Simulink ISA Atmosphere + TAS-to-CAS Anemometry Model

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1. Executive summary

The model takes altitude (m) and true airspeed TAS (m/s) as inputs. It outputs ISA temperature, pressure, density, speed of sound, Mach number, and calibrated airspeed (CAS). All quantities are reported in SI units.

Primary use cases

• Flight mechanics problems (performance, compressibility effects)
• Air-data / anemometry calculations (TAS, Mach, CAS consistency)
• Verification exercises against published ISA tables and calibration relations

2. ABET framing (student outcomes)

This portfolio artifact demonstrates outcomes commonly assessed under ABET Engineering Accreditation Commission criteria (e.g., applying engineering science, analyzing data, and communicating results). The mapping below is paraphrased at a high level.

Outcome	Evidence in this work
1	Applied ISA and compressible-flow equations to compute atmospheric state and airspeed calibration.
3	Produced a structured technical report with clear assumptions, equations, tables, and validation results.
6	Designed verification test cases; compared Simulink outputs to reference computations and published sources.
7	Used authoritative references (NASA/NOAA/USAF, eCFR, ABET criteria) to support independent learning and professional practice.

3. Model overview

Figure 1 shows the top-level architecture: an ISA Atmosphere block and a TAS-to-CAS conversion block.

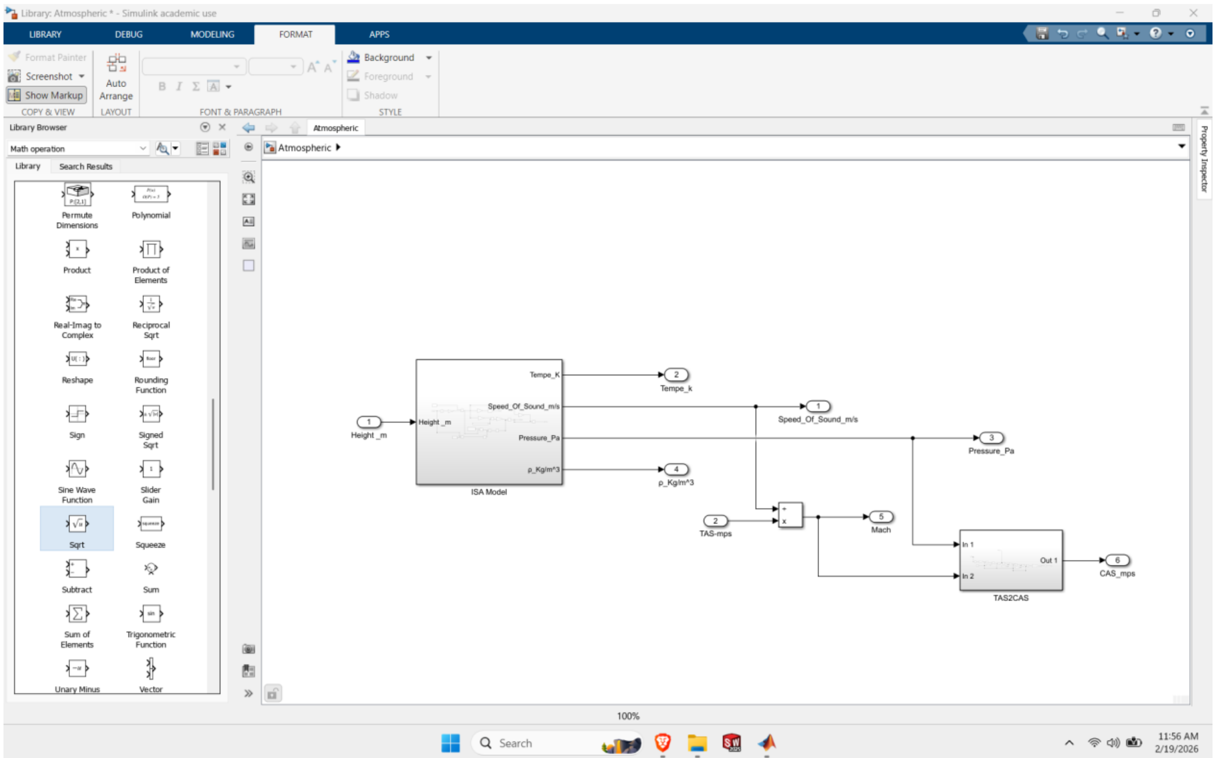

Figure 1. ISA + TAS-to-CAS model block diagram (Simulink).

The ISA subsystem outputs temperature T, pressure p, density ρ, and speed of sound a from altitude.

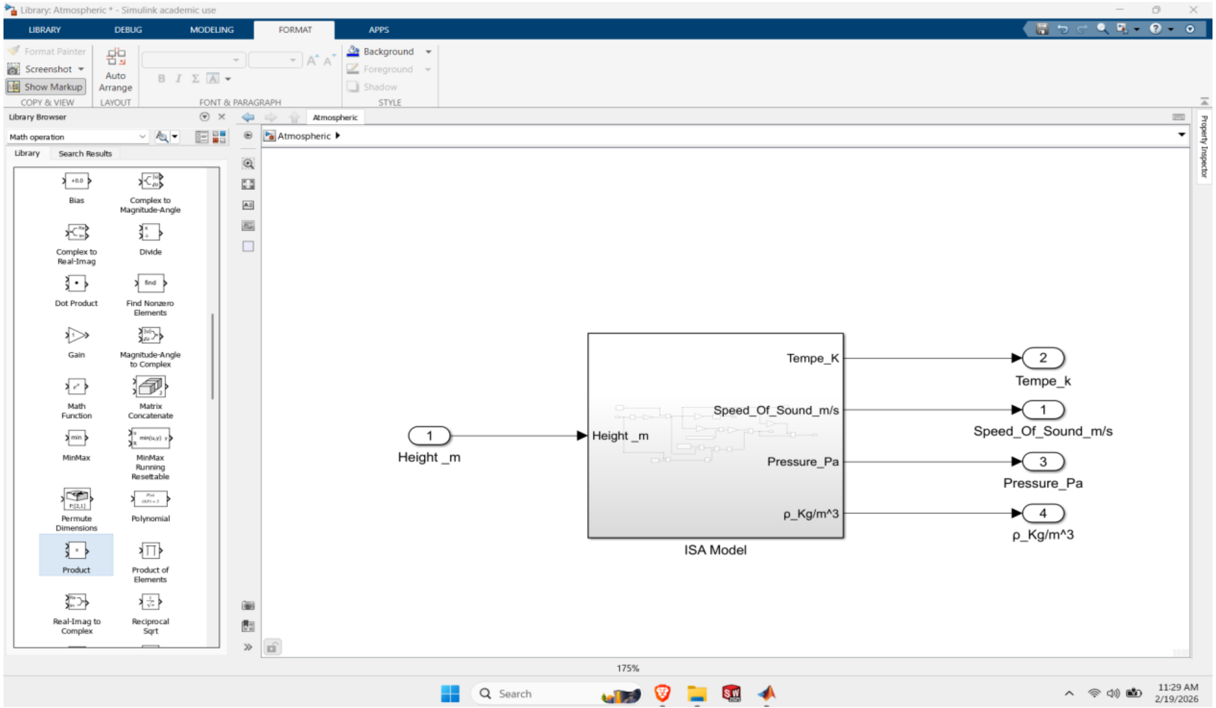

Figure 2. ISA Model subsystem I/O.

The TAS-to-CAS subsystem converts TAS to Mach (using local speed of sound) and then to CAS using compressible pitot relations.

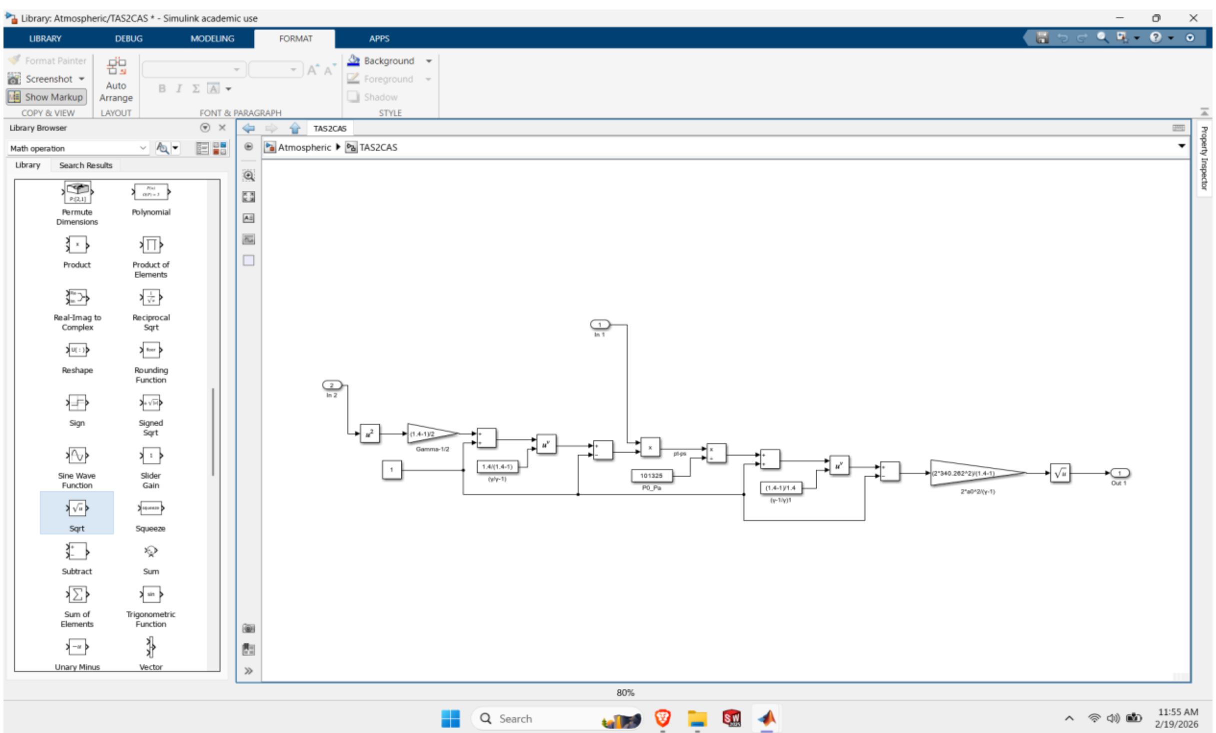

Figure 3. TAS-to-CAS subsystem internals (compressible pitot).

4. Signals, parameters, and units

Table 1 summarizes each model signal so a non-specialist can interpret the inputs and outputs. All reported values use SI units.

Category	Signal name (Simulink)	Symbol	Units	Meaning / why it matters
Input	Altitude / Height_m	h	m	Geometric altitude used by ISA to determine the atmospheric state.
Input	True Airspeed (TAS_mps)	V	m/s	Aircraft speed relative to surrounding air; used to compute Mach and compressibility effects.
Output	Temperature (Temp_K)	T	K	Local air temperature; affects density and speed of sound.
Output	Static pressure (Pressure_Pa)	p	Pa	Ambient pressure at altitude; used for density and pitot-based conversion.
Output	Density (ρ_Kg/m^3)	ρ	kg/m^3	Air mass per unit volume; used for lift/drag and dynamic pressure.
Output	Speed of sound (Speed_Of_Sound_m/s)	a	m/s	Used to compute Mach number M=V/a.
Derived	Mach	M	-	Compressibility measure (dimensionless).
Output	Calibrated airspeed (CAS_mps)	V_C	m/s	Pitot-static based airspeed assuming standard sea-level conditions.

5. Governing equations

Equations are shown as images; each is followed by a short explanation of its terms.

(1) ISA temperature (troposphere)

$$T(h) = T_0 - L\,h \qquad 0 \le h \le 11000 \text{ m}$$

$$T(h) = T_{11} \qquad h > 11000 \text{ m}$$

T0: sea-level temperature (K), L: lapse rate (K/m), h: altitude (m).

(2) ISA pressure (troposphere)

$$p(h) = p_0\left(\frac{T(h)}{T_0}\right)^{\frac{g_0}{RL}} \qquad 0 \le h \le 11000 \text{ m}$$

$$p(h) = p_{11}\exp\left(-\frac{g_0(h-11000)}{R\,T_{11}}\right) \qquad h > 11000 \text{ m}$$

p0: sea-level pressure (Pa), g0: gravity (m/s^2), R: gas constant (J/(kg·K)).

(3) Density (ideal gas)

$$\rho(h) = \frac{p(h)}{R\,T(h)}$$

ρ (kg/m^3) computed from p (Pa) and T (K).

(4) Speed of sound

$$a(h) = \sqrt{\gamma R\,T(h)}$$

a (m/s) depends on γ (dimensionless), R (J/(kg·K)), T (K).

(5) Mach number

$$M = \frac{V_{\text{TAS}}}{a(h)}$$

M (dimensionless) equals TAS divided by a.

(6) Impact pressure (pitot)

$$q_c = p(h)\left[\left(1 + \frac{\gamma - 1}{2}M^2\right)^{\frac{\gamma}{\gamma - 1}} - 1\right]$$

q_c (Pa) is impact pressure for isentropic compressible flow.

(7) Calibrated airspeed (CAS)

$$V_{\text{CAS}} = a_0\sqrt{\frac{2}{\gamma - 1}\left[\left(1 + \frac{q_c}{p_0}\right)^{\frac{\gamma - 1}{\gamma}} - 1\right]}$$

V_C (m/s) derived by mapping q_c to sea-level standard conditions.

6. Model parameters (constants)

Table 2 lists physical constants used in the model. Values follow the U.S. Standard Atmosphere (1976) and common aerodynamics practice.

Constant	Symbol	Value	Units	Notes / source
Sea-level temperature	T0	288.15	K	U.S. Standard Atmosphere (1976).
Sea-level pressure	p0	101325	Pa	U.S. Standard Atmosphere (1976).
Gas constant for dry air	R	287	J/(kg·K)	Specific gas constant for air.
Ratio of specific heats	γ	1.4	-	Assumed constant for subsonic anemometry.
Standard gravity	g0	9.80665	m/s^2	Standard gravity.
Tropospheric lapse rate	L	0.0065	K/m	Linear temperature decrease to tropopause.
Tropopause altitude	h_trop	11000	m	Transition to isothermal layer.

7. Verification and validation

Verification checks that Simulink blocks implement the intended equations. Validation compares numerical outputs against authoritative references for ISA and airspeed calibration.

Reference sources used

• U.S. Standard Atmosphere, 1976 (NASA/NOAA/USAF)
• NASA revised airspeed/altitude/Mach tables
• eCFR 14 CFR 1.1 definition of Calibrated Airspeed (CAS)
• EngineeringToolBox ISA tables (independent cross-check)

7.1 Test cases (Simulink outputs)

Case	h (m)	TAS (m/s)	T (K)	p (Pa)	ρ (kg/m^3)	a (m/s)	M (-)	CAS (m/s)
Simulink #1	0	150	288.1	101300	1.225	340.3	0.4408	150.0
Simulink #2	6000	180	249.1	47170	0.6597	316.4	0.5689	134.8
Simulink #3	12000	200	216.6	19320	0.3108	295.0	0.6779	105.3

7.2 Quantitative comparison to reference equations

Reference values were computed using the ISA layer equations and compressible pitot relations in Section 5. Percent error is (Simulink - Reference) / Reference × 100. Differences are dominated by rounding of display values.

Altitude h = 0 m

Metric	Simulink	Reference	Percent error (%)
T (K)	288.1	288.15	-0.0174
p (Pa)	101300	101325	-0.0247
ρ (kg/m³)	1.225	1.22523	-0.0184
a (m/s)	340.3	340.263	0.0110
Mach (-)	0.4408	0.440836	-0.0081
CAS (m/s)	150	150	0.0000

Altitude h = 6000 m

Metric	Simulink	Reference	Percent error (%)
T (K)	249.1	249.15	-0.0201
p (Pa)	47170	47174.4	-0.0092
ρ (kg/m³)	0.6597	0.659725	-0.0039
a (m/s)	316.4	316.399	0.0002
Mach (-)	0.5689	0.568902	-0.0003
CAS (m/s)	134.8	134.828	-0.0210

Altitude h = 12000 m

Metric	Simulink	Reference	Percent error (%)
T (K)	216.6	216.65	-0.0231
p (Pa)	19320	19324.5	-0.0232
ρ (kg/m³)	0.3108	0.31079	0.0032
a (m/s)	295	295.042	-0.0143
Mach (-)	0.6779	0.677869	0.0046
CAS (m/s)	105.3	105.345	-0.0431

8. Appendix: simulation evidence (screenshots)

The following figures show the three validation runs used in Table 3.

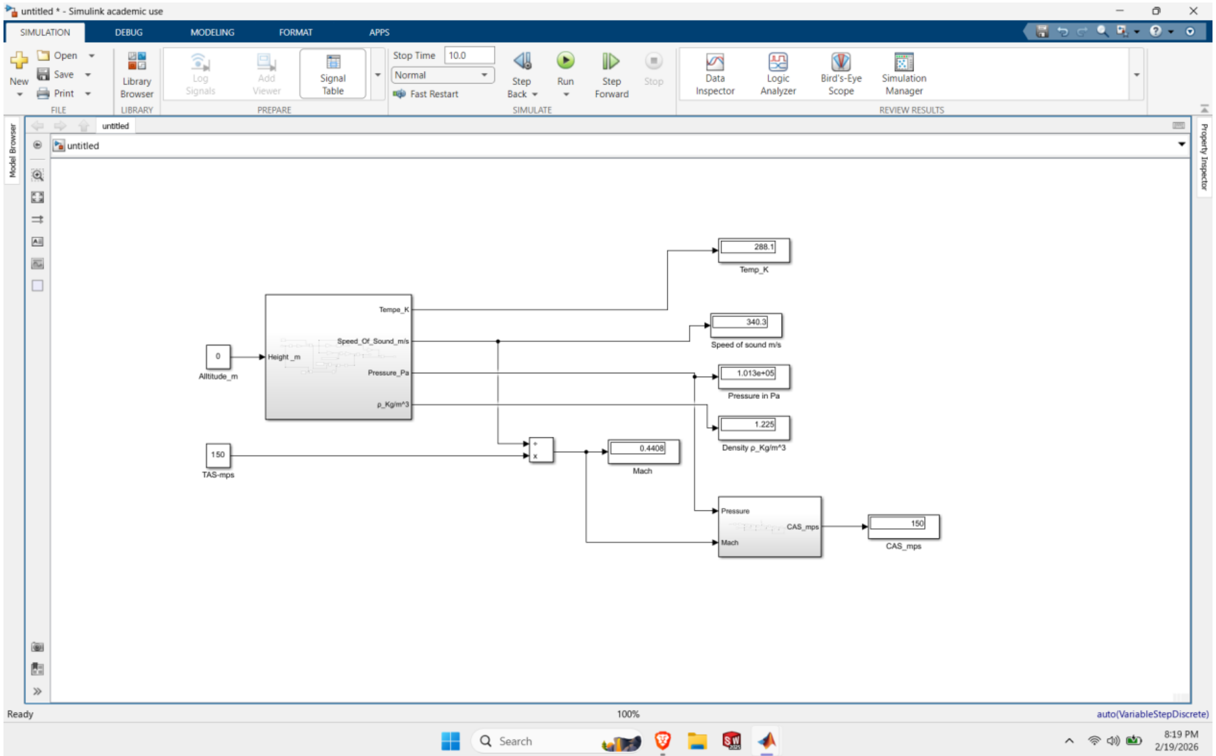

Figure A1. Case #1 (h=0 m, TAS=150 m/s).

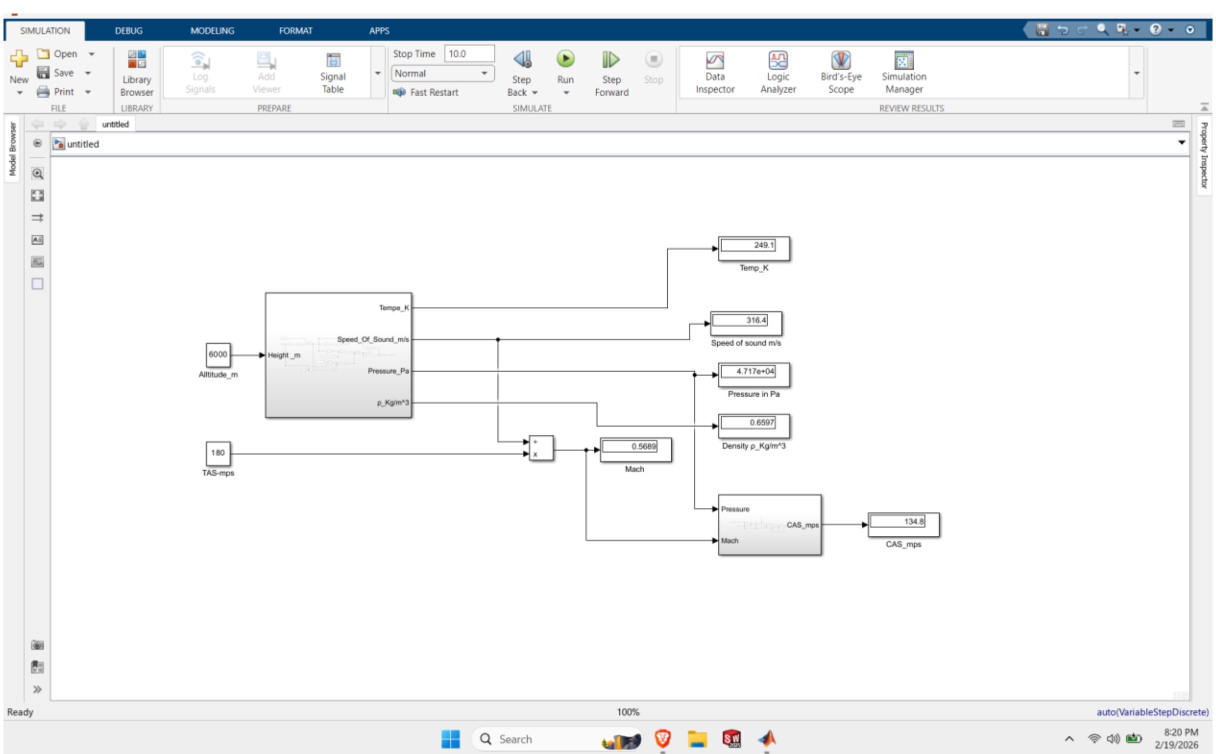

Figure A2. Case #2 (h=6000 m, TAS=180 m/s).

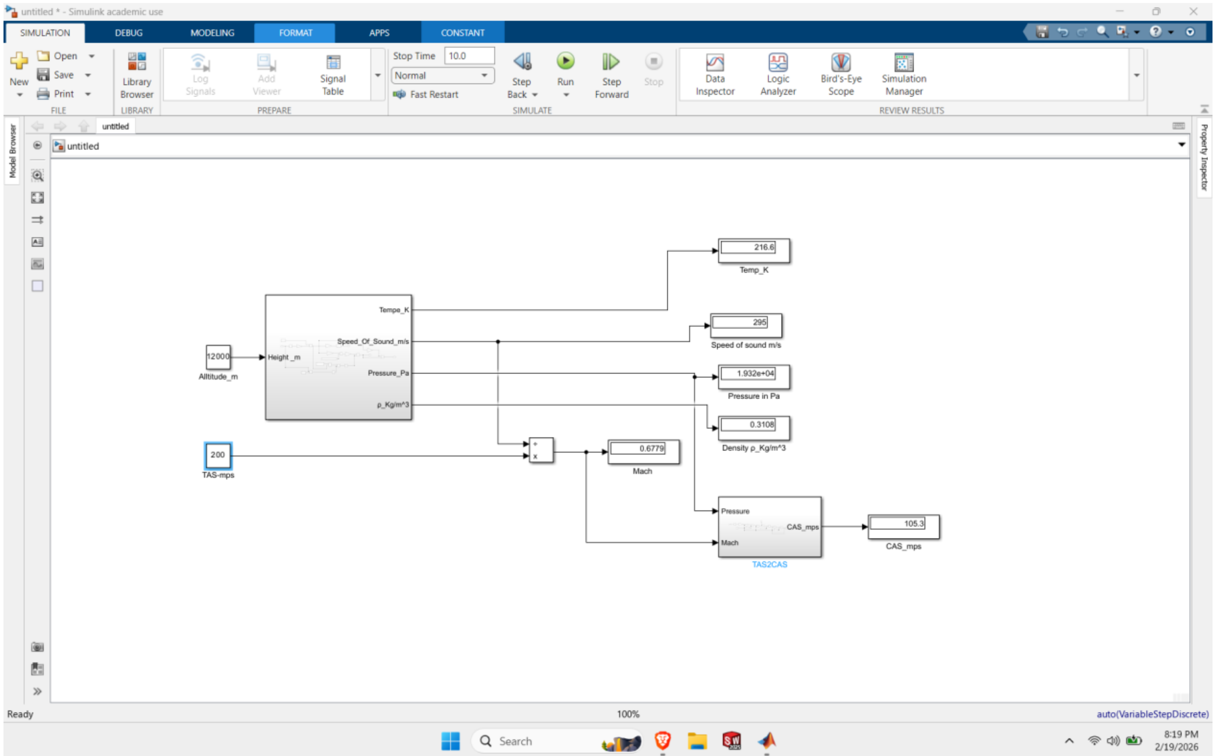

Figure A3. Case #3 (h=12000 m, TAS=200 m/s).

9. References

[1] NASA/NOAA/USAF, U.S. Standard Atmosphere, 1976 (NASA NTRS PDF).
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[3] eCFR, 14 CFR 1.1 - definition of Calibrated Airspeed.
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[5] EngineeringToolBox, International Standard Atmosphere (table).
https://www.engineeringtoolbox.com/international-standard-atmosphere-d_985.html