Sensors of a Beechcraft C90 Aircraft for Extension of Data Acquisition System

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Abstract: *In-flight data acquisition is a key point in the aircraft design process. For the control of a simulated prototype using the control surfaces, state variables such as acceleration, pitch rate for longitudinal motion, and roll rate or slideslip angle for lateral-directional motion are commonly defined as control variables. The purpose of this paper is to evaluate the risk of in -flight laboratory modification through extension of data acquisition system for collection of additional data related to pilot command input and the reaction of the system.*

Key Words: *ARINC 429, Data Acquisition, α angle, β angle*

1. INTRODUCTION

The continuous improvement in reliability and performance of the flight control systems has caused an abrupt increase in technical complexity. The functionality of these systems is based on many information sources and has become more likely to suffer from errors and environmental conditions. The guidance, navigation and control systems developed to overcome these anomalies lack in-flight data validation. Wind tunnel tests are difficult and prohibitively expensive for an exact simulation of flight conditions. Flight testing and data acquisition provide the basis of the optimization of control systems and play an important role in estimating errors and correcting aircraft measurements. Data acquisition on a research aircraft cannot be discussed unless all the mission configurations and the multitude of individual sensors associated with that total mission are considered [6]. It must be integrated into a system simple enough to ensure proper calibration and safe operation with minimum prior training. Today's air traffic volume and its prospective growth, as well as the rising fuel costs and the ambitious targets such as the reduction of fuel consumption can be achieved by decreasing airframe weight. For this reason one of the main aspects to be considered on the installation of sensors on board is the weight factor. In general, an aircraft (AC) is designed to withstand the flight loads (forces and moments) which act on the AC structure in response to externally applied forces (aerodynamics, inertia, thrust, etc.). These design loads are calculated according to the airworthiness regulations CS-23 or CS-25 respectively [1] in which various loading scenarios are defined. These include discrete gusts 1 (DG) and continuous turbulence (CT). Often these design conditions contribute to the loads envelope. For instance at the wing roots, they can define the strength of the structure and thereby translate into weight of the wing. Besides the choice of lightweight sensors, the ability to perform real calculations flight also represents a great opportunity to reduce additional weight. Furthermore, using the acquired data, the introduction of a suitable control scheme is possible, that can actively improve performance without compromising safety. This would imply fuel savings and consequently a reduction of direct operating costs, making the AC more attractive for operators. In other words aviation imposes many challenges and the initiative of acquiring data and modelling further more efficient aircrafts calls for technical development. The purpose of this paper is to present some aspects of data acquisition that can be tailored to be used in dynamics of flight.

2. PROBLEM FORMULATION

The parameters of interest in flight dynamics are standard and can be determined through practical aircraft instruments corrected for instrument error.

The actual aircraft axis system is usually noted using a notation considered to have the origin in the center of mass O. The purpose of the paper is to determine not only the movement of the control surfaces associated with each and every axis, but also the angles associated with the relative motion (Fig. 1). The normal or vertical axis, known as OX, is an axis drawn from top to bottom, and perpendicular to the other two axes which is actually parallel to the fuselage station. The angular displacement about this axis or yaw is controlled by the pilot by using the rudder. The lateral or transverse axis, defined as OY is running from the pilot's left to right in piloted aircraft, and parallel to the wings. The movement about it is noted as pitch through the control of the elevator. The longitudinal axis, or roll axis noted OZ, is drawn through the body of the vehicle from tail to nose in the normal direction of flight, or the direction the pilot faces through the movement of the ailerons. To determine the movement of the aircraft, in addition to the incremental position of the elevator, rudder and ailerons, the alpha angle of attack and beta sideslip angle are also quite important.

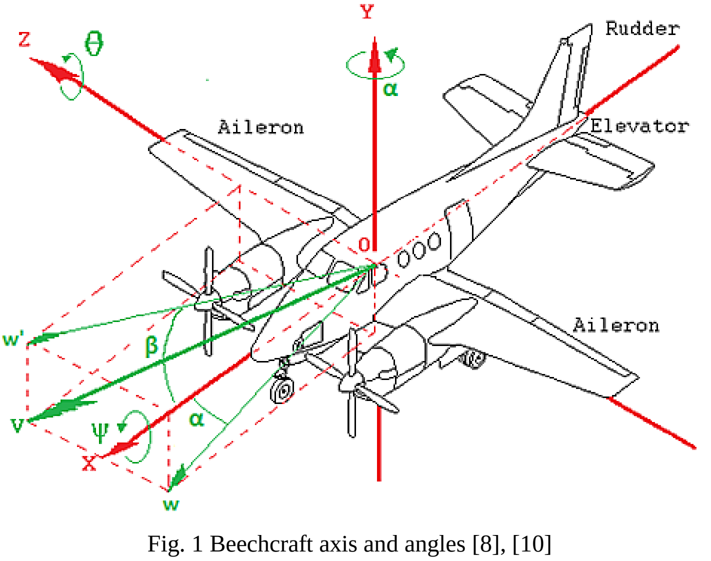

Fig. 1 Beechcraft axis and angles [8], [10]

The system rotations always refer to the orthogonal basis of the right-handed orthogonal base. The convention of the orientation of the angles follows the right-hand rule, which is normal in mathematics, and a positive angle thus shows counter-clockwise.

All further rotation axes are obtained dynamically according to the defined order of the rotations.

If the angle of yaw is defined by α, the pitch angle as θ, and the roll angle as ψ then, the graphical representation on (Fig. 1) shows that:
$\Theta \stackrel{\text{def}}{=} \widehat{V0W}$ becomes the angle between $\overrightarrow{V}$ and $\overrightarrow{W}$ which is the projection of $\overrightarrow{V}$ on the vertical plane noted XOY.

The rotation matrix that corresponds to this definition is as follows[11]:

$$\begin{pmatrix} \cos\alpha\cos\theta & \cos\alpha\sin\theta\sin\psi - \sin\alpha\cos\psi & \cos\alpha\sin\theta\cos\psi + \sin\varphi\sin\psi \\ \sin\alpha\cos\theta & \sin\alpha\sin\theta\sin\psi + \cos\alpha\cos\psi & \sin\alpha\sin\theta\cos\psi - \cos\varphi\sin\psi \\ -\sin\theta & \cos\theta\sin\psi & \cos\theta\cos\psi \end{pmatrix}$$

Besides the rotation matrix, there are also other ways to describe the aircraft orientation, such as quaternions or Euler angles. However the scope of this paper is to describe the technical solution of measuring these angles through flight testing.

3. SENSOR FUNDAMENTALS ON ADDITIONAL FLIGHT PARAMETERS RECORDING

From an engineering standpoint, the basic problem is to extend the data acquisition system described in [9] that is already installed in such manner that it is not only capable of providing sufficient information to gather flight control data of the Be C90, but also capable of providing realistic data in the techniques and problems that are unique to airborne data acquisition.

Both the overall system and individual system components were evaluated with respect to several specific parameters.

While this section discusses the overall system requirements, specifications peculiar to each system component are discussed in the following sections of this paper.

The greatest challenge in the use of airborne sensors is not only the space and mass restrictions but also the technical specifications when it comes to power consumption, airworthiness limitations and also finding a solution that allows for the continuity in the operation of the already installed sensors. The airworthiness of the aircraft and the current configurations have also to be maintained.

Due to the limitations in the aircraft capability, hardware availability, and financial resources, the design of the complete instrumentation system has to be carefully evaluated [7] with respect to the following criteria:

1) Number and complexity of sensors already installed,
2) Type of measurement readout,
3) Software tools,
4) Desired accuracy of the system,
5) Availability of hardware and finances,
6) Aircraft limitations.

In order to achieve an accurate and repeatable digital reading for the position of the aileron, elevator and rudder, a set of sensors should be considered.

A previous investigation of different sensors functionality and especially means of displacement measurement is necessary.

4. STUDY FOR THE MEASUREMENT OF THE CONTROL SURFACE POSITIONS

The control surfaces of the Beechraft C90 are positioned by the pilot or co-pilot through mechanical linkages of cables, pulleys, and bell-cranks, as shown in Figures 2a through 2c. Since direct movement of the linkage system is required for any control deflection, the determination of control surface positions can be accomplished by measuring the displacements of the linkage assemblies, preferably at points near the control surfaces in order to minimize the error due to the cable elongation.

The key step of the project would be to install 3 Position Transducers attached to the control cables. They should be installed on brackets mounted below the floor [5]. The Transducers will be connected to the control cables to determine the position of the control surfaces (Fig. 2a, b, c).

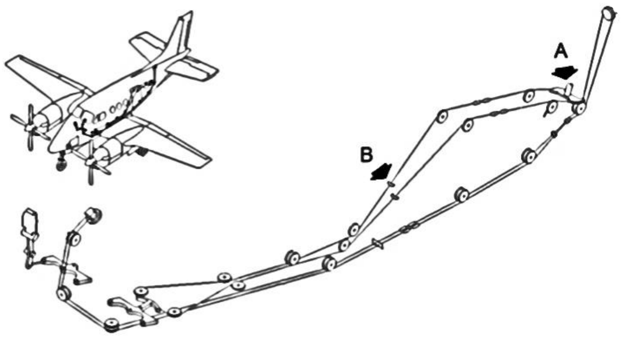

Fig. 2a Beechcraft rudder and rudder tab [2]

In order to measure the displacement, the first option is to use a LVDT (Linear Variable Differential Transformer) because it is a frictionless device, less prone to mechanical problems. LVDTs require electronic connection through either direct integration or a signal conditioner box. This additional electronic integration increases the amount of at-risk components for data collection, causing LVDTs to be environmentally sensitive [4].

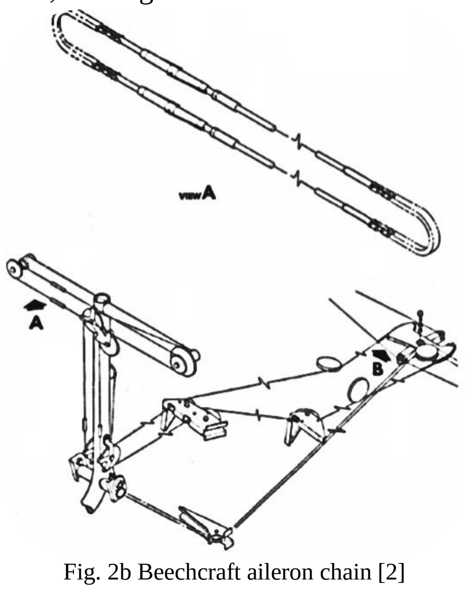

Fig. 2b Beechcraft aileron chain [2]

Considering the conditions, the limited space and weight available, sudden accelerations on an airplane etc., electrical components can be easily affected during flight. LVDT data can thus prove to be unreliable while the plane is in motion.

In addition, the complex electronics involved with LVDTs tend to cause them to be more expensive than the standard position transducers.

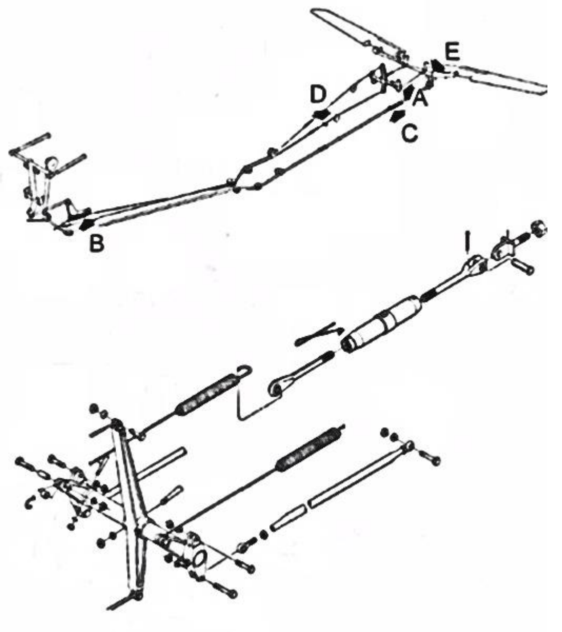

Fig. 2c Beechcraft elevator and elevator tab [2]

However, after vibrations measurements on the Beechcraft during flight, on the floor, close to the location where the sensors are supposed to be measured, it seems that 10G levels can occur (Fig. 3).

The measurements were conducted in 2014 on the mission rack on three different axis (OX, OY, OZ) using a data acquisition board, 3 accelerometers, a vibration calibrator and a dedicated software installed on a laptop.

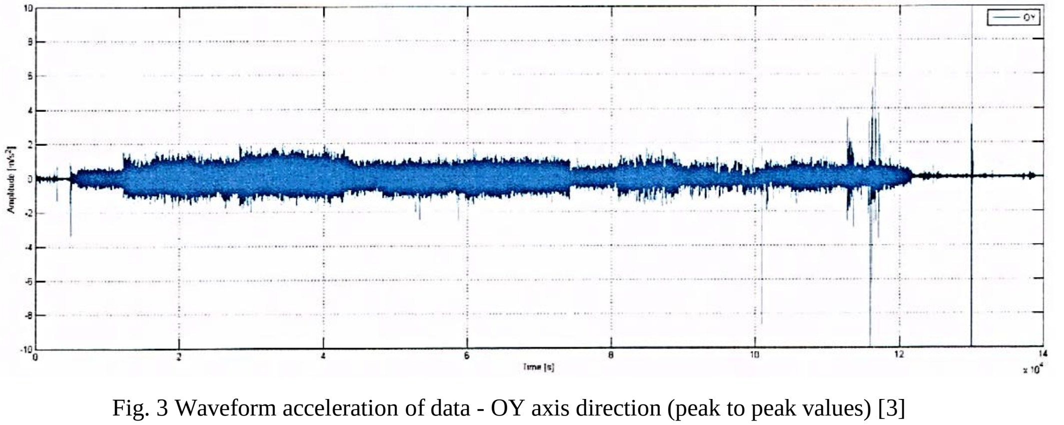

Fig. 3 Waveform acceleration of data - OY axis direction (peak to peak values) [3]

The acceleration (variation in time) in relation to amplitude, speed variation in time and frequency analysis for the given time period, displacement variation and analysis in frequency with time and noise level variation in time were also measured.

In terms of vibration measured, the instrument covered the range between 1 and 10kHz (FFT lines 12801; Resolution 0.25e+00 Hz; window: Hanning) while the noise signals were between 20 and 20kHz.

The results indicated that the highest noise levels due to engine regimes and low speed occurred during the takeoff.

The primary cause is the propeller and components of the two Pratt & Whitney Canada PT6A-135A engines.

LVDT potentiometer withstands less g than string pot type sensors. For that reason, and as the last type mentioned are widely used for aircraft installations to serve as position transducers in Flight Data Recorder Installations, it is better to use LVDT and cable-actuated displacement-sensing devices.

The method has been employed by NASA in the 70's to support flight test programs in their evaluation projects.

Operationally, the products work by mounting in a fixed position and attaching the displacement cable to a moving object such as an aileron or any other aircraft moving component.

As movement occurs, a cable under tension extracts and retracts producing an electrical output, via a potentiometer proportional to the cable travel (Fig. 4).

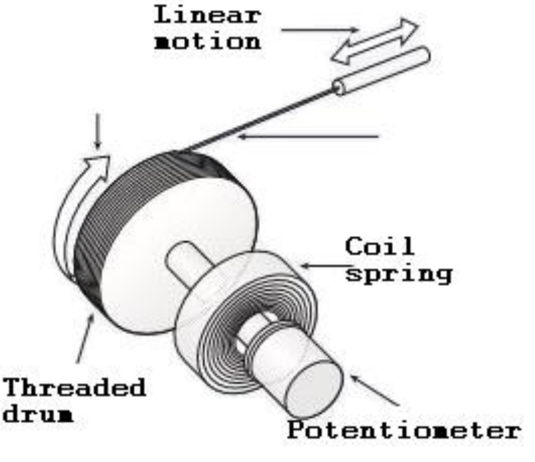

Fig. 4 Cable actuated position transducer

Probably the foremost benefit of using cable-actuated sensors in aerospace applications is the additional safety factor that exists with these devices through the fact that it has no inflexible components that have the potential to bind, bend, or otherwise disrupt the free movement of the aircraft command being monitored.

5. DETERMINATION OF RELEVANT FLIGHT ANGLES

In order to determine the Alpha and Beta angles, installing a Mini Air Data Test Boom (Fig. 5) is the most accessible option.

The Boom will be installed on an adapter plate, mounted on the existing R/H wing pylon instead of the Hawkeye sensor.

The placement of the boom must not affect the flying characteristics of the aircraft to any significant degree.

In theory the boom will generate drag causing a right yawing force, but the effect of the boom is predicted to be negligibly small and easily corrected with trim whether the plane flies with another instrument mounted or not on the left wing.

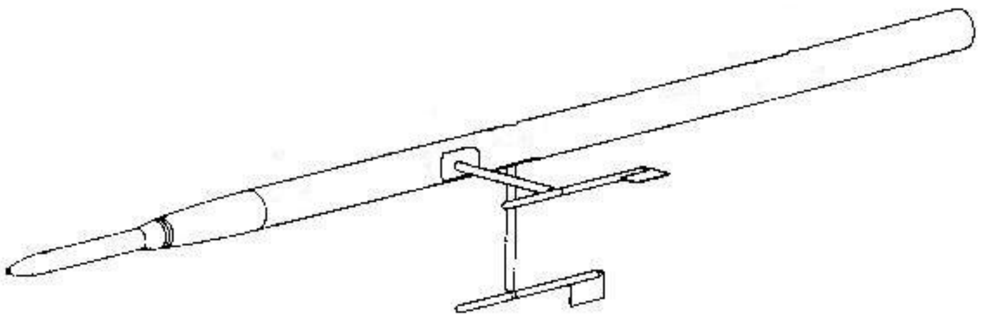

Fig. 5 Air Data Test Boom

Angle of attack instruments measure the angle between the airspeed vector and a predefined line on a cross-section of the airplane wing (Fig. 1).

This line is usually selected either as the zero-lift line or the chord line of the airfoil. The boom is a quite good location for the placement of alpha and beta vanes because its structure minimizes the issue caused by the airflow around the air mass.

These vanes are simple flat plate structures mounted perpendicular to each other that deflect with the relative wind and provide yaw and angle of attack measurements.

6. FLIGHT CONTROL DATA VALIDATION

Due to the lack of time available to conduct an in-flight evaluation of the extension of the data acquisition system, besides the vibrations measurements and calculations that have already been made, the sensors described in this report should be considered as components of a proposed improvement, rather than a fully operational system.

The first step in the development of the future system must be the flight testing of all the currently installed instrumentation throughout the aircraft flight envelope. Thought must be given to refinement and expansion of the system.

After knowing the capabilities of the system, controllability may be studied as the capability of the airplane to perform, any maneuver that the pilot wants to carry out during the total fulfillment of the mission. The characteristics of the airplane should be such that these maneuvers can be performed precisely and easily with a minimum of effort from the pilot. The pilot's opinion of controllability is shaped by several factors.

The most apparent of these factors are the initial response of the airplane to a control input and the total attitude change which results.

In addition, the cockpit control forces and deflections required to accomplish the necessary pilot tasks are extremely important. These factors depend on the static and dynamic stability of the airplane and the characteristics of the flight control system.

The complexity or the degree of difficulty which the pilot encounters during the maneuvering tasks is directly dependent on the stability characteristics of the airplane to be determined in the flight evaluation sequence.

7. CONCLUSIONS

Acquisition of flight control data is necessary to provide an optimum performance in different mission flight configurations and efficiency in takeoff, approach, and landing modes. Flight controls transducers mounting is the first step in the design of an actuators system which is the key in developing the in-flight simulation missions.

Detailed information concerning the operation and the capabilities of the Beechcraft is available in several sources listed in the bibliography.

The extension of data acquisition system has quite a lot of advantages such as:

- Data validation in developing a flight simulator,
- Possibility to simulate different aircrafts while acquiring data on a single one,
- Cost efficiency,
- Opportunity to analyze the pilot's input and response,
- Gust load alleviation for Lidar missions to calculate the reduction of the metal fatigue.

Certain aspects of data acquisition system installed on a flying laboratory are examined and considered.

The key step in a future development of the system must be the thorough flight testing of all the currently installed instrumentation throughout the aircraft flight envelope.

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APPENDIX A. ACRONYMS

α – Angle of attack: the angle measured in the XZ plane between the X axis and the relative air flow; also designated as AOA, alpha, or α; angle of attack is not the same concept as "pitch" which indicates the rotation of the aircraft relative to three imaginary lines running through an airplane and intersecting at right angles at the airplane's center of gravity.

β – Angle of sideslip: the angle measured in the XY plane between the Y axis and the relative air flow; also designated as AOS, beta, or β; angle of sideslip is not the same concept as "yaw" which indicates the rotation of the aircraft relative to three imaginary lines running through an airplane and intersecting at right angles at the airplane center of gravity.

A 429 – ARINC 429 Data Bus.

ARINC – Aeronautical Radio Inc.

CT – Continuous Turbulence.
DDC – Data Device Corporation.
DG – Discrete Gust.
LVDT – Linear Variable Differential Transformer.

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