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OPTIMISATION STUDY FOR STRUCTURAL ACOUSTICAL CONTROL CONFIGURATION ON THE FOKKER 100 USING RECIPROCAL TESTING

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INTRODUCTION

Interior noise reduction in aircraft is a topic on which a considerable research effort is spent. Active noise control is one of the main topics addressed to this purpose. In the previous years, an extensive evaluation was made of the possibilities of pure acoustical control configurations using loudspeakers. Commercial systems have been developed and are being used industrially. Recent research has been directed to apply structural secondary sources.This topic is for example addressed in the Brite Aeronautics project "ASANCA 2".

In order to predict the performance of such systems and to optimise the actual configuration in terms of number and location of actuators and sensors, a methodology combining in-flight data with vibro-acoustic system data into an optimisation procedure was developed and applied to the case of a Fokker F70/100.

OPTIMISATION METHODOLOGY

The distribution of the interior noise at a specific frequency is called the primary field. This primary field is referred to as $\{p\}_n$, a vector containing the response at n microphone positions. The secondary field $\{s\}_n$ is the sound field, at the microphone positions, generated by the $\{q\}_m$ actuators. The resulting sound field, when the control is active, is called the residual field $\{e\}_n$. With $[H]_{nxm}$, a matrix containing the transfer functions between the m actuator source strengths and n microphone responses, one may write

$$\{e\}_n = \{p\}_n - \{s\}_n = \{p\}_n - [H]_{nxm}\{q\}_m^t \quad (1)$$

The optimisation strategy will search for an optimal subset of d sources. The vector containing the set of d corresponding source strengths is referred to as $\{q\}_d$. The optimisation can be calculated for one single spectral line or over a set of frequencies or a frequency band. Different procedures can now be followed to this purpose [1,2,3,4]. In the present study, the "forward build" and the "spatial fit" methods were used.

The criterion used in the *build* method results in a selection of the actuator source which offers the best possible additional noise reduction. This is done by means of a least squares approximation.

In step one of the optimisation procedure the overdetermined equation $\{p\}_n= -\{H_j\}_n q_j$ is solved in a least square sense for all possible sources j. The solution of this equation q_j is the source strength that is needed to have a secondary field that is as close as possible to the (negative) primary field. This source strength q_j is used to calculate the secondary field $\{s\}_n=-\{H_j\}_n q_j$, the residual field $\{e\}_n=\{p\}_n+\{s\}_n$ and the norm $\left\|\{e\}_n\right\|$. The source actuator $s1$ for which $\left\|\{e\}_n\right\|$ is minimal is selected as the first actuator source.

In the next step an additional actuator source is selected which gives the best possible reduction in combination with the first actuator source $s1$. In order to determine this additional actuator source equation (2) is solved for all actuator sources j, except for the one already selected $s1$.

$$\{p\}_n = \left[\{H_{s1}\}_n \quad \{H_j\}_n\right]_{nx2} \begin{Bmatrix} q_{s1} \\ q_j \end{Bmatrix}_{2x1} \quad (2)$$

The source actuator $s2$ for which $\left\|\{e\}_n\right\|$ is minimal is selected as the second actuator source. This procedure is repeated until the desired number of source actuators or the desired attenuation is reached.

In the *spatial fit* method, the procedure will look for the source with the best spatial correlation to the primary field rather than looking for the source with the best reduction. The idea is to have a better compromise between noise reduction and power consumption.

In the first step of the optimisation procedure the *spatial fit* (4) of all the columns of the $\{H_j\}_n$ of the transfer function matrix $[H]_{nxm}$ to the primary field $\{p\}_n$ is calculated. The *spatial fit* of two vectors is the absolute value of their inner product divided by the norm of both vectors.

$$spf1_j = \frac{\left|\{H_j\}_n^H \{p\}_n\right|}{\left\|\{H_j\}_n\right\|\left\|\{p\}_n\right\|} \quad (3)$$

The value of the spf1 will always reside between 0 and 1. The bigger this value, the better the vector $\{H_j\}_n$ corresponds to the primary field vector $\{p\}_n$. The actuator source j for which spf_j is maximal is selected as the first actuator source $s1$.

In the following steps the *spatial fit* (4) of all vectors $\{H_j\}_n$ to the residual field $\{e\}_n$ is calculated, where j is one of the not yet selected actuator sources.

$$spf1_j = \frac{\left|\{H_j\}_n^H \{e\}_n\right|}{\left\|\{H_j\}_n\right\|\left\|\{e\}_n\right\|} \quad (4)$$

The residual field $\{e\}_n$ is the resulting sound field, when the already selected actuator sources are active.

Finally, additional constraints limiting the maximum level or power of the actuators can be involved in the procedure.

TEST PROCEDURE

The primary field data were measured during flight at 36 locations, corresponding with the head positions in the aft cabin part. The data were measured as referenced spectra (complex fields, coherent with engine tacho signal references). The objective of the ground tests then was to determine the FRF matrix between all feasible second source exciter locations and the target acoustic responses.

In total 144 of such locations were identified.

Given the large complexity of mounting the exciting shakers at all locations, a reciprocal test procedure was adopted: the 144 possible second source locations were instrumented with accelerometers and loudspeaker excitation was applied at the target microphone locations. This conforms with the vibro-acoustical reciprocity [5,6,7].

Let p_j be the pressure, and $\dot{q}_j$, the volume acceleration at point j and $\ddot{x}_i$ the acceleration and f_i the force at point i, then:

$$\left.\frac{p_j}{f_i}\right|_{\dot{q}_j=0} = \left.\frac{\ddot{x}_i}{\dot{q}_j}\right|_{f_i=0} \quad (5)$$

This vibro-acoustic reciprocity was verified at a number of typcial locations using hammer impact excitation (Figure 1).

OPTIMISATION STUDY

The optimisation was then performed for a maximum number of 45 actuators at three engine tones (0.5NR1, 1NR1 and 2NR1). The cabin noise levels are optimised on 36 control sensors.

The results are given in table 1 for up to 20 exciters using the "build" method. For each step of the optimisation procedure the selected actuator source is printed together with the obtained reduction and necessary power.

In a second step, the optimisation was performed for the three engine tones together. The results for this optimisation are given in table 2. The "spatial fit results" correspond well with the "build" ones.

	0.5NR1			1NR1			2NR1		
NR	SOURCE NR	RED [dB]	STR.	SOURCE NR	RED [dB]	STR.	SOURCE NR	RED [dB]	STR.
1	112	0.51	4.72	58	4.65	16.61	8	1.46	23.99
2	107	0.94	5.79	41	5.94	20.99	47	2.14	19.33
3	42	1.79	4.88	17	7.78	45.84	39	2.55	18.11
4	25	2.35	5.01	30	9.10	47.61	65	2.97	18.13
5	12	2.65	6.36	100	10.11	47.20	100	3.41	16.96
6	62	2.93	7.18	9	11.43	88.02	37	3.76	17.99
7	18	3.15	7.17	112	12.26	122.85	90	4.22	21.59
8	83	3.41	7.59	94	12.90	112.91	17	4.90	22.99
9	31	3.71	8.73	96	14.12	130.79	47	5.27	24.14
10	3	4.25	11.06	97	15.01	136.30	32	6.05	27.14
11	103	4.52	12.69	79	15.63	127.74	33	6.57	30.42
12	95	4.92	13.95	55	16.28	121.58	105	6.94	32.77
13	85	5.21	15.25	38	16.87	110.40	67	7.50	34.32
14	75	5.95	16.29	111	17.73	113.28	60	7.86	37.11
15	30	6.52	17.94	82	18.34	120.94	104	8.41	35.57
16	22	6.97	20.40	93	18.97	114.25	66	8.99	44.16
17	19	7.48	21.16	51	20.07	118.49	4	9.53	65.36
18	55	8.08	22.27	38	21.67	130.00	1	10.37	103.95
19	72	8.74	24.63	40	22.29	133.63	80	11.06	114.37
20	53	9.52	27.08	90	22.90	134.90	88	12.19	105.03

Table 1

	0.5NR1 + 1NR1 + 2NR1		
NR	SOURCE NR	RED [dB]	STRENGTH
1	58	3.86	6.12
2	41	4.87	8.04
3	17	6.23	16.91
4	20	7.26	21.51
5	100	8.00	21.45
6	9	8.65	31.46
7	84	9.33	31.50
8	82	9.94	36.35
9	47	10.46	42.31
10	55	11.02	43.19
11	97	11.46	42.87
12	66	11.96	49.58
13	110	12.96	49.50
14	36	13.73	49.44
15	47	14.41	56.19
16	70	14.93	58.78
17	13	15.47	59.36
18	90	16.10	60.14
19	91	17.16	61.46
20	112	17.76	65.34

Table 2

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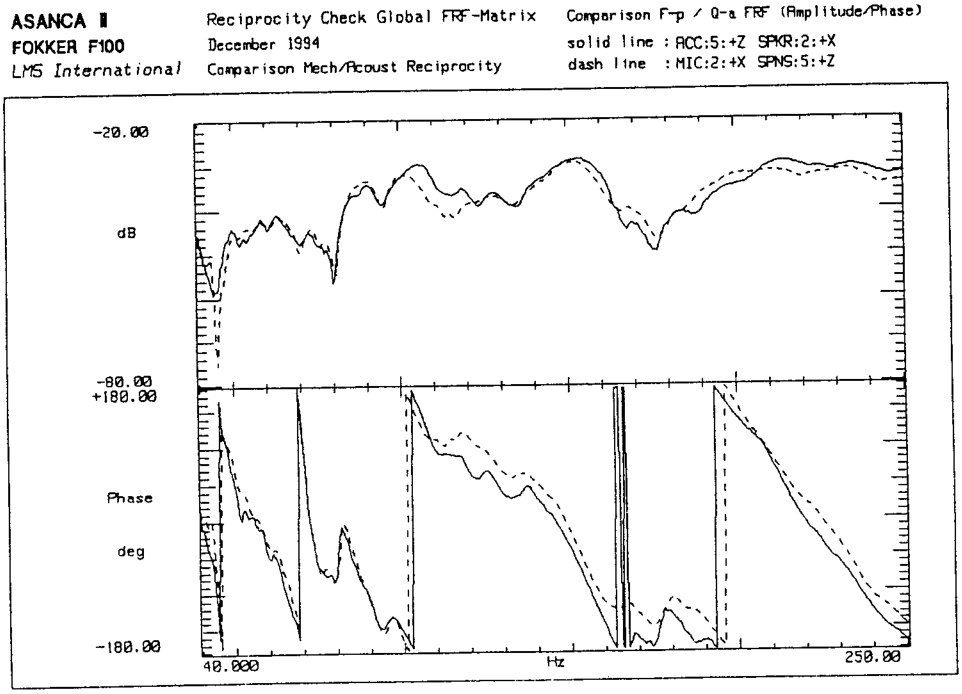

Figure 1: Typical vibro-acoustic reciprocity verification result