Base Characteristics

In [1]:

```python
# Graph: Distribution of engine lifespans (histogram)

def plot_engine_lifespan_hist(df, dataset_name="FD001", bins=20, savepath=None, ax=None):
    """
    Plot a histogram of engine lifespans (max cycles per unit) using the
    C-MAPSS column names: 'unit_number' and 'time_in_cycles'.

    Args:
        df (pd.DataFrame): Raw or preprocessed dataset with required columns.
        dataset_name (str): Label used in the plot title.
        bins (int): Number of histogram bins.
        savepath (str | Path | None): If provided, saves the figure.
        ax (matplotlib.axes.Axes | None): Optional axes to draw on.

    Returns:
        pd.Series: Lifespan (max cycles) per engine, indexed by unit_number.
    """
    required_cols = {"unit_number", "time_in_cycles"}
    missing = required_cols - set(df.columns)
    if missing:
        raise KeyError(f"Missing columns {missing}. Expected {required_cols}.")

    # Compute lifespan per engine (max cycles before failure)
    lifespans = df.groupby("unit_number")["time_in_cycles"].max().sort_values()

    # Prepare axes
    created_fig = False
    if ax is None:
        fig, ax = plt.subplots(figsize=(10, 6))
        created_fig = True

    # Plot histogram
    ax.hist(lifespans, bins=bins, edgecolor="black")
    ax.set_title(f"Distribution of Engine Lifespans ({dataset_name})")
    ax.set_xlabel("Max Cycles Before Failure")
    ax.set_ylabel("Number of Engines")
    ax.grid(True, linestyle="--", alpha=0.5)

    # Annotate mean ± std for quick reference
    mean_cycles = lifespans.mean()
    std_cycles = lifespans.std()
```

```python
    ax.axvline(mean_cycles, linestyle="--", linewidth=1)
    ax.text(mean_cycles, ax.get_ylim()[1] * 0.95,
            f"mean={mean_cycles:.1f}\nσ={std_cycles:.1f}",
            ha="center", va="top")

    if savepath:
        plt.savefig(savepath, dpi=300, bbox_inches="tight")

    if created_fig:
        plt.tight_layout()
        plt.show()

    return lifespans

#===================================================================================================================

# Graph: example rul trajectories
from typing import Iterable, Dict, List, Optional, Tuple

def plot_example_rul_trajectories(df, unit_ids, max_rul=130,
                                   dataset_name="FD001", savepath=None):
    """Line plots of RUL vs cycles for selected engines."""
    import matplotlib.pyplot as plt
    import pre_processing as pp

    df = df.copy()
    df = pp.calculate_rul(df, max_rul=max_rul)
    plt.figure(figsize=(10, 6))

    for uid in unit_ids:
        g = df[df.unit_number == uid].sort_values('time_in_cycles')
        plt.plot(g['time_in_cycles'], g['RUL'],
                 marker='.', linewidth=1, label=f"Engine {uid}")

    plt.title(f"Example RUL Trajectories ({dataset_name})")
    plt.xlabel("Cycle")
    plt.ylabel("RUL")
    plt.legend(ncol=2, fontsize=9)
    plt.grid(True, alpha=0.3)
    plt.tight_layout()
    plt.show()

```

```python

#==========================================================================================================================

# Graph: Sensor correlation heatmap
def plot_sensor_correlation_heatmap(df, dataset_name="FD001", method="pearson", savepath=None):
    """
    Plot a correlation heatmap for C-MAPSS sensor columns (sensor_measurement_*).

    Args:
        df (pd.DataFrame): DataFrame with sensor columns.
        dataset_name (str): Label for the title.
        method (str): Correlation method ('pearson', 'spearman', 'kendall').
        savepath (str|Path|None): If provided, save the figure.

    Returns:
        pd.DataFrame: Correlation matrix used for the plot.
    """
    import matplotlib.pyplot as plt

    sensor_cols = [c for c in df.columns if c.startswith("sensor_measurement")]
    if not sensor_cols:
        raise ValueError("No sensor_measurement_* columns found.")

    corr = df[sensor_cols].corr(method=method)

    # Prefer seaborn if available, else matplotlib fallback
    try:
        import seaborn as sns
        plt.figure(figsize=(12, 10))
        sns.heatmap(corr, cmap="coolwarm", center=0, square=True,
                    linewidths=0.5, cbar_kws={"shrink": 0.8})
    except Exception:
        plt.figure(figsize=(12, 10))
        im = plt.imshow(corr, cmap="coolwarm", vmin=-1, vmax=1)
        plt.colorbar(im, fraction=0.046, pad=0.04)
        labels = [s.replace("sensor_measurement_", "S") for s in sensor_cols]
        plt.xticks(range(len(sensor_cols)), labels, rotation=90)
        plt.yticks(range(len(sensor_cols)), labels)

    plt.title(f"Sensor Correlation Heatmap ({dataset_name})")
    plt.tight_layout()
    if savepath:
```

```python
        plt.savefig(savepath, dpi=300, bbox_inches="tight")
    plt.show()

    return corr

#==============================================================================================================

import numpy as np
import pandas as pd

def summarize_sensor_correlations(df, method="pearson", top_k=5):
    """
    Summarize inter-sensor correlations and list top +/- pairs.

    Returns:
        stats (dict): mean/median of corr and |corr| over unique pairs
        top_pos (pd.DataFrame): top-k most positively correlated pairs
        top_neg (pd.DataFrame): top-k most negatively correlated pairs
        corr (pd.DataFrame): full correlation matrix for reuse
    """
    sensor_cols = [c for c in df.columns if c.startswith("sensor_measurement")]
    if len(sensor_cols) < 2:
        raise ValueError("Need at least two sensor_measurement_* columns.")

    corr = df[sensor_cols].corr(method=method)

    # take upper triangle (unique pairs, exclude diagonal)
    iu = np.triu_indices_from(corr, k=1)
    pair_list = []
    for i, j in zip(iu[0], iu[1]):
        pair_list.append({
            "sensor_a": sensor_cols[i],
            "sensor_b": sensor_cols[j],
            "corr": corr.iloc[i, j],
            "abs_corr": abs(corr.iloc[i, j]),
        })
    pairs = pd.DataFrame(pair_list)

    # summary stats
    stats = {
        "mean_corr": float(pairs["corr"].mean()),
        "median_corr": float(pairs["corr"].median()),
```

```
        "mean_abs_corr": float(pairs["abs_corr"].mean()),
        "median_abs_corr": float(pairs["abs_corr"].median()),
        "n_pairs": int(len(pairs)),
    }

    # top-k lists
    top_pos = pairs.sort_values("corr", ascending=False).head(top_k).reset_index(drop=True)
    top_neg = pairs.sort_values("corr", ascending=True ).head(top_k).reset_index(drop=True)

    return stats, top_pos, top_neg, corr

```

In [2]:

```python
# Load Dataset


# Standard libs
from pathlib import Path
import numpy as np, pandas as pd
import matplotlib.pyplot as plt
import joblib


# Project modules
import data_loader as dl
import pre_processing as pp
import evaluator as ev
import base_model as base
import lstm_model as lstm
import cnn_model as cnn
import cnn_lstm_model as cnnlstm

# ---- Paths ----
ROOT = Path.cwd()
CMAPS = ROOT / "CMaps"  # keep correct folder case
# ==== Minimal config you tweak next time ====
DATASET = "FD003"       # <— change this to FD002/FD003/FD004 later
SEQ_LEN = 30            # sliding window
MAX_RUL = 130           # RUL clipping
VAL_SPLIT = 0.30        # val split by unit

# Files derived from DATASET (so you edit one line only)
TRAIN_PATH = CMAPS / f"train_{DATASET}.txt"
TEST_PATH  = CMAPS / f"test_{DATASET}.txt"
RUL_PATH   = CMAPS / f"RUL_{DATASET}.txt"

# Artifacts folder for this dataset
ART_DIR = ROOT / f"{DATASET} data & artefacts"
ART_DIR.mkdir(exist_ok=True)

print(f"backend: torch | dataset: {DATASET}")
print("Train:", TRAIN_PATH.name, "| Test:", TEST_PATH.name, "| RUL:", RUL_PATH.name)


```

```
# --- Load FD001 ---
train_df = dl.load_raw_data(CMAPS / f"train_{DATASET}.txt")
test_df, rul_df = dl.load_test_data(
    CMAPS / f"test_{DATASET}.txt",
    CMAPS / f"RUL_{DATASET}.txt"
)

print("Loaded.")
print("  train_df:", train_df.shape, "  test_df:", test_df.shape, "  rul_df:", rul_df.shape)
assert train_df.shape[1] == 26 and test_df.shape[1] == 26
```

```
WARNING:root:Limited tf.compat.v2.summary API due to missing TensorBoard installation.
WARNING:root:Limited tf.compat.v2.summary API due to missing TensorBoard installation.
WARNING:root:Limited tf.compat.v2.summary API due to missing TensorBoard installation.
WARNING:root:Limited tf.summary API due to missing TensorBoard installation.
WARNING:root:Limited tf.compat.v2.summary API due to missing TensorBoard installation.
WARNING:root:Limited tf.compat.v2.summary API due to missing TensorBoard installation.
WARNING:root:Limited tf.compat.v2.summary API due to missing TensorBoard installation.
```

```
backend: torch | dataset: FD003
Train: train_FD003.txt | Test: test_FD003.txt | RUL: RUL_FD003.txt
Loaded.
  train_df: (24720, 26)   test_df: (16596, 26)   rul_df: (100, 1)
```

Preamble

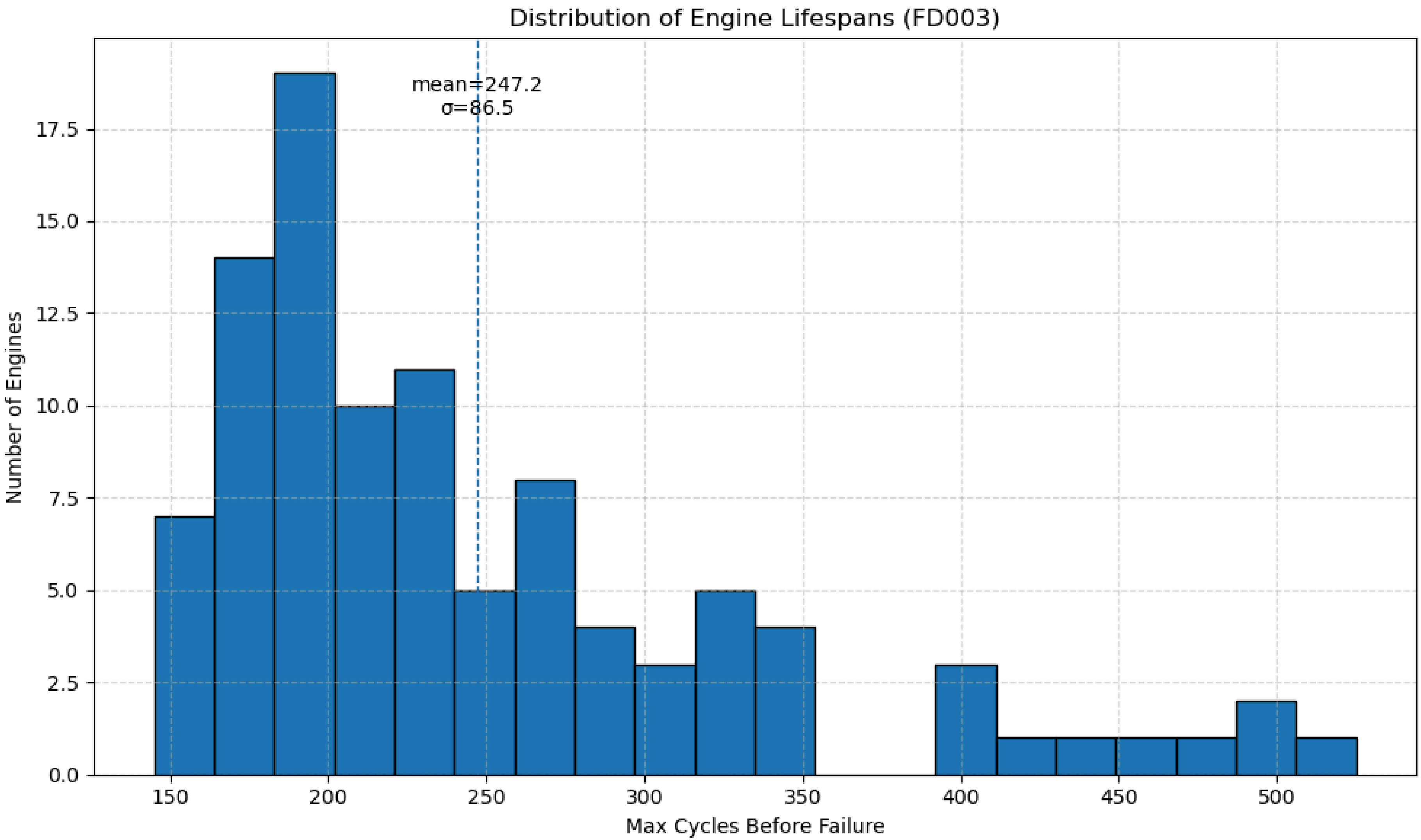
```
In [3]: 1 dl.inspect_data(train_df)
```

```
Shape: (24720, 26)

Unique engines: 100

Missing values:
 0

Max cycles per engine:
count    100.00000
mean     247.20000
std       86.48384
min      145.00000
25%      189.75000
50%      220.50000
75%      279.75000
max      525.00000
Name: time_in_cycles, dtype: float64

First 5 rows:
```

	unit_number	time_in_cycles	op_setting_1	op_setting_2	op_setting_3	sensor_measurement_1	sensor_measurement_2	sensor_measurement_3	se
0	1	1	-0.0005	0.0004	100.0	518.67	642.36	1583.23	
1	1	2	0.0008	-0.0003	100.0	518.67	642.50	1584.69	
2	1	3	-0.0014	-0.0002	100.0	518.67	642.18	1582.35	
3	1	4	-0.0020	0.0001	100.0	518.67	642.92	1585.61	
4	1	5	0.0016	0.0000	100.0	518.67	641.68	1588.63	

5 rows × 26 columns

```
In [4]: plot_engine_lifespan_hist(train_df, dataset_name=DATASET)
```



```
Out[4]: unit_number
99      145
80      147
100     152
76      153
91      156
       ...
34      459
10      481
96      491
24      494
55      525
Name: time_in_cycles, Length: 100, dtype: int64
```

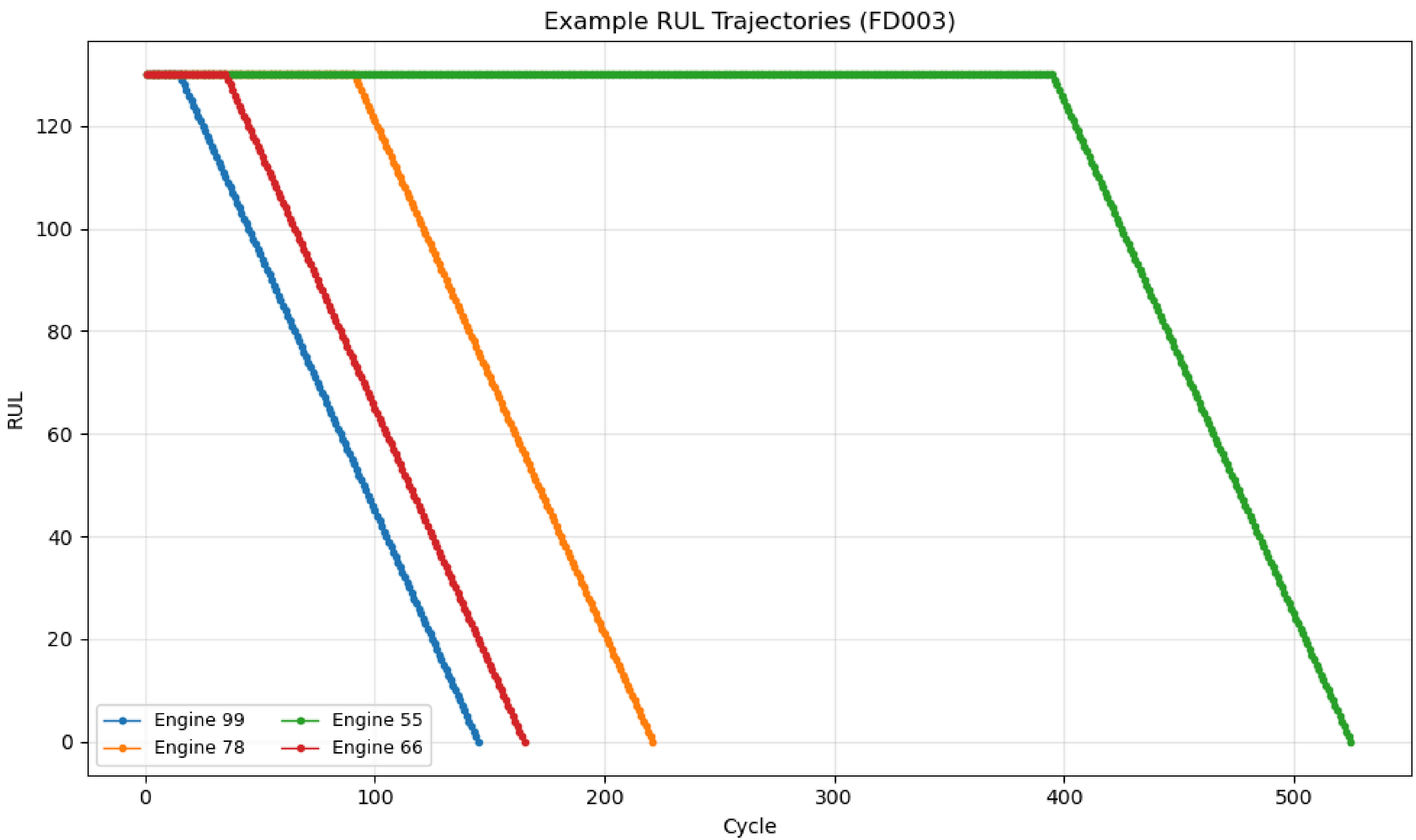
In [5]:

```python
import numpy as np

def select_representative_units(df, random_state=42):
    """
    Select representative engine units:
    - Shortest-lived
    - Median-lived
    - Longest-lived
    - One random unit (reproducible with random_state)

    Args:
        df (pd.DataFrame): Engine dataset with 'unit_number' and 'time_in_cycles'.
        random_state (int): Seed for reproducibility.

    Returns:
        list[int]: List of selected engine IDs.
    """
    # Compute max cycles per engine
    lifespans = df.groupby("unit_number")["time_in_cycles"].max().sort_values()

    # Shortest-lived
    shortest = lifespans.index[0]
    # Median-lived
    median = lifespans.index[len(lifespans) // 2]
    # Longest-lived
    longest = lifespans.index[-1]
    # One random
    rng = np.random.default_rng(random_state)
    random_unit = rng.choice(lifespans.index)

    return [shortest, median, longest, int(random_unit)]

```

In [6]:

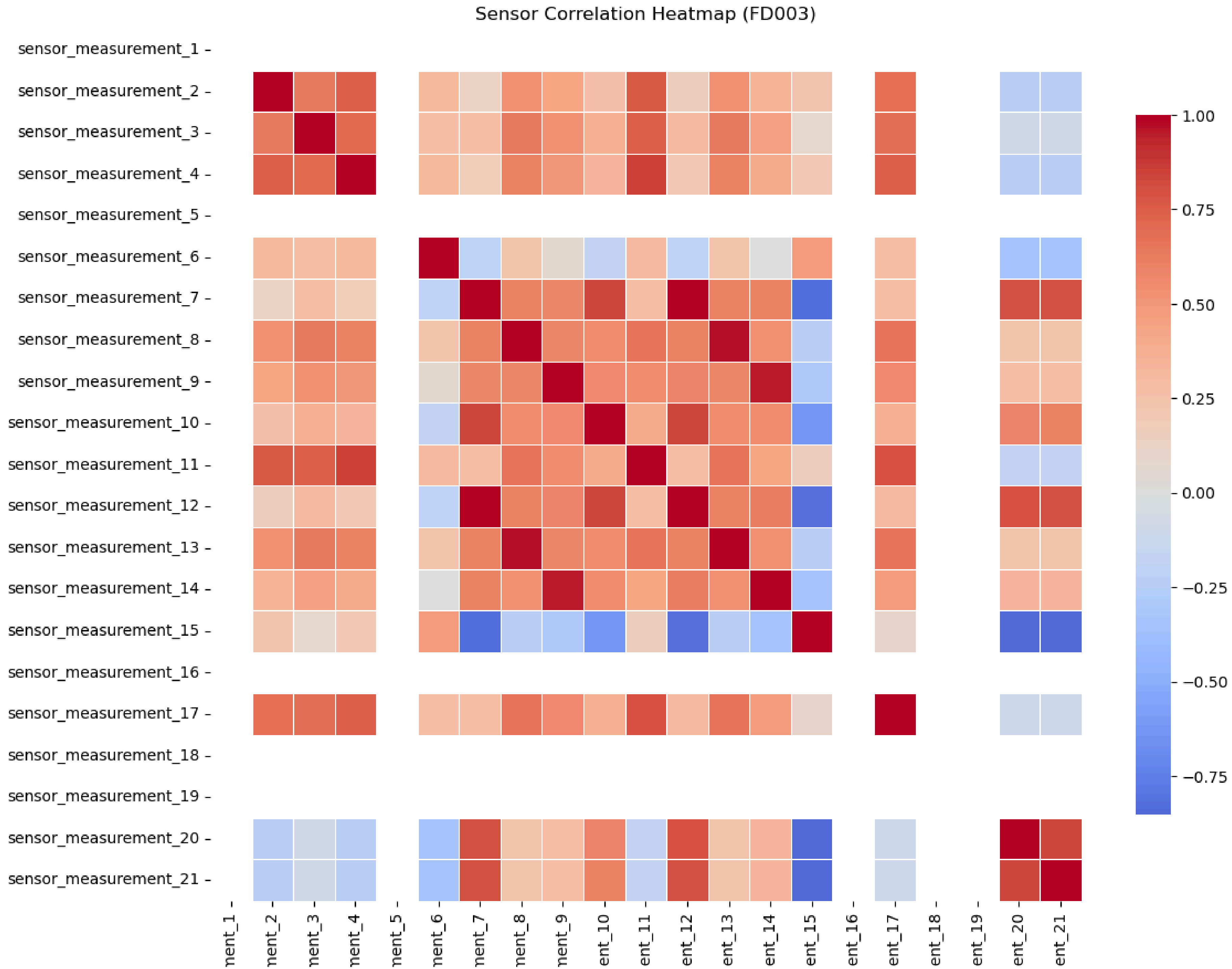
```python
example_units = select_representative_units(train_df, random_state=42)
print("Selected engines:", example_units)

plot_example_rul_trajectories(train_df, unit_ids=example_units,
                              max_rul=MAX_RUL, dataset_name=DATASET)

```

```
Selected engines: [99, 78, 55, 66]
```



In [7]:

```
plot_sensor_correlation_heatmap(train_df, dataset_name=DATASET)
```



Sensor Correlation Heatmap (FD003)
sensor_measurement_1
sensor_measurement_2
sensor_measurement_3
sensor_measurement_4
sensor_measurement_5
sensor_measurement_6
sensor_measurement_7
sensor_measurement_8
sensor_measurement_9
sensor_measurement_10
sensor_measurement_11
sensor_measurement_12
sensor_measurement_13
sensor_measurement_14
sensor_measurement_15
sensor_measurement_16
sensor_measurement_17
sensor_measurement_18
sensor_measurement_19
sensor_measurement_20
sensor_measurement_21
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75

sensor_measurer sensor_measurer sensor_measurer sensor_measurer sensor_measurer sensor_measurer sensor_measurer sensor_measurer sensor_measurer sensor_measurem sensor_measurem sensor_measurem sensor_measurem sensor_measurem sensor_measurem sensor_measurem sensor_measurem sensor_measurem sensor_measurem sensor_measurem sensor_measurem

Out[7]:

	sensor_measurement_1	sensor_measurement_2	sensor_measurement_3	sensor_measurement_4	sensor_measurement_5	ser
sensor_measurement_1	NaN	NaN	NaN	NaN	NaN	
sensor_measurement_2	NaN	1.000000	0.640503	0.745167	NaN	
sensor_measurement_3	NaN	0.640503	1.000000	0.716890	NaN	
sensor_measurement_4	NaN	0.745167	0.716890	1.000000	NaN	
sensor_measurement_5	NaN	NaN	NaN	NaN	NaN	
sensor_measurement_6	NaN	0.314799	0.269463	0.319139	NaN	
sensor_measurement_7	NaN	0.124167	0.282007	0.181976	NaN	
sensor_measurement_8	NaN	0.533915	0.637926	0.601272	NaN	
sensor_measurement_9	NaN	0.441283	0.535074	0.509782	NaN	
sensor_measurement_10	NaN	0.256388	0.367705	0.330834	NaN	
sensor_measurement_11	NaN	0.762269	0.746093	0.854030	NaN	
sensor_measurement_12	NaN	0.141785	0.298941	0.202106	NaN	
sensor_measurement_13	NaN	0.532745	0.636513	0.601254	NaN	
sensor_measurement_14	NaN	0.343954	0.454205	0.404686	NaN	
sensor_measurement_15	NaN	0.232947	0.076820	0.216773	NaN	
sensor_measurement_16	NaN	NaN	NaN	NaN	NaN	
sensor_measurement_17	NaN	0.670062	0.677216	0.749907	NaN	
sensor_measurement_18	NaN	NaN	NaN	NaN	NaN	
sensor_measurement_19	NaN	NaN	NaN	NaN	NaN	
sensor_measurement_20	NaN	-0.246286	-0.091851	-0.235016	NaN	
sensor_measurement_21	NaN	-0.241318	-0.089035	-0.230134	NaN	

21 rows × 21 columns

In [8]:

```
stats, top_pos, top_neg, corr = summarize_sensor_correlations(train_df, method="pearson", top_k=5)

print("Correlation summary:", {k: round(v, 3) if isinstance(v, float) else v for k, v in stats.items()})

display(top_pos.round(3))
display(top_neg.round(3))
```

```
Correlation summary: {'mean_corr': 0.323, 'median_corr': 0.373, 'mean_abs_corr': 0.458, 'median_abs_corr': 0.448, 'n_pa
irs': 210}
```

	sensor_a	sensor_b	corr	abs_corr
0	sensor_measurement_7	sensor_measurement_12	0.989	0.989
1	sensor_measurement_8	sensor_measurement_13	0.964	0.964
2	sensor_measurement_9	sensor_measurement_14	0.954	0.954
3	sensor_measurement_4	sensor_measurement_11	0.854	0.854
4	sensor_measurement_20	sensor_measurement_21	0.839	0.839

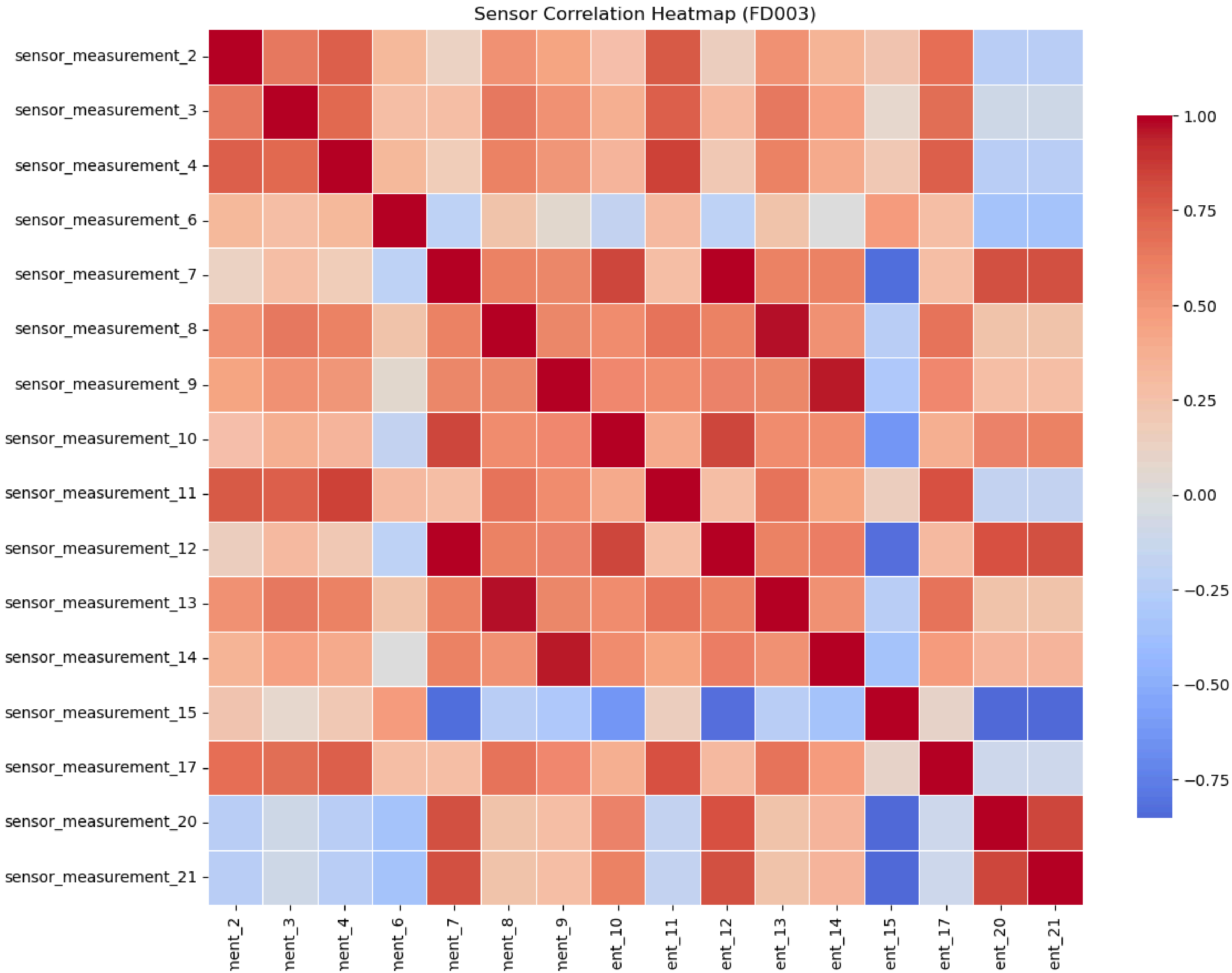
	sensor_a	sensor_b	corr	abs_corr
0	sensor_measurement_15	sensor_measurement_21	-0.852	0.852
1	sensor_measurement_15	sensor_measurement_20	-0.850	0.850
2	sensor_measurement_7	sensor_measurement_15	-0.827	0.827
3	sensor_measurement_12	sensor_measurement_15	-0.820	0.820
4	sensor_measurement_10	sensor_measurement_15	-0.632	0.632

In [9]:

```
train__clean = pp.drop_flat_sensors(train_df.copy())
```

In [10]:

```
plot_sensor_correlation_heatmap(train__clean, dataset_name=DATASET)
```



Sensor Correlation Heatmap (FD003)
sensor_measurement_2
sensor_measurement_3
sensor_measurement_4
sensor_measurement_6
sensor_measurement_7
sensor_measurement_8
sensor_measurement_9
sensor_measurement_10
sensor_measurement_11
sensor_measurement_12
sensor_measurement_13
sensor_measurement_14
sensor_measurement_15
sensor_measurement_17
sensor_measurement_20
sensor_measurement_21
nent_2
nent_3
nent_4
nent_6
nent_7
nent_8
nent_9
ent_10
ent_11
ent_12
ent_13
ent_14
ent_15
ent_17
ent_20
ent_21
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75

sensor_measurer sensor_measurer sensor_measurer sensor_measurer sensor_measurer sensor_measurer sensor_measurer sensor_measurem sensor_measurem sensor_measurem sensor_measurem sensor_measurem sensor_measurem sensor_measurem sensor_measurem sensor_measurem

Out[10]:

	sensor_measurement_2	sensor_measurement_3	sensor_measurement_4	sensor_measurement_6	sensor_measurement_7	ser
sensor_measurement_2	1.000000	0.640503	0.745167	0.314799	0.124167	
sensor_measurement_3	0.640503	1.000000	0.716890	0.269463	0.282007	
sensor_measurement_4	0.745167	0.716890	1.000000	0.319139	0.181976	
sensor_measurement_6	0.314799	0.269463	0.319139	1.000000	-0.208690	
sensor_measurement_7	0.124167	0.282007	0.181976	-0.208690	1.000000	
sensor_measurement_8	0.533915	0.637926	0.601272	0.247480	0.596510	
sensor_measurement_9	0.441283	0.535074	0.509782	0.065131	0.579004	
sensor_measurement_10	0.256388	0.367705	0.330834	-0.184268	0.830550	
sensor_measurement_11	0.762269	0.746093	0.854030	0.305777	0.270774	
sensor_measurement_12	0.141785	0.298941	0.202106	-0.200906	0.988725	
sensor_measurement_13	0.532745	0.636513	0.601254	0.247099	0.597169	
sensor_measurement_14	0.343954	0.454205	0.404686	0.008579	0.601013	
sensor_measurement_15	0.232947	0.076820	0.216773	0.485677	-0.826574	
sensor_measurement_17	0.670062	0.677216	0.749907	0.285658	0.285796	
sensor_measurement_20	-0.246286	-0.091851	-0.235016	-0.345912	0.802838	
sensor_measurement_21	-0.241318	-0.089035	-0.230134	-0.347739	0.807138	

In [11]:

```python
stats, top_pos, top_neg, corr = summarize_sensor_correlations(train__clean, method="pearson", top_k=5)

print("Correlation summary:", {k: round(v, 3) if isinstance(v, float) else v for k, v in stats.items()})

display(top_pos.round(3))
display(top_neg.round(3))
```

```
Correlation summary: {'mean_corr': 0.323, 'median_corr': 0.373, 'mean_abs_corr': 0.458, 'median_abs_corr': 0.448, 'n_pa
irs': 120}
```

	sensor_a	sensor_b	corr	abs_corr
0	sensor_measurement_7	sensor_measurement_12	0.989	0.989
1	sensor_measurement_8	sensor_measurement_13	0.964	0.964
2	sensor_measurement_9	sensor_measurement_14	0.954	0.954
3	sensor_measurement_4	sensor_measurement_11	0.854	0.854
4	sensor_measurement_20	sensor_measurement_21	0.839	0.839

	sensor_a	sensor_b	corr	abs_corr
0	sensor_measurement_15	sensor_measurement_21	-0.852	0.852
1	sensor_measurement_15	sensor_measurement_20	-0.850	0.850
2	sensor_measurement_7	sensor_measurement_15	-0.827	0.827
3	sensor_measurement_12	sensor_measurement_15	-0.820	0.820
4	sensor_measurement_10	sensor_measurement_15	-0.632	0.632

In [ ]:

```python

```