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Data Inversion of Pressure Transducers of Air Data System for Evaluation of Fly-By-Wire Flight Control System on Hardware-In-Loop Simulator

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Abstract - Pressure measurements from the pitot probes as part of the Air Data System are used for feedback / automation to the safety critical Fly-By-Wire Flight Control System as well as for navigation to the pilot. The measurements include Total and Static pressures, derived parameters like Mach No., Pressure altitude, Calibrated Air Speed. Additionally, flow angles i.e., Angle of Attack (AOA) and Angle of Side Slip (AOSS / SSA) are computed by using differential pressure measurements. The measured pressure along with accounting for the compensation for surrounding temperature is converted to frequency by the transducer (P & T to F). Subsequently, through on-board software, this digital frequency is used for computation of the digital pressures by using inverse relation of pressure to frequency which is obtained from the characteristics of the transducers. This raw digital pressure is then corrected for the sensor-position error on the aircraft to have free stream signals. Thus, the accuracy of the complete system depends on the accuracy of each and every element used in the chain, and the process adopted for measurement. The on-ground test rig elements, models thereof and relevant processes adopted play a crucial role in clearance of the fly-by-wire flight control system. This article deals with procedure evolved for transducer data inversion and used for evaluation and clearance of the Air Data System and Fly-By-Wire Flight Control System.

Keywords: **Air Data System (ADS), Air Data Computer (ADC), Coefficients, Transducer, Pass/Fail, Hardware-In-Loop-Simulator (HILS), Real Time Flight Dynamic Simulator (RTFDS), Iron Bird, Diode voltage, Inversion Process, Frequency, Pressure, OEM.**

1. INTRODUCTION

Air Data System (ADS) is an integral part of the Fly-By-Wire (FBW) Flight Control System (FCS). It involves measurements of the following parameters relative to the air:

1) Pressures measurements, specifically:
   - 1.1) Total pressure (Pt), and
   - 1.2) Static pressure (Ps),

     Derived parameters like Mach No. (Mach), Pressure altitude (Zp), Calibrated Air Speed (CAS) are computed from these pressures.
2) Flow Angles (Aircraft angles relative to the wind axis) which include measurements of:
   - 2.1) Angle of Attack (AoA), and
   - 2.2) Angle of side Slip (AoSS).
3) Temperature (Tt or TAT)

All the pressure measurements are done using the pitot pressure probes. Each of the pneumatic pressure measurement along with the surrounding temperature is converted to frequency (P & T to F) by using the

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transducer. The Resonance Pressure Transducer (RPT) or Trenched Etched Resonance Pressure (TERP) transducers by Baker Huges [3] use in-built diode in the circuit for measurement of surrounding temperature. The diode voltage of the transducer is function of the temperature as per the Original Equipment Manufacturer (OEM) data sheet [3]. Subsequently, through on-board software, this digital frequency is used for computation of the digital pressures by using inverse relation of pressure to frequency which is obtained from the characteristics of the transducers. This raw digital pressure is then corrected for the sensor-position error on the aircraft to have free stream signals. The on-ground test rig elements, models thereof and relevant processes adopted play a crucial role in clearance of the fly-by-wire flight control system. This article deals with procedure evolved for transducer data inversion and used for evaluation and clearance of the Air Data System and Fly-By-Wire Flight Control System.

The article is organised as follows: Section 2 presents generic architectural details and elements of ADS. Section 3 presents the details on the evaluation and clearance process of the ADS at on-ground test rig which is also referred to Hardware-In-Loop Simulator (HILS) or Iron Bird (IB). Section 4 presents various methods evolved to arrive at transducer model or the process of data inversion. Section 5 presents the relevant results, and Section 6 concludes the article.

2. ARCHITECTURE AND ELEMENTS OF ADS

A schematic block diagram of the Fly-By-Wire Flight Control System involving ADS and Control Laws (CLAW) is shown in Figure 1. The free stream air data signals are used for gain scheduling as well as for feedback to the Fly-By-Wire (FBW) control laws (CLAW). Further, the flight condition parameters such as Mach No., Altitude and Calibrated Air Speed (CAS) etc. derived from the basic air data signals (Pt and Ps) are used for navigation purpose. Therefore, precise, accurate, reliable and redundant measurements from the ADS are very important during all manoeuvres and over entire flying mission of the fighter aircraft. ADS measurements on the aircraft broadly involve the followings steps in the order to have the final free stream or corrected signals:

1) ***Measurement of raw or local pneumatic pressure on the aircraft and converting it to raw digital form inside the on-board ADC***. It involves the following elements and processes:
    - 1.1) The following ***elements*** are involved in measurement of the local or raw pneumatic pressure and converting it to raw digital pressure values:
        - 1.1.1) pitot pressure probe,
        - 1.1.2) transducer (measurement of pneumatic pressure to frequency along with compensation for temperature), Transducers with different range of pressure measurements are used for redundancy.
        - 1.1.3) electronic signal conditioner etc.
    - 1.2) The following ***computational processes*** are involved to have raw digital pressure measurement:
        - 1.2.1) Use of transducer-inverse characteristics (frequency and temperature to pressure) computations to have raw digital pressure.
2) ***Processing of the raw digital pressure for Position Error Corrections (PEC) to have free stream signals by using the inverted aerodynamic estimation / wind tunnel test data***. This process is carried out as part of the on-board software involving relevant computational algorithms.

Thus, the accuracy of the complete system depends on the accuracy of each and every element, and the process adopted for measurement and corrections. The system can have the total minimum inaccuracy based on the acceptable inaccuracies of the both the elements, i.e., a chain of physical hardware and software. In the above listings, Sl. No. 1.1 is treated as part of the hardware elements (mechanical and electronics), while Sl. Nos. 1.2 and 2 are treated as part of the on-board software. Process of Sl. No. 1.2.1 which is implemented in the software, does the functionality exactly opposite (or complementary) to the characteristics of the transducer (a physical hardware).

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2.1 Position Error Corrections (PEC) to Pressure Measurements

The ADS sensors usually measure the local quantities where they are mounted on the aircraft. These measurements are affected due to the local flow of the air along the body of the aircraft. Hence, local air data measurements need to be corrected by a suitable mechanism to obtain the free stream or corrected measurements.

2.1.1 Challenges for applying on-board PEC corrections to Pressure Measurements

The data generated at on-ground which is also referred to 'inverse ADS data / tables' (or 'inverse tables' in short) provide the estimates of the local / raw measurements expected to be obtained from the sensor at the given location on the aircraft for the given free stream condition. In short, inverse ADS data provide free stream inputs to local measurement outputs (or simply free stream to local measurement). The inverse ADS data is generated either of the following or blend thereof:

1) Computational Fluid Dynamics (CFD) estimates,
2) Wind Tunnel Experiments

However, on-board aircraft, we require corrections for local to free stream measurements, i.e., exactly opposite of the inverse ADS data. This is because sensor measures raw or local measurement at the location where it is mounted on the aircraft. Therefore, need for inverting the inverse ADS data arises to the have forward ADS tables (or 'forward tables' in short) which are inverted 'inverse table'. These forward tables are used for local to free stream measurement corrections (PEC) in the on-board computer.

The table inversion process is a very challenging and complex task due to the following characteristics of the inverse ADS tables / data:

1) It is a function of multiple parameters (multi-input). Same data used is for computing multiple outputs for some of the measurements. Thus, the data is a kind of multi-input multi-output system,
2) Highly nonlinear characteristics of the data,
3) Multi-valued characteristics for a few of them result in indeterminacy for inversion.

A systematic and well laid down procedures have been evolved to tackle these problems [1-2]. Figure 2 shows the schematic of the validation process for table inversion. The detailed process of aerodynamic or PEC data inversion is beyond the scope of the present article.

2.2 Transducer Characteristics

The selected transducer is an integral element in deciding the kind of minimum inaccuracy level system shall have forever. The RPT or TERP transducer converts the applied pneumatic pressure (P) to Frequency (F) along with Temperature (T) compensation done by using the Voltage (V) measured by the diode. The RPT or TERP Transducer characteristics [3] are described by the Equation (1) which in fact is an inverse relation between the pressure and frequency along with diode voltage (for temperature compensation).

$$P = \sum_{i=o}^{M}\sum_{j=0}^{N} C_{i,j} \times (f - f_o)^i \times (v - v_o)^j$$

For simplicity , let

$$\Delta f = (f - f_o) \text{ and } \Delta v = (v - v_o), \text{ then} \qquad \text{Eq (1)}$$

$$P = \sum_{i=o}^{M}\sum_{j=0}^{N} C_{i,j} \times \Delta f^{\,i} \times \Delta v^{\,j}$$

The symbols / nomenclatures used in Equation (1) designate the followings:

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$P = \text{Applied or Computed Pressure}$

$C_{i,j} = \text{Calibration Coefficient}$

$f = \text{Measured Frequency in Hz}$

$f_o = \text{Normalizing Frequency in Hz}$

$v = \text{Measured Diode Voltage in mv (indicates the Measured Temperature in Deg. C)}$

$v_o = \text{Normalizing Diode Voltage in mv (Normalizing Measured Temperature in Deg. C)}$

$M = \text{Integer showing the maximum oder of function fitment on frequency}$

$N = \text{Integer showing the maximum oder of function fitment on diode voltage}$

$i = \text{index for counting order for frequency from 0 to M}$

$j = \text{index for counting order for diode voltage from 0 to N}$

Thus, the above function has got $(M+1)\times(N+1)$ number of calibration coefficients.

Figure 3 shows the typical experimental data format in 3-Dimensional (3D) matrix of the transducer characteristics, i.e., frequency values (output of the transducer) for the selected grid values of pressure and temperature (inputs to the transducer). Typical characteristics of RPT and TERP transducers are shown in Figure 4. TERP transducers are more sensitive to temperature variations as compared to RPT transducers.

3. EVALUATION OF FBW FCS INCLUDING ADS ON HARDWARE-IN-LOOP SIMULATOR

Figure 5 shows the block schematic of the Iron Bird or Hardware-In-Loop Simulator (HILS) setup, elements and process thereof used for evaluation of Fly-By-Wire Flight Control System including ADS. The on-board devices to be evaluated include the followings:

1) Digital Flight Control Computer (DFCC) wherein Flight Control Laws (CLAW) are residing, and
2) Air Data Computers (ADC) wherein Air Data System computational algorithms are residing.

As part of the ground test rig, a Real Time Flight Dynamic Simulator (RTFDS), Engineers Test Stations (ETS), and AIRDATSs are shown along with the cockpit as part of the avionics system.

Aircraft motions are simulated through a six Degrees Of Freedom (6-DOF) simulation for this fixed base test rig. The 6-DOF model / software thereof is residing inside the RTFDS. The RTFDS also includes sensor models including ‘inverse ADS model’. The ‘inverse ADS model’ computes the local measurements for the given free stream condition based on the inverse ADS tables / data.

ETS and AIRDATS are elements of test rig and they are used for:

1) Accessing the data for complete system evaluation and analysis, and
2) making the signals compatible for interface within the on-board and off-board (test rig) elements.

The local measurements from the inverse ADS model residing inside the RTFDS are passed through AIRDATS to the on-board ADCs. ADCs have been provisioned with the followings for operational use and on-ground testing, respectively:

1) **Real / Actual Pressurization Path:** Actual / real pressure can be given to the pneumatic port available. This real pressure is sensed by the transducers (RPT / TERP) and then it is converted to Frequency. As a default option, this path is used on the aircraft for actual operation. However, it would be challenging to meet the required bandwidth by the real pressurization unit during closed loop evaluation at on-ground test rig.
2) **Synthetic Path for injecting equivalent Frequency:** ADCs have provision for injecting the frequency signal which is computed for the corresponding pneumatic pressure based on the transducer characteristics. This frequency signal is injected through a synthetic path (instead of pneumatic pressure path) for on-ground evaluation instead of real pressurization unit in order to overcome the challenge of meeting the bandwidth requirement.

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Figure 6 shows the detailed the processes or models residing inside the RTFDS and ADCs for P to F and F to P conversions, respectively. Both these units broadly work in complementary mode during on-ground evaluation. The injected signals get processed in the following order:

1) **Inside the on-ground RTFDS:**
   1.1) **Process A:** The digital values of free stream signals (Mach No., AOA, AOSS) given to the inverse model inside the RTFDS computes local pressures (equivalent to pneumatic pressures that would be actually measured by the sensor mounted on the aircraft at their location),
   1.2) **Process B:** Local pressures are passed through the forward model of transducer (it designates the transducer characteristics) to compute the corresponding frequency (P to F computations). It may be noted that in Figure 6, it is shown as transducer data inversion process in respect of Equation (1), however it is representing the model of the transducer or characteristics thereof (forward model of transducer) for P to F conversion.
2) **Inside on-board ADC:**
   2.1) **Process B^{-1}:** The frequency is converted to digital raw pressure along with diode voltage (temperature compensation) by using inverse model of transducer as per Equation (1), i.e., F to P conversion,
   2.2) **Process A^{-1}:** The raw digital pressure is corrected for PEC to have free stream digital values of Mach No., AOA, and AOSS.

The free stream signals pass through A, B, B^{-1}, and A^{-1} process in series. Mathematically it indicates the passing of the signals through the product of $A*B*B^{-1}*A^{-1}$, which results in becoming Identity, i.e., $I = A*B*B^{-1}*A^{-1}$. Thus, the free stream outputs obtained in ADCs are expected to be same as the free stream inputs from the RTFDS. Figure 6 shows the details of validation of inversion procedures for transducer model (P to F and F to P computations) as well as for inverse and forward ADS model. A brief on the inverse and forward ADS model is presented in earlier section. The next section details regarding the transducer forward model computations in optimized way.

4 TRANSDUCER FORWARD MODEL FOR P TO F COMPUTATIONS

The forward model of the transducer for P to F computations can be obtained by suitably inverting the Equation (1) for implementation in RTFDS. It may be noted that Equation (1) computes pressure for the given frequency and diode voltage (for the corresponding temperature as per diode sensitivity given in OEM data sheet). It is exactly opposite of what actually transducer does. Therefore, with reference to Equation (1), the 'transducer forward model' of P to F computation is also referred to 'transducer data inversion model' as it is obtained by inverting F to P data relation. The digital pressure computed from the inverse ADS model within the RTFDS is fed to the 'transducer forward model'. However, transducer data inversion model (inversion of Equation (1)) also requires actual ambient temperature in the vicinity of the transducers (measured by the diode voltage), in order to have computed frequency (F) output. Thus, the requirement for acquiring the diode voltage from the transducer in ADC to the RTFDS arises. Since, on-board F to P conversion happens within the ADC by using the diode voltage being available there only, and thus it is not necessary to acquire and record it. However, the need for acquiring such an intermediate signal (diode voltage / temperature) for on-ground evaluation makes it as an additional requirement for the on-board device. Further, it requires to interface the diode voltage signal from ADC to RTFDS. It was not thought of initially, due to the unavailability of the details of the transducers / relevant systems. Therefore, there was need to find out an alternate solution to compensate for unavailability of the diode voltage (temperature) and move ahead for on-ground evaluation [7]. Table 1 presents the details of the methods (M1 to M6) that have been evolved for arriving at transducer forward model for P to F computations (or transducer data inversion model) to be implemented inside RTFDS for evaluation of ADS at on-ground test rig. Table 1 presents the advantages and disadvantages, and detailed comparative analysis as well. Methods M1 and M2 with 1D polynomial approximations have been used for evaluation of ADS. However, M5 methods is most accurate due to the direct use of transducer characteristics data.

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5. RESULTS

The results of in series evaluation of transducer forward model (data inversion model) corresponding to method M1 and on-board model of Equation (1) are shown in Figures 7 and 8. Similarly, the results of method M5 are shown in Figure 9.

The Nominal Diode Sensitivity (NDS) is computed as given below:
NDSc = (Vmin-Vmax)/(Tmax-Tmin);
Where
Vmin and Vmax are the Minimum and Maximum voltage range of diode,
Tmin, and Tmax are the Minimum and Maximum Temperature range used for Diode voltage measurement

The following differently named diode sensitivities and their values for each transducer are made available in the OEM supplied data sheet.

1) NDS: Nominal Diode Sensitivity given in the OEM data sheet,
2) NDSmin: Limits of the NDS given in OEM data sheet
3) NDSmax: Limits of the NDS given in OEM data sheet
4) NDSc: Nominal Diode Sensitivity computed using the Minimum and Maximum voltage range of Diode (Vmin, Vmax) and range of temperature (Tmin, and Tmax),
5) NDS_DVM = NDS computed using the diode voltage from ADC. First the mean of the Diode voltage for each temperature data is computed and then considered that value for computing NDS_DVM by considering the corresponding known temperature grid point.

Figures 7 and 8 show the results of the TERP and RPT transducers pressure validation. Here the input pressure (Pin) is passed through a polynomial with an estimated coefficients for a fixed Temperature value to have frequency output. The computed frequency is passed through the onboard transducer model with respective coefficients to have digital pressures (Output Pressure: Po). Figures 7 (a) to (d) and Figures 8 (a) to (d) show the Output pressure vs Input Pressures, while Figures 7 (e) to (h) and Figures 8 (e) to (h) show the corresponding pressure error (Po-Pin) in mbar. The error is well within the bound of +/- 2mbar. At very high values of pressures, the error exceeds 2 mbar. However, such pressures found to be occurring at outside the flight envelope and hence it was acceptable.

Figure 9 shows the data plots of the end-to-end error between input pressure and output pressure computed using the diode voltage, different NDS, and using the method M5 of Table 1 (transducer forward model for implementation in RTFDS). The overall error is well within the ±2mbar, precise, and consistent.

6. CONCLUSIONS

Procedure evolved for transducer data inversion and used for evaluation and clearance of the Air Data System and Fly-By-Wire Flight Control System is presented in this article. Methods M1 and M2 have been used for clearance of FBW FCS. These methods require offline computation of coefficients and configuration, and work for a fixed mean value of temperature with permitted scatter. These procedures helped in clearance of the on-board ADS system at on-ground test platforms, and ultimately resulted in successful flight tests.

Method M5 found to be most precise and does not require any additional offline data generation and configuration thereof. However, it requires acquisition of diode voltage from the on-board device.

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Table 1: Evolved methods for arriving at transducer forward model of P to F computations (or transducer data inversion model) to be implemented inside RTFDS for evaluation of ADS at on-ground test rig.

Sl. No. for the evolved method	Diode Voltage (DV) measurement acquisition (for temperature measurement) provision on ADC and interface to RTFDS or an alternate		Evolved transducer model / method thereof for use inside the RTFDS	Advantages and Disadvantages, and Discussions
	ADC (on-board device)	RTFDS (on-ground test rig device)		
M1	DV not acquired but used internally on-board for raw digital pressure computations	Assumed to be a well-maintained laboratory standard mean temperature of 25 Deg. C and allowed variation of 10 to 15 deg C.	A one-Dimensional (1-D) polynomial fit for a fixed mean value of diode voltage corresponding to the laboratory standard mean temperature [4]. The polynomial output (Frequency) is function of input digital pressure (P) only which is obtained from inverse ADS model, i.e., it is independent of the temperature variation. 1) Compute the diode voltage as per the transducer data sheet (based on the diode sensitivity in mV/Deg. C.) for the mean temperature. The diode sensitivity is -ve. 2) The polynomial coefficients for each transducer are computed a priori offline by using the evolved process, configured, and stored in the RTFDS for forever use in future. 3) Based on the specific transducer used (part number thereof) inside the ADC, the corresponding polynomial coefficients inside the RTFDS are used during the evaluation.	• Method works well for transducers like RPT which are less sensitive to temperature variations. • The acceptance limit for end-to-end error between input pressure to the 1-D polynomial model of transducer inside the RTFDS and output digital raw pressure from the ADC was set to ±2mbar (designated as **Pressure Threshold 1** in Figure 6). Accordingly, the order of the 1-D polynomial order was arrived at which was almost half the size of $(M+1)\times(N+1)$ coefficients that are used for F to P computations as given in Equation (1). The acceptance limit for end-to-end pressure variation was arrived at considering the followings: 1) Temperature variation between 15 Deg. C. to 40 Deg. C (for 10 to 15 Deg. C variation at 25 Deg. C. mean temperature). The 10 to 15 Deg. C. temperature variation was considered based on the following facts: 1.1) Laboratory mean temperature may have variation on ambient conditions of the day (morning / afternoon / evening /

Sl. No. for the evolved	Diode Voltage (DV) measurement acquisition (for temperature measurement) provision on ADC and interface to RTFDS or an alternate		Evolved transducer model / method thereof for use inside the RTFDS	Advantages and Disadvantages, and Discussions
				night etc.), and 1.2) During the evaluation process lasting for a few hours, the ambient temperature surrounding the ADC or transducers may vary with respect to the starting condition due to local heat dissipation. 2) Scatter in characteristics of a set of RPT transducers • However, this method imposes certain limitations for evaluation of TERP transducers as they are highly sensitive to temperature variations.
M2		Same as that of against SL. No. M1	The 1-D polynomial fit process as mentioned against Sl. No. M1 to be used which is independent of DV or temperature. ***However, laboratory standard temperature although maintained within certain limits needs to be measured prior to the start of evaluation*** [5-6]. 1) Compute the diode voltage as per the transducer data sheet (based on the diode sensitivity) for the **mean temperature measured at the start**, 2) Compute the polynomial coefficients for specific transducer used inside the ADC by using the evolved process, configured and then stored inside the RTFDS. **Thus, the polynomial coefficients need to be computed every time, if temperature is slightly different**. 3) Based on the specific transducer used (part number thereof) inside the ADC, the corresponding polynomial coefficients inside the RTFDS are used	• This method is expected to be suitable for both RPT and TERP transducers • The acceptance limit for end-to-end error between input pressure to the transducer model inside the RTFDS and output digital raw pressure from the ADC was set to **±4mbar in order to cater for sensitivity of TERP transducers** to temperature variations. • However, it becomes laborious due to every time measuring temperature, compute and upload polynomial coefficients. It consumes a lot of time for making readiness of the test rig including the efforts for certification.

Sl. No. for the evolved	Diode Voltage (DV) measurement acquisition (for temperature measurement) provision on ADC and interface to RTFDS or an alternate		Evolved transducer model / method thereof for use inside the RTFDS	Advantages and Disadvantages, and Discussions
			during the evaluation.	
M3		Same as that of against SL. No. M2	Same as that of against SL. No. M2 ***except computing the polynomial coefficients dynamically (instead of computing offline and then storing) and storing inside the RTFDS by setting the measured temperature by the user.***	• Same as that of against SL. No. M2. • Advantage of this method is that it reduces the efforts of offline computations of polynomial coefficients and then storing them inside the RTFDS • However, to get those benefits, the dynamic process / model of computations of polynomial coefficients implemented inside the RTFDS (in lieu of earlier offline process) needs to much more robust. Specifically, the process should produce reliable values of coefficients in all aspects for closed loop evaluation.
M4	DV Acquired for recording and sending to other devices	It uses the DV obtained from the ADC for compensation and does not necessitate to assume the specific temperature range for computations. However, it is worth to maintain the laboratory standard mean temperature from the perspectives of overall on-ground evaluation of the flight control system.	A Two-Dimensional (2-D) polynomial fit by inverting the Equation (1) can be implemented. Diode voltage obtained from the ADC and digital pressure obtained from the inverse ADS model within RTFDS can be used to have the corresponding frequency output for sending back to ADCs. 1) The 2-D polynomial coefficients for each transducer are computed a priori offline by using the evolved process, configured, and stored in the RTFDS for forever use in future. 2) Based on the specific transducer used (part number thereof) inside the ADC, the corresponding polynomial coefficients inside the RTFDS are used during the evaluation.	• Obtaining 2-D polynomial fit is too complex for the given characteristics of the transducer, • The number of coefficients for this polynomial would be almost be same as the size of $(M+1)\times(N+1)$ coefficients used in Equation (1). • The recursive solution of 2-D polynomial would result in degradation of efficacy of overall evaluation in real time. • Therefore, this method was not considered.
M5		Same as that against Sl. No. M3	OEM data sheet provides the sample experimental data, showing the characteristics of each transducer which are governed by Equation (1), coefficients thereof, diode	• Advantage of this method is that is does neither require to compute any new coefficients nor to be separately configured.

Sl. No. for the evolved	Diode Voltage (DV) measurement acquisition (for temperature measurement) provision on ADC and interface to RTFDS or an alternate		Evolved transducer model / method thereof for use inside the RTFDS	Advantages and Disadvantages, and Discussions
			sensitivity etc. Thus, in lieu of inverting Equation (1) to have 2-D polynomial and relevant coefficients, a simple way could be to incorporate the 3-D lookup table data of each transducer as per the format shown in Figure 3. Diode voltage obtained from the ADC and digital pressure obtained from the inverse ADS model within RTFDS can be used. 1) Transducer specific data obtained either by in house characterization or as it is supplied by OEM can be configured, stored, and used in RTFDS for computation of Frequency during evaluation. A simple interpolation for table lookup process can be used.	• OEM data is enough to configure for each transducer. Thus, it eliminates the process of prone to introduce manual errors in generating the coefficients and entry thereof. • Due to the direct use of OEM supplied actual data of transducer, corresponding DV from ADCs and digital pressure from inverse ADS model, this method / model provides the most accurate and precise results. It is due to the fact that there is no approximation done like it is done in case of polynomial fit. Thus, the acceptance bound (tolerable pressure variation) for end-to-end process could be further reduced at least to half of the values used in other methods.
M6	DV not acquired but used internally on-board for raw digital pressure computations	Assumed to be a well-maintained laboratory standard mean temperature of 25 Deg. C and allowed variation of 10 to 15 Deg C.	Same as that of against Sl. No. M5, i.e., use of 3-D lookup table data of each transducer as per the format shown in Figure 3. However, a fixed mean value of diode voltage corresponding to the laboratory standard mean temperature is used along with the digital pressure obtained from the inverse ADS model.	• This method is useful in case either DV is not provisioned (neither from ADC nor from RTFDS) or in case of DV acquisition failure in RTFDS (despite having provisions in both ADC and RTFDS), till the time rectification is done in the test rig. • Accuracy of this method (end-to-end pressure variation) could be slightly less than the methods / model used against Sl. No. M5 due to use of approximated temperature or DV. However, accuracy would be better than the rest of methods from Sl. No. M1 to M4 due to the approximation in polynomial fit as well as approximation in DV for mean temperature.

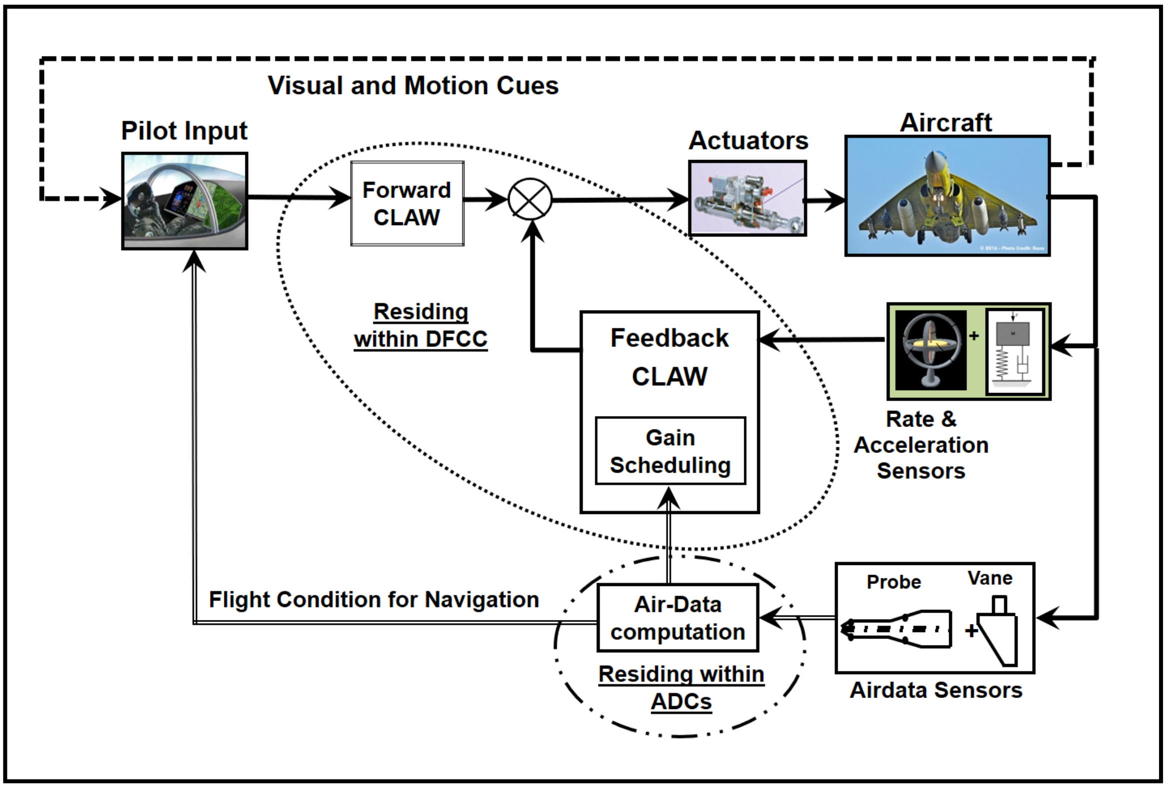

Figure 1: Flight Control System Structure

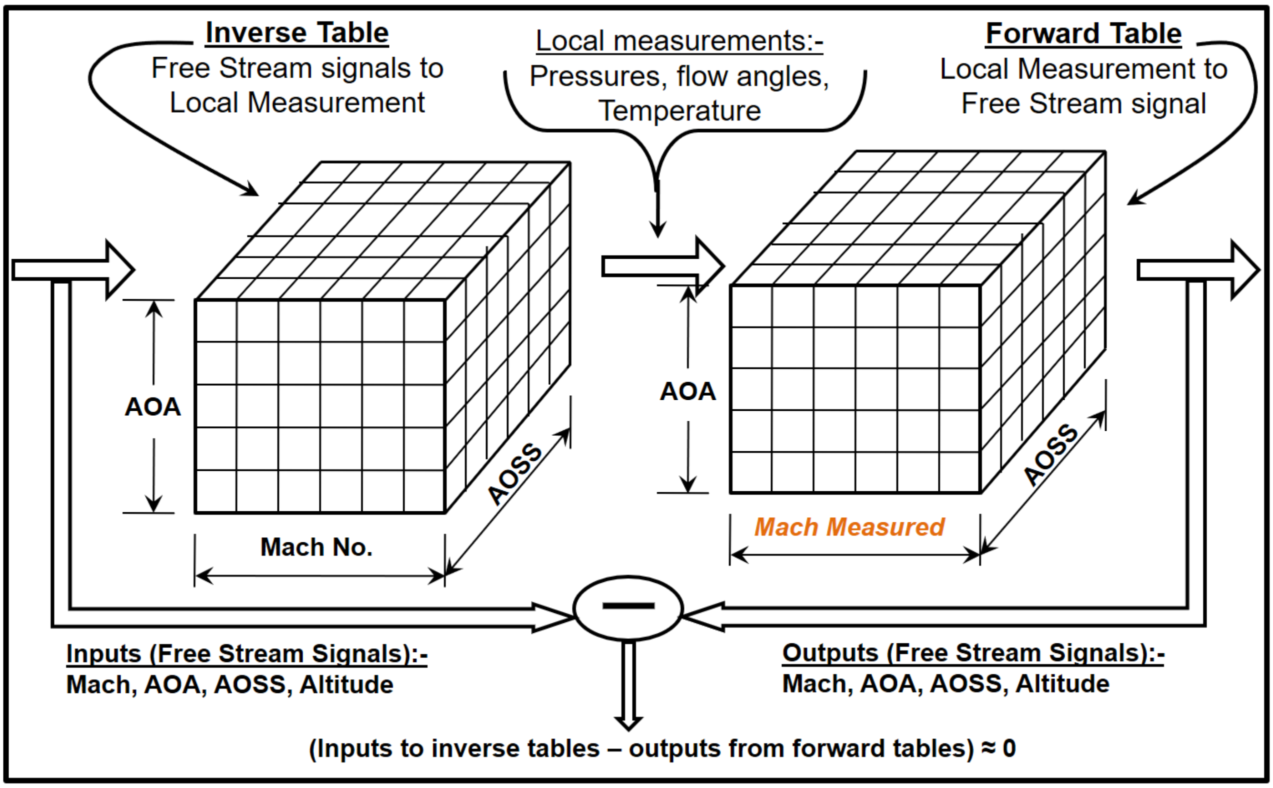

Figure 2: Validation Process for Inverted Data of ADS Sensors

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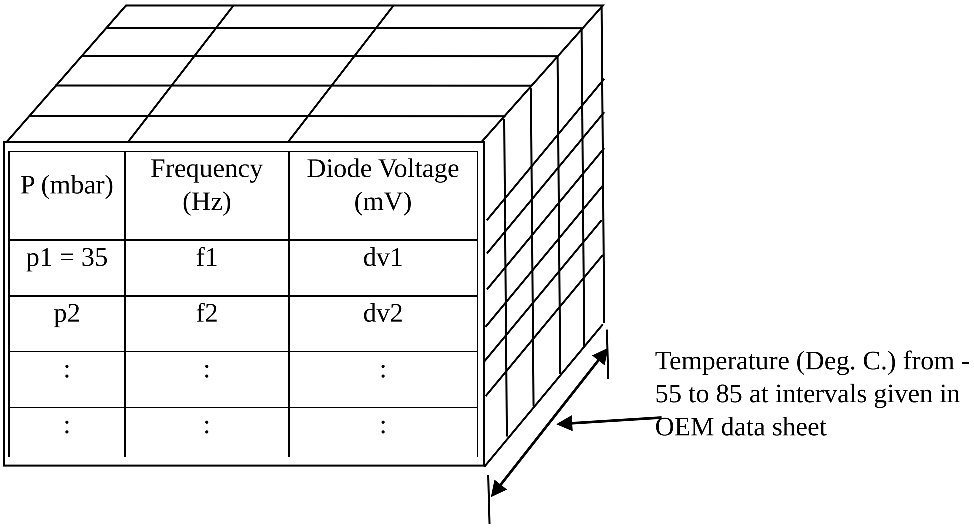

Figure 3: 3D Matrix of Transducer characterization data of transducer given by OEM

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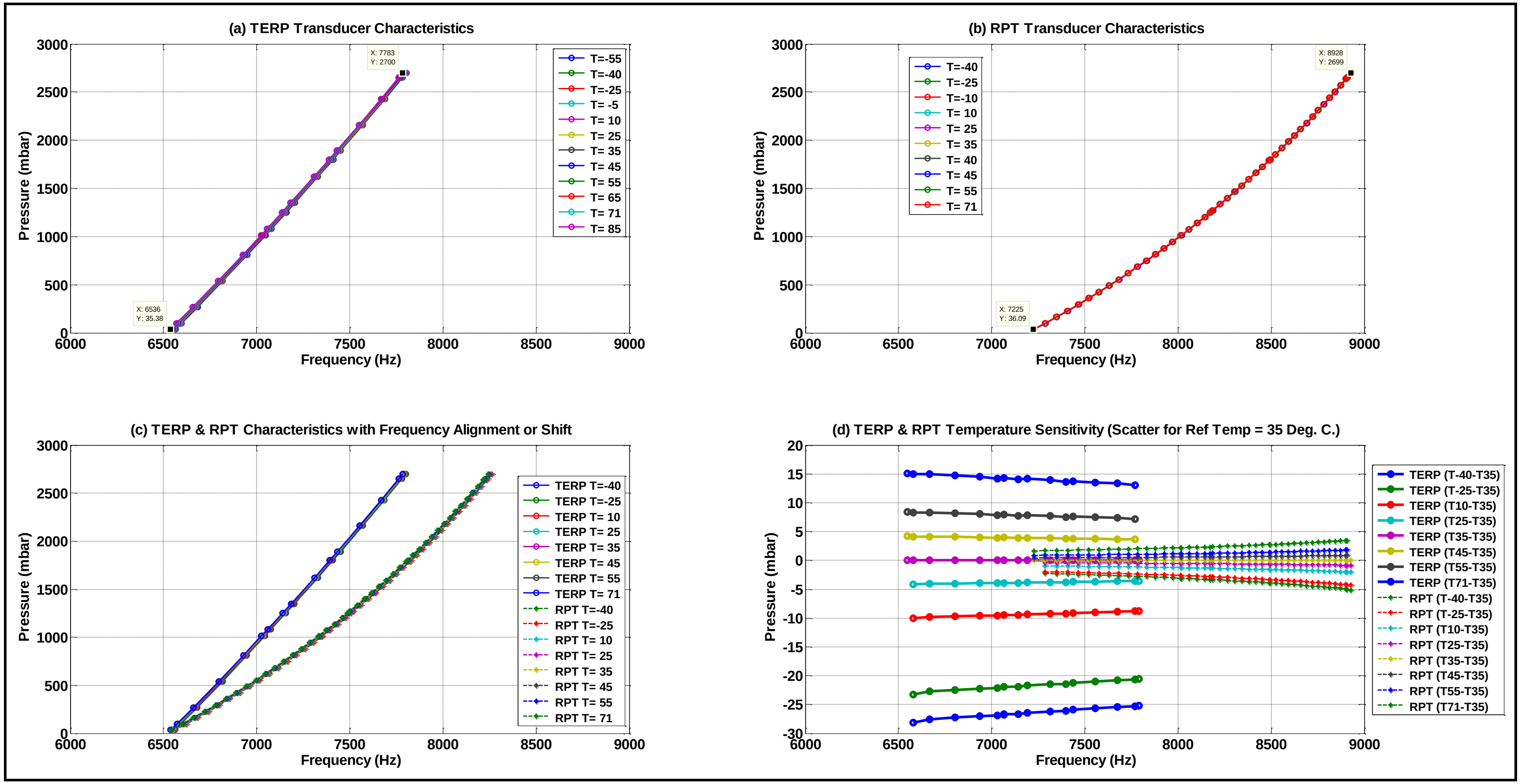

- TERPS Transducers are more sensitive to temperature variation as compared to RPT Transducers.
- The overall scatter in error for 35 to 2700 mbar range transducers (RPT and TERP) for a reference temperature of at 35 Deg. C. is:
  - +/-5 mbar for RPT Transducer over a span of about 9 mbar, and
  - -27 mbar to +15 mbar for TERPS Transducers over a span of about 45 mbar span.

Figure 4: Characteristics plots of RTP and TERP transducers

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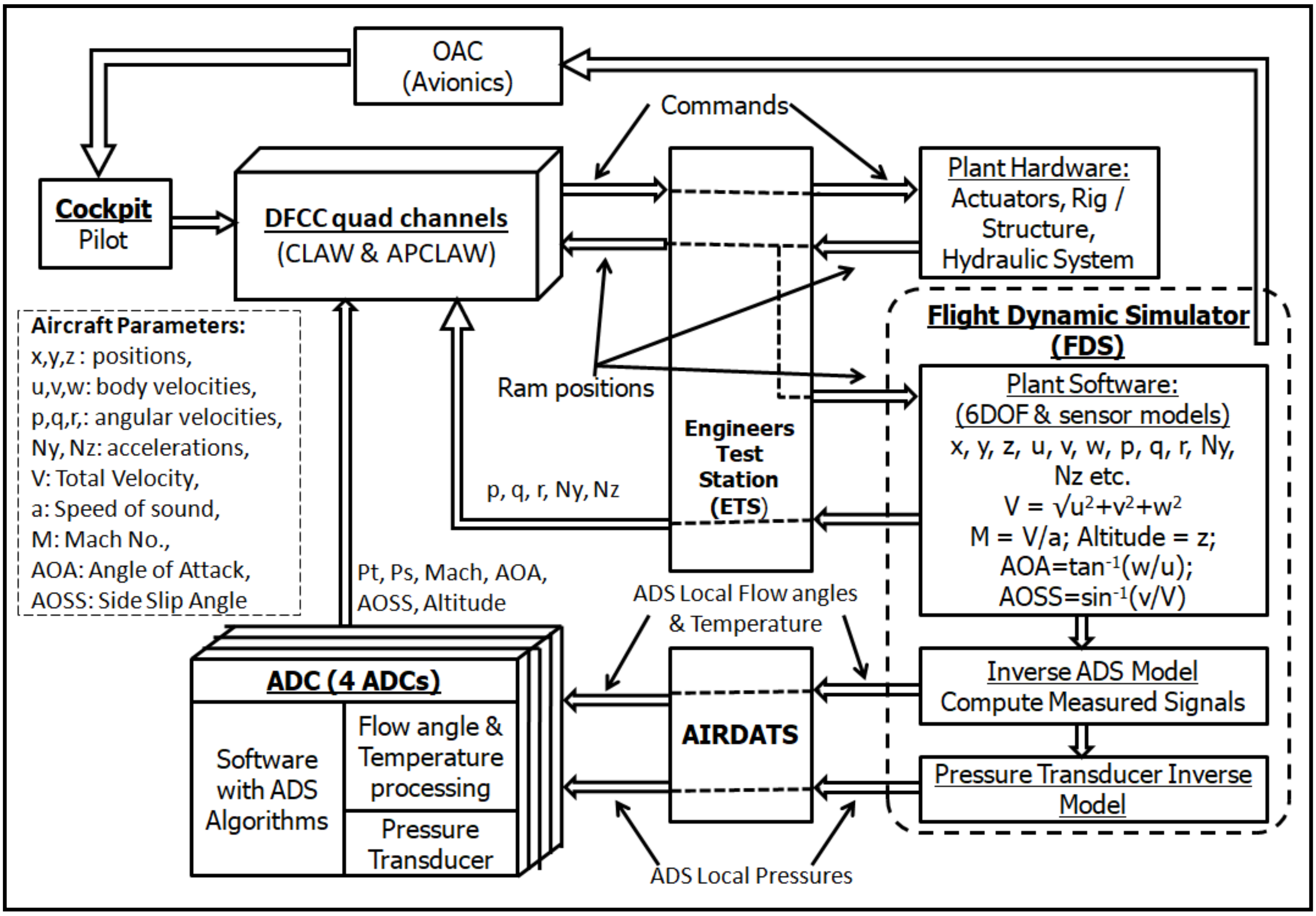

Figure 5: Iron Bird FCS Closed Loop Block Schematic

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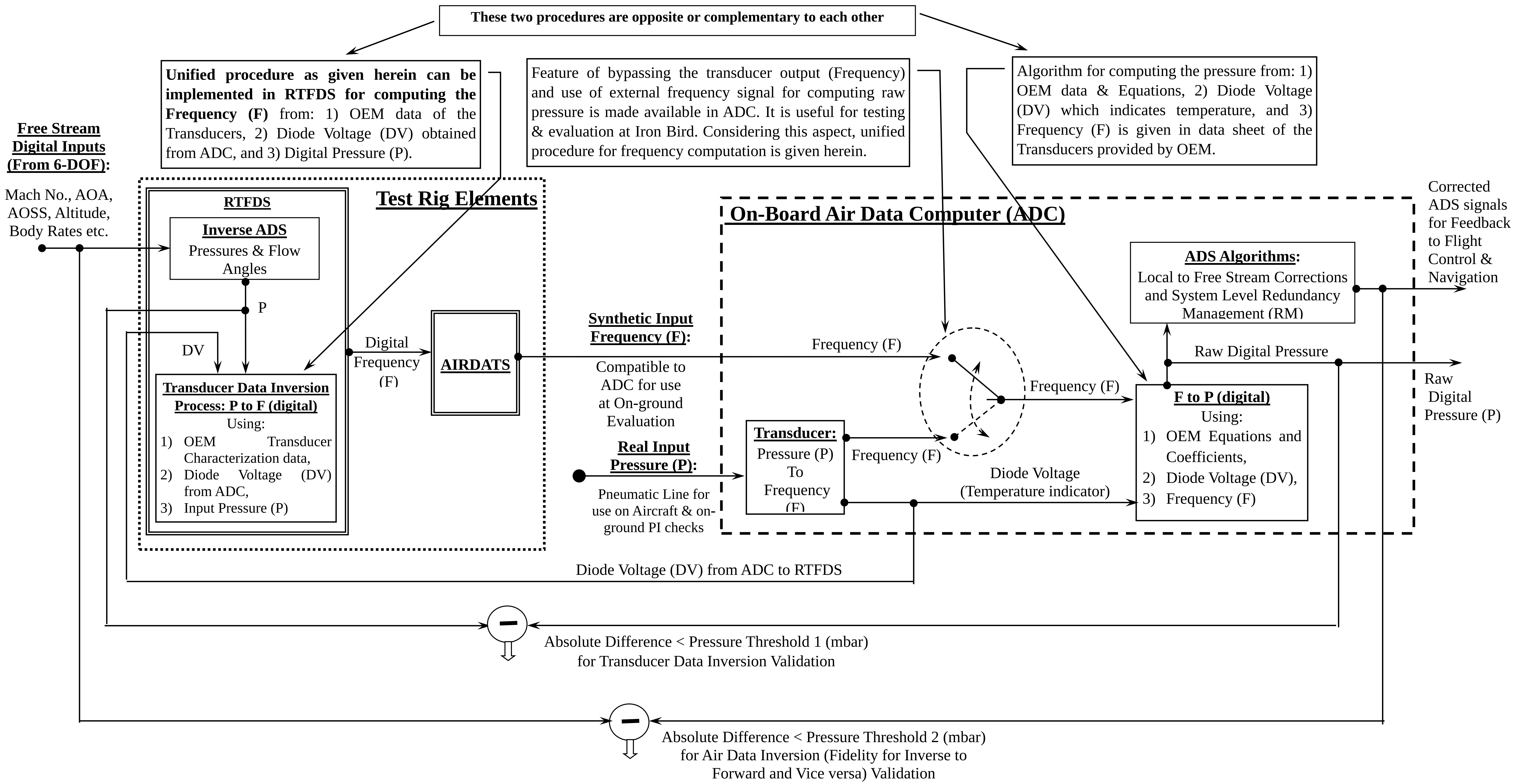

Figure 6: Detailed illustration of Transducer data inversion model usage in ADS evaluation process on Iron Bird

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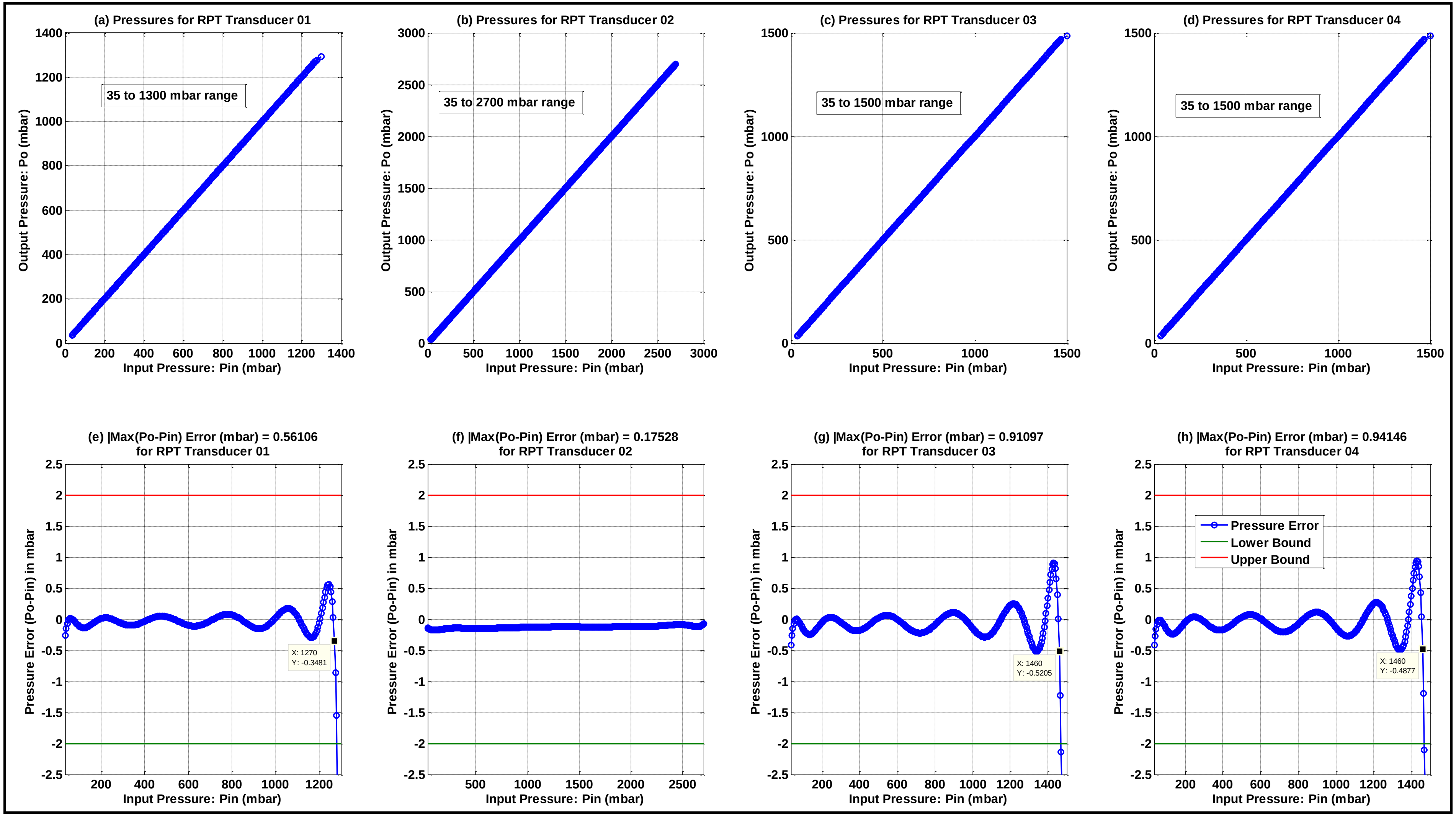

Figure 7: Results of data inversion with 1D polynomial (for a fixed mean temperature or diode voltage) for RPT transducers

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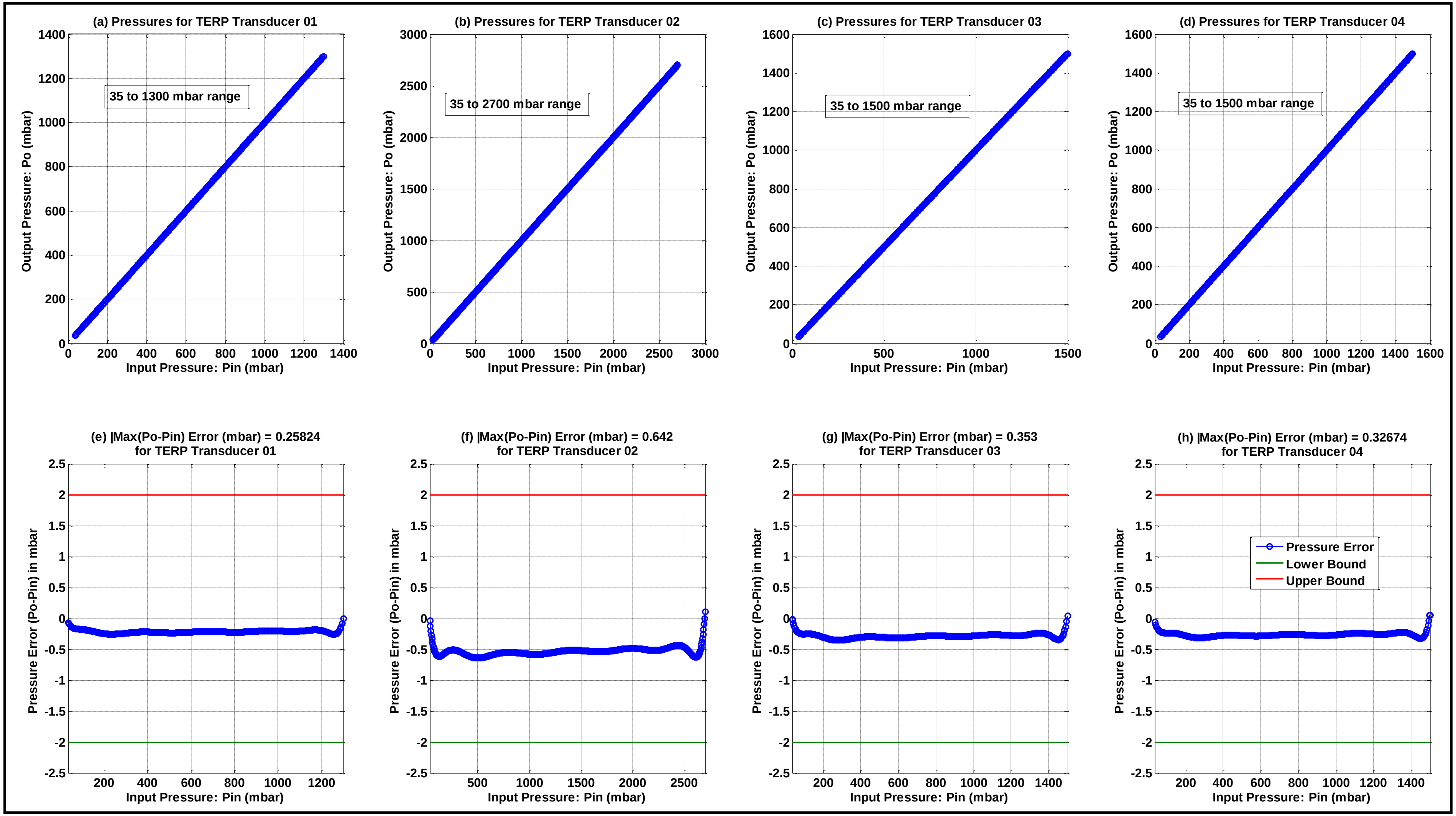

Figure 8: Results of data inversion with 1D polynomial (for a fixed mean temperature or diode voltage) for TERP transducers

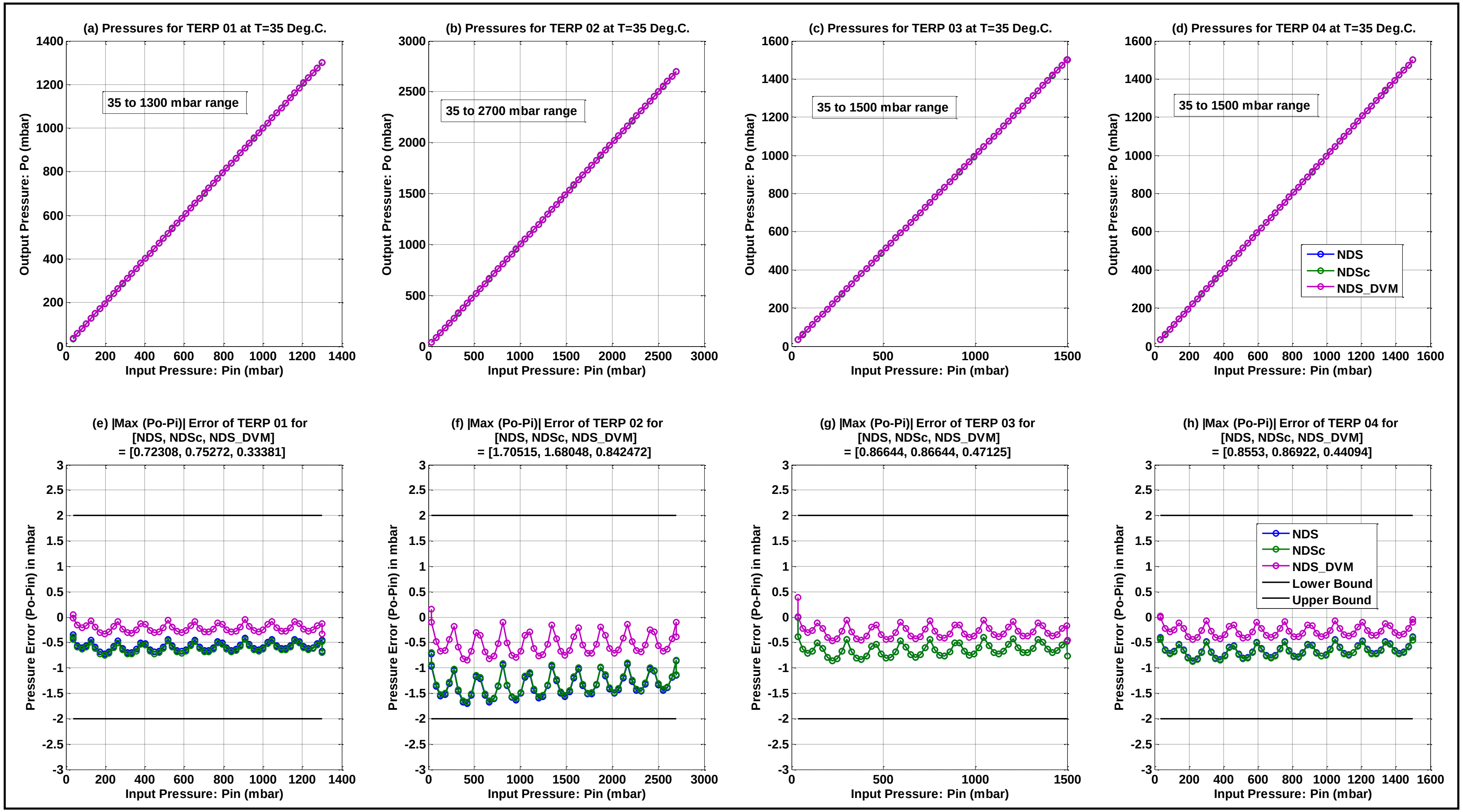

Figure 9: Results of data inversion with 2D set of Pressure and Temperature for TERP transducers