***inter.noise 2000***
***The 29th International Congress and Exhibition on Noise Control Engineering***
***27-30 August 2000, Nice, FRANCE***

**I-INCE Classification:** 3.8

# FEED FORBACK$^{\text{TM}}$ CONTROL COMPARE TO CLASSICAL CONTROLS

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**Keywords:**
ACTIVE NOISE CONTROL, FEED FORBACK, ANCAS SEAT, TECHNOFIRST

**ABSTRACT**
The main idea of the Feed ForBack$^{(\text{TM})}$ control is not to simply add the feed forward and the feedback control, but rather to intimately combine the two effects in order to create a new form of hybrid control. Any experiences using feed forward show that this control needs a very good coherence between reference microphone and control microphone. A good point in favor of feedback, is "independence" with regards to the reference signal, which gives a useful alternative in comparison to feed forward. But, by using the Feed ForBack$^{(\text{TM})}$, instead of feed forward or feedback, we can avoid several limitations given by these two classical technologies. The paper presents what are the improvements given by a Feed ForBack$^{(\text{TM})}$ in comparison to a feedback or a feed forward. Some applications using the Feed ForBack$^{(\text{TM})}$ control and already presented during the last Active 99 convention [1] held in Florida will be checked in detail in order to really understand these improvement. This third way to manage active control is a new strategy control incorporating a combination and not an addition of the two classical principles systems. We will also give some specific results related to this new principle.

## 1 - INTRODUCTION
The paper presents a third way to manage active control with a new strategy incorporating a combination of feed forward and feedback systems. During the last Active 99, we have focused our presentation on the improvements given by a Feed ForBack$^{(\text{TM})}$ system compared to feed back and feed forward systems. According to each experiments presented in this last paper, we have chosen each of them in order to be specific for the feedback, for the feed forward control. The ANCAS$^{(\text{TM})}$ seat provides a better noise reduction especially for a propagate system and pure tone noise when using a feed forward control. For this reason, the ANCAS$^{(\text{TM})}$ system provides good results according to the wavelength, and we can get a diameter from about $\lambda/4$ to $\lambda/10$ of noise reduction volume. To improve this ANR volume around the passenger head, and not only for tonal propeller noise but also for wide band jet noise, we have to take care of the given feedback control properties. That are the reasons why a Feed ForBack$^{(\text{TM})}$ control system applied to an ANCAS$^{(\text{TM})}$ seat improves the noise reduction [1]. In order to compare the Feed ForBack$^{(\text{TM})}$ to the feed forward and the feedback control we are going to do these three different controls on the same experiment (Fig. 1).

## 2 - EXPERIMENTAL SET UP

### 2.1 - The feedback control
The feed back controller uses, as described in Fig. 1a, a collocated microphone, a loudspeaker and an analog fixed filter. This feed back controller is installed inside the seat produced by Zodiac and used for the ATR 42 and 72 airplane. All the measurements are done inside an aircraft mock up (Fig. 2) with a dummy head produced by HEAD Acoustic. The primary source is given by two large sound enclosures able to provide low frequencies with a significant noise level. We use, as primary source, a noise recorded from a jet aircraft. The result given on Fig. 3 with the feed back control, can not get a large bandwidth of ANC, even by using the CloverLeaf Filter$^{(\text{TM})}$ [2]. A pumping phenomenon appears and increases

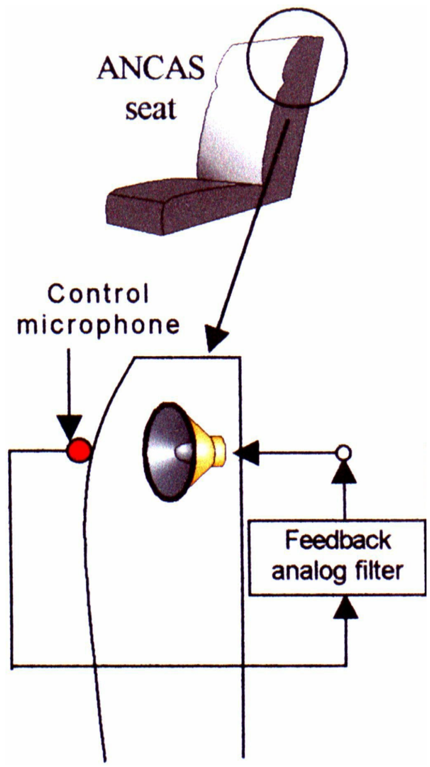


**Figure 1(a):** Feedback.

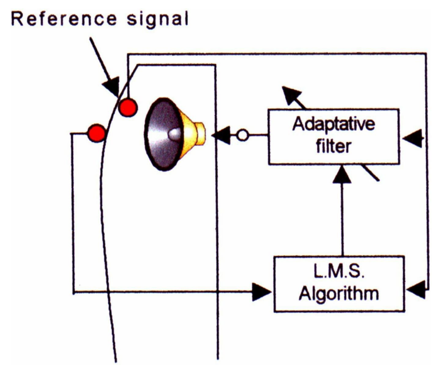


**Figure 1(b):** Feed Forward.

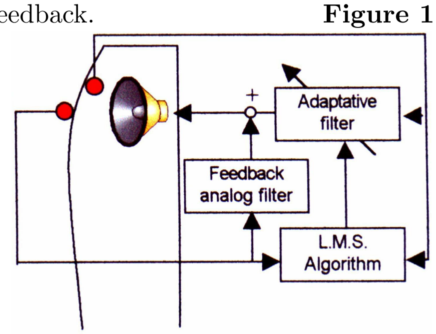


**Figure 1(c):** Feed ForBack$^{(TM)}$.

the level of noise outside the frequency bandwidth controlled by the feedback loop. The CloverLeaf Filter$^{(TM)}$ optimizes the compromise between stability and rapid control, and improves the ANC gain result by allowing a larger value of loop gain in comparison with standard filtering [1]. However, we still have an enhancement of noise outside the controlled frequency bandwidth.

**2.2 - The feed forward control**

To improve the experiment § 2-1, we add a reference signal correlated to the disturbance in order to get a feed forward control as describe to Fig. 1b. The reference signal is passed into an array of adaptive FIR digital filters, and applied to secondary sources in order to minimize an error signal from appropriate sensors. To implement this feed forward control, we use a NOVACS$^{(TM)}$ controller [3]. The parameters are adapted with a multichannel Least Mean Square (LMS) algorithm called "x-Filtered LMS" in SISO configuration [4, 5]. The method does not need a precise model of the system, but only an estimate of the impulse response. To be efficient, the feed forward control has to combine predictive noise propagation, and a very good coherence between both reference and control microphones. For this configuration, Fig. 2, the jet noise does not help to get a good coherence and the controller treats only pure tones. As we can see on Fig. 3, the result given by the feed forward control is less good than the feedback, and not adapted at all, for a random noise.

**2.3 - The Feed ForBack$^{(TM)}$ control**

The Feed ForBack$^{(TM)}$ control applied to the ANCAS$^{(TM)}$ seat is described in Fig. 1c. We have used the transducers placed in a classical feedback system: a collocated sensor and an actuator. Actually, the collocated sensor is also the control microphone of the feed forward control system. We have used

**Figure 2:** Experimental set-up.

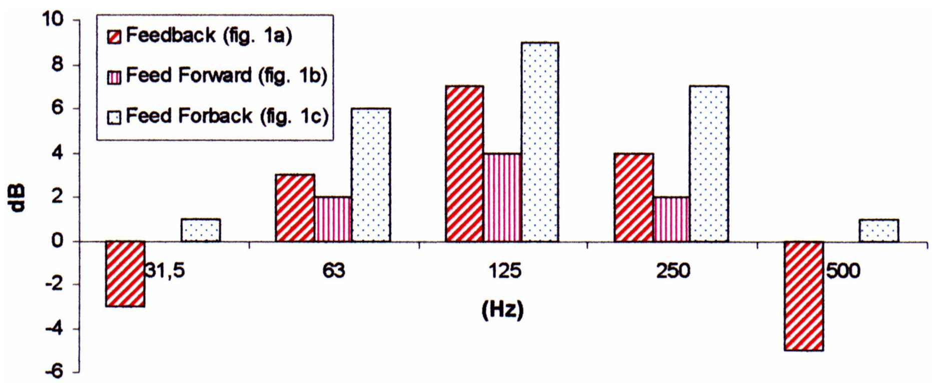


**Figure 3:** Active Noise Control Attenuation.

an external microphone for the reference signal that is the feed forward control signal combined to the feedback filtering control signal. The resulting signal is amplified and is entered in the loudspeaker. The way to use this Feed ForBack$^{(TM)}$ is very simple and generic [1], [6], because the feedback control allows a very fast control. Indeed, even for an impulse noise, we measure the transfer function between the control microphone and the loudspeaker through the existing feedback control. The result is a shorter impulse response, and means less data and time computing for the feed forward system. By doing this transfer function measurement with the feedback control on, we are modifying the impulse response so the feed forward model. This modification drives the feed forward to a different way to control the system. Thus, Feed ForBack$^{(TM)}$ is definitely different of a simple addition of the two previous systems. To implement this Feed ForBack$^{(TM)}$ control, we are using a Hybrid NOVACS controller Fig. 2, which can be used also for vibration control [6] and other applications. The synergy between the two types of control, represented by the Feed ForBack$^{(TM)}$ control is pointed out on Fig. 3.

## 3 - CONCLUSION

The Feed ForBack$^{(TM)}$ control can be used whenever the system is subjected to impulsive and stationary disturbances provided that a reference correlated to the disturbance is available; there is no detrimental interaction between feedback and feed forward, and they can be used with the same set of actuators and sensors. The precision pointing and the ANC applications show that feed forward control can deal with stationary disturbances, which are outside the bandwidth of a model-based feedback controller, and more generally over a wide range of frequencies, limited only by the sampling period and the hardware available. The feed forward control extends the bandwidth of the controller for steady state disturbances with a correlated reference, while the feedback control reduces drastically the impulse response of lightly damped structures, avoiding the problems associated with truncation. The feedback control allows a very fast control even for an impulse noise. The transfer function between the transducers is measured through the existing feedback control. The result is a shorter impulse response, and means less data and time computing for the feed forward system. The most important result of this study is that the

Feed ForBack$^{(TM)}$ control gives the addition of both positive performances of each technology feedback and feed forward control, and increases also the quality of these technologies by canceling their inherent drawbacks according the following points:

- For the feedback, no more pumping effect outside the frequency bandwidth controlled by the feedback,
- For the feed forward, a faster control.

The following table summarizes the advantages and drawbacks of the Feed ForBack$^{(TM)}$ control compare to the feed back and feed forward control.

| **Criterion** | Feed back | Feed forward | Feed ForBack$^{(TM)}$ |
|---|---|---|---|
| Pumping effect | **Yes** | **No** | **No** |
| Model needed | **Yes** | **No** | **No** |
| Local method | **Yes** | **No** | **Yes** |
| Propagate | **No** | **Yes** | **Yes** |
| Long impulse response | **No** | **Yes** | **No** |
| Large computation | **No** | **Yes** | **No** |
| Wide band control | **No** | **Yes** | **Yes** |
| Stability robustness | **No** | **Yes** | **Yes** |
| Spillover | **Yes** | **No** | **No** |
| Disturbance outside ANC bandwidth | **Yes** | **No** | **No** |

**Table 1:** Advantages and drawbacks of the three noises control principles.

By using the hybridization combination of these two standard technologies of active noise and vibration control we have demonstrated that it is possible to increase efficiency of this active control, compared to the individual performance of each separated technology.
The Feed ForBack$^{(TM)}$ control is definitely a generic control and the third way to manage active control. It is applicable to all situations requiring active noise or vibration control.

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