = $61.9 - 0.778t + 0.0082t^2 - 0.00008t^3$ where t is the number of months after January 1990.

Table 4 Failure Evaluation		
ATA No.	Title	Entry Rate/flight
21	Air-conditioning	8.04e-5
22	Auto Pilot	5.29e-6
23	Communications	1.15e-5
24	Electrical	5.63e-5
26	Fire Protect.	7.18e-5
27	Flight control	1.31e-4
28	Fuel	1.97e-5
29	Hydraulic	5.72e-5
30	Anti-Ice	2.3e-5
32	Landing Gear	4.16e-5
34	Navigation	6.51e-5
35, 36, 37	Oxygen, Pneumatic, Vacuum	4.55e-5
52,53, 56	Fuselages, Doors, Windows	1.35e-3
55, 57	Empennage, Wings	5.07e-4
72-79	Engine, Fuel, Ignition, Bleed, Controls, Indicating, Exhaust, Oil	2.98e-4
	Total	2.76e-03

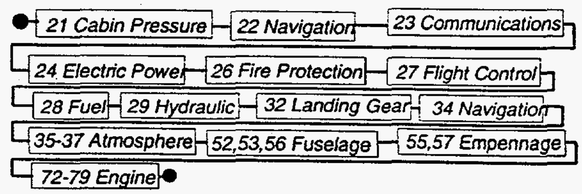

Figure 5 Reliability Block Diagram

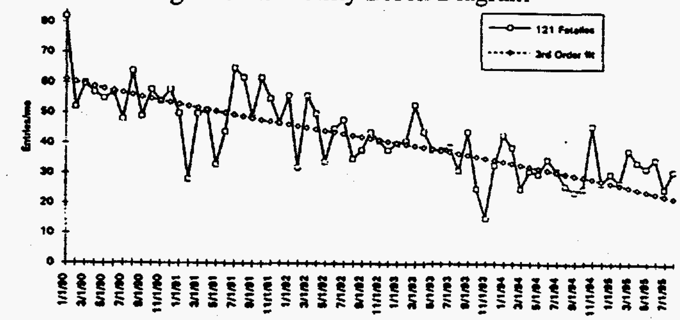

Figure 6 Third-Order Fit and Reference Data

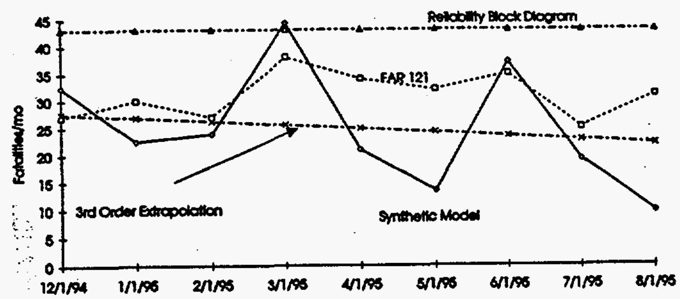

Figure 7 Prediction Test
FAR121, Synthetic Model, RBD, and 3rd Order Fit

VIII. TEST OF PREDICTIONS

Figure 7 uses data previous to December 1994 to predict the fatalities from December 1994 to August 1995. The RBD prediction is high because it is based on data averaged over 5.5 years; the third-order fit continues the downward trend of the data while there is a suggestion that there are increasing fatality rates from February 1995 to the end of data. The synthetic model, based on SDR inspection data seems to show this increasing tendency.

IX. TEST OF ROBUSTNESS

The synthetic model uses data in one time region to construct a model from the SDR data to predict the fatality rate in future time. The stability of this model to the time region of fitting was tested. Figure 9 shows the prediction of the synthetic model for different fitting times: first 5.5 years, first 2.5 years and second 2.5 years. The results are remarkably independent of the fitting time for this data.

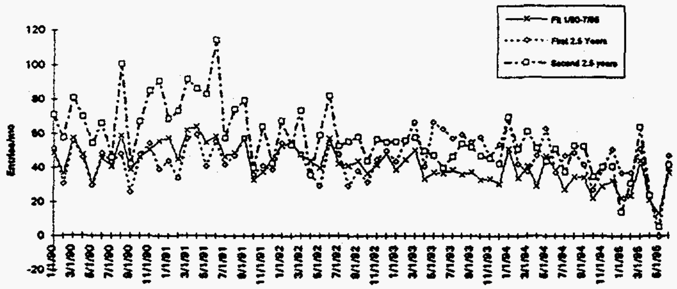

Figure 8 Test of Synthetic Model Stability

X. CONCLUSIONS

The spectra of critical system difficulties have been numerically related to the spectrum of fatalities for scheduled, commercial air carriers to construct a synthetic model to predict near-future aviation experience. Tests show that the synthetic model is a better predictor than the reliability block diagram model or by analytic continuation of a power series in time fit to data.

In the course of this work, the entry frequency for the 48 ATA system classifications was prepared and presented. Work not reported here determined the linear regression slope and intercept as well as a correlation coefficient with the reference data.

Table 1 provides the amplitudes of the system spectra which are used to rank-order the systems according to their importance to the fit. The negative coefficients caused by rotorcraft data confuse the interpretation. However, it should be noted that they are of low amplitude. Future work may entail separation of fixed-wing and rotor craft.

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