```
# 1. Mount Google Drive and Setup
from google.colab import drive
drive.mount('/content/drive')
```

```
Mounted at /content/drive
```

```
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
import tensorflow as tf
from tensorflow import keras
from tensorflow.keras import layers
import os

# Set random seeds for reproducibility
tf.random.set_seed(42)
np.random.seed(42)

# Check TensorFlow version
print("TensorFlow version:", tf.__version__)
```

```
TensorFlow version: 2.18.0
```

```
# 2. Load Data from Google Drive
# Update this path to your dataset location in Google Drive
drive_path = '/content/drive/MyDrive/Colab Notebooks/jena_climate_2009_2016.csv/jena_climate_2009_2016.csv'

try:
    df = pd.read_csv(drive_path)
    print("File loaded successfully from Google Drive!")

    # Display basic info
    print("\nDataset shape:", df.shape)
    print("\nFirst 5 rows:")
    display(df.head())

except Exception as e:
    print(f"Error loading file: {e}")
    print("\nTroubleshooting steps:")
    print("1. Make sure you've mounted Google Drive correctly")
    print("2. Verify the file exists at the specified path")
    print("3. Check the filename is exactly 'jena_climate_2009_2016.csv'")
    print("4. Ensure you have permission to access the file")
```

```
File loaded successfully from Google Drive!

Dataset shape: (420551, 15)

First 5 rows:
```

	Date Time	p (mbar)	T (degC)	Tpot (K)	Tdew (degC)	rh (%)	VPmax (mbar)	VPact (mbar)	VPdef (mbar)	sh (g/kg)	H2OC (mmol/mol)	rho (g/m**3)	wv (m/s)	ma
0	01.01.2009 00:10:00	996.52	-8.02	265.40	-8.90	93.3	3.33	3.11	0.22	1.94	3.12	1307.75	1.03	1.
1	01.01.2009 00:20:00	996.57	-8.41	265.01	-9.28	93.4	3.23	3.02	0.21	1.89	3.03	1309.80	0.72	1.
2	01.01.2009 00:30:00	996.53	-8.51	264.91	-9.31	93.9	3.21	3.01	0.20	1.88	3.02	1310.24	0.19	0.
3	01.01.2009 00:40:00	996.51	-8.31	265.12	-9.07	94.2	3.26	3.07	0.19	1.92	3.08	1309.19	0.34	0.
4	01.01.2009 00:50:00	996.51	-8.27	265.15	-9.04	94.1	3.27	3.08	0.19	1.92	3.09	1309.00	0.32	0.

```
# 3. Data Preparation
# Extract numerical data (skip Date Time column)
data = df.iloc[:, 1:].values.astype('float32')

def prepare_data(data, split_fraction=0.715):
    train_split = int(split_fraction * data.shape[0])

    # Normalize using training set statistics
    mean = data[:train_split].mean(axis=0)
    std = data[:train_split].std(axis=0)

    data -= mean
    data /= std

    return data, mean, std

data, mean, std = prepare_data(data)

# Parameters for time-series windows
sampling_rate = 6
sequence_length = 120
delay = sampling_rate * (sequence_length + 24 - 1)
batch_size = 256

def create_dataset(data, sequence_length, delay, sampling_rate, batch_size, shuffle=False):
    dataset = keras.utils.timeseries_dataset_from_array(
        data[:-delay],
        targets=data[delay:][:, 1],  # Temperature is column 1
        sampling_rate=sampling_rate,
        sequence_length=sequence_length,
        shuffle=shuffle,
        batch_size=batch_size,
    )
    return dataset

train_dataset = create_dataset(data[:200000], sequence_length, delay, sampling_rate, batch_size, shuffle=True)
val_dataset = create_dataset(data[200000:300000], sequence_length, delay, sampling_rate, batch_size)
test_dataset = create_dataset(data[300000:], sequence_length, delay, sampling_rate, batch_size)

print(f"\nTraining samples: {len(train_dataset)*batch_size}")
print(f"Validation samples: {len(val_dataset)*batch_size}")
```

```
print(f"Test samples: {len(test_dataset)*batch_size}")
```

```
Training samples: 198656
Validation samples: 98560
Test samples: 119040
```

```
# 4. Model Training Function
def train_and_evaluate_model(model, train_data, val_data, test_data, epochs=10, model_name="Model"):
    model.compile(optimizer="rmsprop", loss="mse", metrics=["mae"])

    print(f"\nTraining {model_name}...")
    history = model.fit(
        train_data,
        epochs=epochs,
        validation_data=val_data,
        verbose=1
    )

    plt.figure(figsize=(10, 5))
    plt.plot(history.history["mae"], label="Training MAE")
    plt.plot(history.history["val_mae"], label="Validation MAE")
    plt.title(f"{model_name} - Training History")
    plt.xlabel("Epochs")
    plt.ylabel("MAE")
    plt.legend()
    plt.show()

    print("\nTest evaluation:")
    test_results = model.evaluate(test_data, verbose=0)
    print(f"Test MAE: {test_results[1]:.4f}")
    print(f"Test MSE: {test_results[0]:.4f}")

    return test_results


# 5. Model Architectures
# Model 1: Baseline GRU
print("\n" + "="*50)
print("Building Baseline GRU Model")
print("="*50)
model1 = keras.Sequential([
    layers.Input(shape=(sequence_length, data.shape[-1])),
    layers.GRU(32),
    layers.Dense(1)
])
model1.summary()
test_results1 = train_and_evaluate_model(model1, train_dataset, val_dataset, test_dataset, model_name="Baseline GRU")

# Model 2: Stacked GRU
print("\n" + "="*50)
print("Building Stacked GRU Model")
print("="*50)
model2 = keras.Sequential([
    layers.Input(shape=(sequence_length, data.shape[-1])),
    layers.GRU(64, return_sequences=True),
    layers.GRU(64),
    layers.Dense(1)
])
model2.summary()
test_results2 = train_and_evaluate_model(model2, train_dataset, val_dataset, test_dataset, model_name="Stacked GRU")

# Model 3: Stacked LSTM
print("\n" + "="*50)
```

```
                tacked LSTM Model")
print("="*50)
model3 = keras.Sequential([
    layers.Input(shape=(sequence_length, data.shape[-1])),
    layers.LSTM(64, return_sequences=True),
    layers.LSTM(64),
    layers.Dense(1)
])
model3.summary()
test_results3 = train_and_evaluate_model(model3, train_dataset, val_dataset, test_dataset, model_name="Stacked LSTM")

# Model 4: CNN + RNN Hybrid
print("\n" + "="*50)
print("Building CNN+RNN Hybrid Model")
print("="*50)
model4 = keras.Sequential([
    layers.Input(shape=(sequence_length, data.shape[-1])),
    layers.Conv1D(64, 5, activation="relu"),
    layers.MaxPooling1D(3),
    layers.Conv1D(64, 5, activation="relu"),
    layers.GRU(64, return_sequences=True),
    layers.GRU(64),
    layers.Dense(1)
])
model4.summary()
test_results4 = train_and_evaluate_model(model4, train_dataset, val_dataset, test_dataset, model_name="CNN+RNN Hybrid")
```

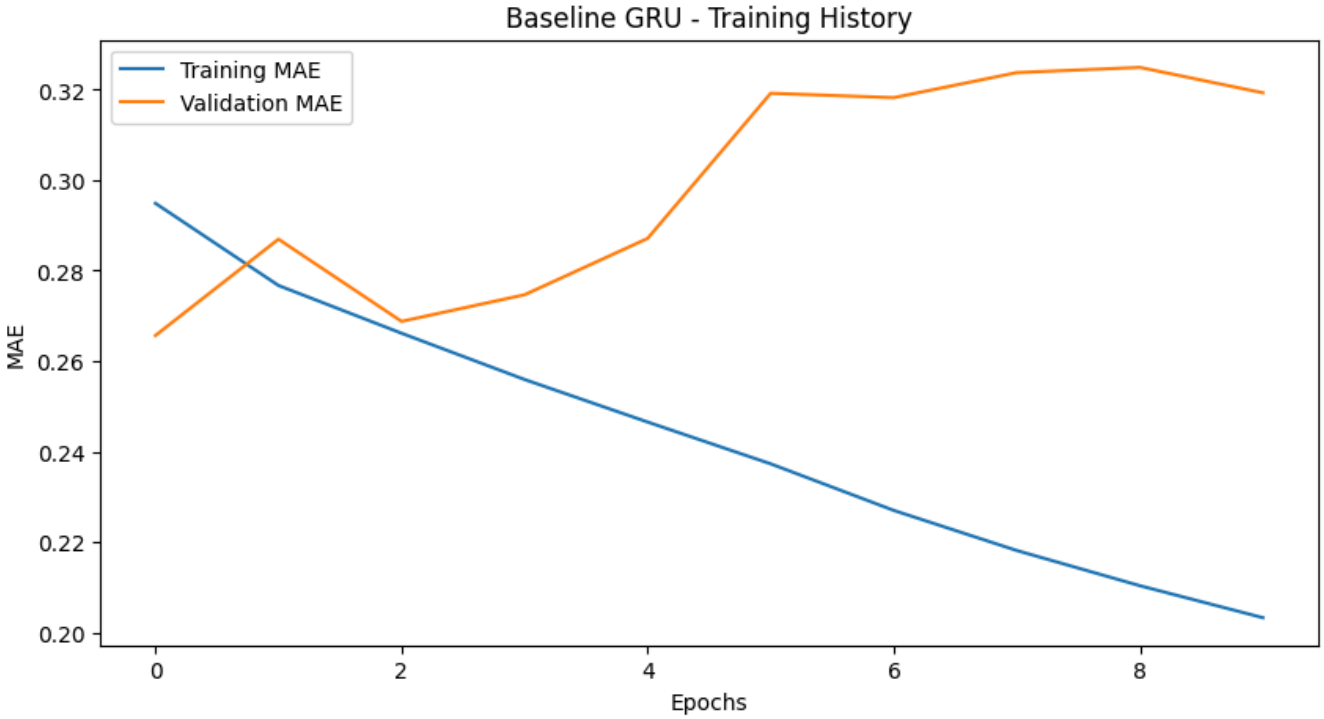
```
==================================================
Building Baseline GRU Model
==================================================
```

Model: "sequential"

Layer (type)	Output Shape	Param #
gru (GRU)	(None, 32)	4,608
dense (Dense)	(None, 1)	33

Total params: 4,641 (18.13 KB)
Trainable params: 4,641 (18.13 KB)
Non-trainable params: 0 (0.00 B)

```
Training Baseline GRU...
Epoch 1/10
776/776 ━━━━━━━━━━━━━━━━━━━━ 160s 199ms/step - loss: 0.1794 - mae: 0.3202 - val_loss: 0.1169 - val_mae: 0.2657
Epoch 2/10
776/776 ━━━━━━━━━━━━━━━━━━━━ 195s 190ms/step - loss: 0.1268 - mae: 0.2780 - val_loss: 0.1335 - val_mae: 0.2870
Epoch 3/10
776/776 ━━━━━━━━━━━━━━━━━━━━ 149s 191ms/step - loss: 0.1175 - mae: 0.2684 - val_loss: 0.1199 - val_mae: 0.2688
Epoch 4/10
776/776 ━━━━━━━━━━━━━━━━━━━━ 150s 192ms/step - loss: 0.1084 - mae: 0.2581 - val_loss: 0.1240 - val_mae: 0.2747
Epoch 5/10
776/776 ━━━━━━━━━━━━━━━━━━━━ 147s 190ms/step - loss: 0.1004 - mae: 0.2483 - val_loss: 0.1358 - val_mae: 0.2871
Epoch 6/10
776/776 ━━━━━━━━━━━━━━━━━━━━ 154s 198ms/step - loss: 0.0930 - mae: 0.2395 - val_loss: 0.1629 - val_mae: 0.3192
Epoch 7/10
776/776 ━━━━━━━━━━━━━━━━━━━━ 164s 211ms/step - loss: 0.0850 - mae: 0.2290 - val_loss: 0.1626 - val_mae: 0.3182
Epoch 8/10
776/776 ━━━━━━━━━━━━━━━━━━━━ 190s 196ms/step - loss: 0.0780 - mae: 0.2197 - val_loss: 0.1667 - val_mae: 0.3238
Epoch 9/10
776/776 ━━━━━━━━━━━━━━━━━━━━ 150s 193ms/step - loss: 0.0723 - mae: 0.2116 - val_loss: 0.1693 - val_mae: 0.3249
Epoch 10/10
776/776 ━━━━━━━━━━━━━━━━━━━━ 199s 189ms/step - loss: 0.0673 - mae: 0.2042 - val_loss: 0.1631 - val_mae: 0.3193
```



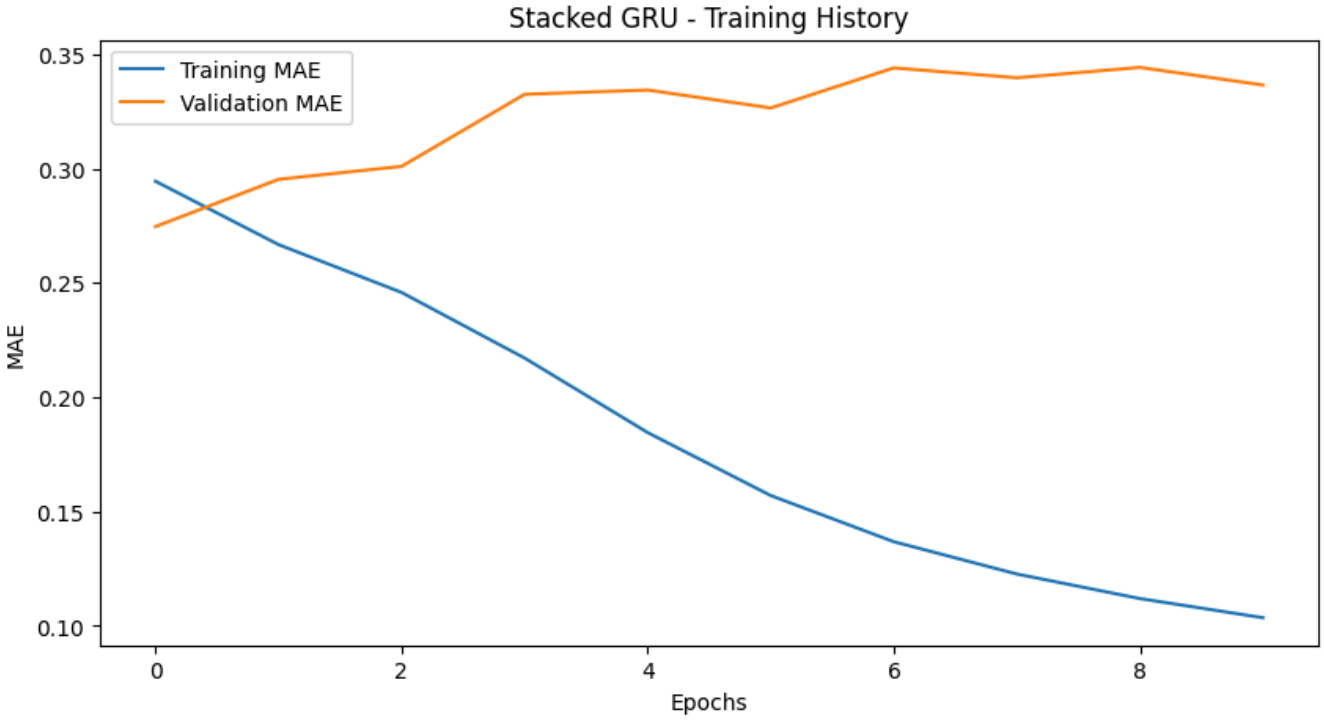

```
Test evaluation:
Test MAE: 0.3364
Test MSE: 0.1851

==================================================
Building Stacked GRU Model
==================================================
```

quential_1

Layer (type)	Output Shape	Param #
gru_1 (GRU)	(None, 120, 64)	15,360
gru_2 (GRU)	(None, 64)	24,960
dense_1 (Dense)	(None, 1)	65

Total params: 40,385 (157.75 KB)
Trainable params: 40,385 (157.75 KB)
Non-trainable params: 0 (0.00 B)

```
Training Stacked GRU...
Epoch 1/10
776/776 ━━━━━━━━━━━━━━━━━━━━ 612s 783ms/step - loss: 0.1615 - mae: 0.3109 - val_loss: 0.1254 - val_mae: 0.2747
Epoch 2/10
776/776 ━━━━━━━━━━━━━━━━━━━━ 604s 778ms/step - loss: 0.1201 - mae: 0.2713 - val_loss: 0.1423 - val_mae: 0.2953
Epoch 3/10
776/776 ━━━━━━━━━━━━━━━━━━━━ 623s 780ms/step - loss: 0.1027 - mae: 0.2513 - val_loss: 0.1467 - val_mae: 0.3010
Epoch 4/10
776/776 ━━━━━━━━━━━━━━━━━━━━ 687s 864ms/step - loss: 0.0818 - mae: 0.2246 - val_loss: 0.1794 - val_mae: 0.3325
Epoch 5/10
776/776 ━━━━━━━━━━━━━━━━━━━━ 621s 785ms/step - loss: 0.0598 - mae: 0.1927 - val_loss: 0.1815 - val_mae: 0.3344
Epoch 6/10
776/776 ━━━━━━━━━━━━━━━━━━━━ 623s 786ms/step - loss: 0.0430 - mae: 0.1627 - val_loss: 0.1737 - val_mae: 0.3265
Epoch 7/10
776/776 ━━━━━━━━━━━━━━━━━━━━ 678s 860ms/step - loss: 0.0326 - mae: 0.1409 - val_loss: 0.1920 - val_mae: 0.3441
Epoch 8/10
776/776 ━━━━━━━━━━━━━━━━━━━━ 626s 786ms/step - loss: 0.0260 - mae: 0.1256 - val_loss: 0.1883 - val_mae: 0.3397
Epoch 9/10
776/776 ━━━━━━━━━━━━━━━━━━━━ 667s 860ms/step - loss: 0.0215 - mae: 0.1141 - val_loss: 0.1911 - val_mae: 0.3443
Epoch 10/10
776/776 ━━━━━━━━━━━━━━━━━━━━ 609s 784ms/step - loss: 0.0185 - mae: 0.1055 - val_loss: 0.1855 - val_mae: 0.3366
```




```
Test evaluation:
Test MAE: 0.3533
Test MSE: 0.2011

==================================================
Building Stacked LSTM Model
==================================================
```

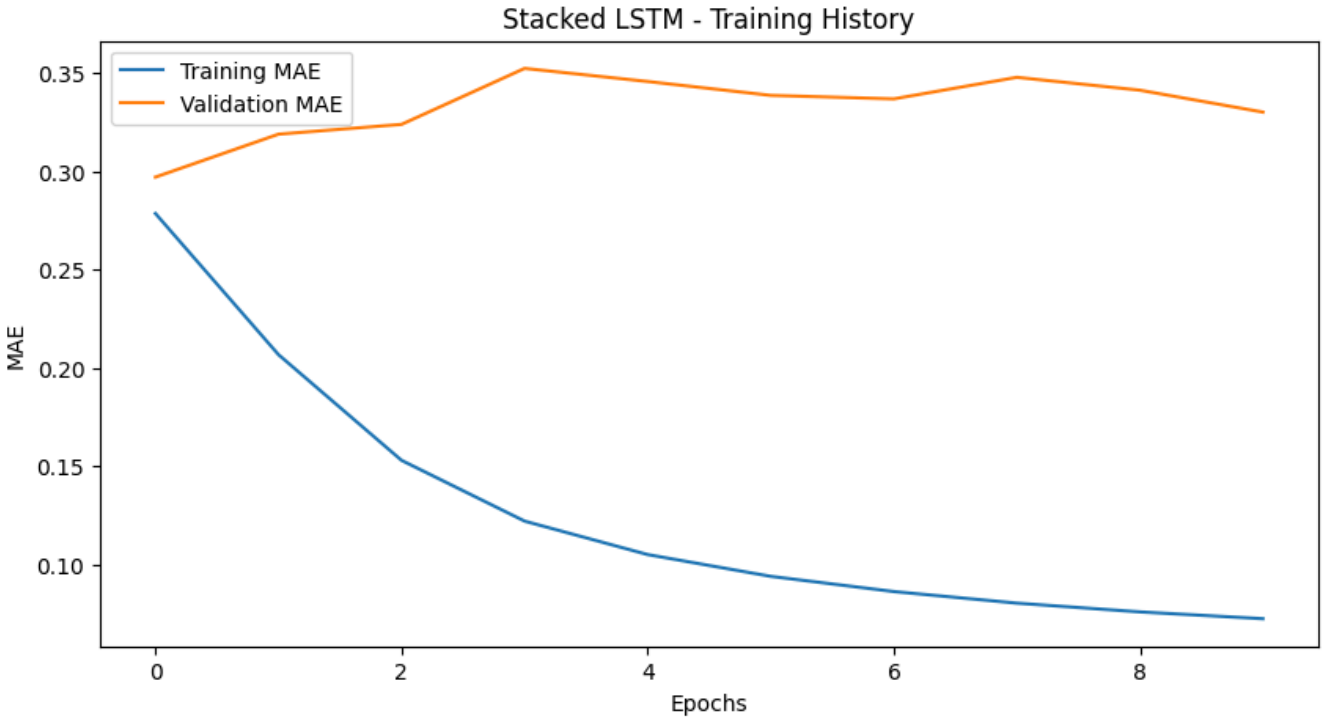
Model: "sequential_2"

Layer (type)	Output Shape	Param #

l)	(None, 120, 64)	20,224
lstm_1 (LSTM)	(None, 64)	33,024
dense_2 (Dense)	(None, 1)	65

Total params: 53,313 (208.25 KB)
Trainable params: 53,313 (208.25 KB)
Non-trainable params: 0 (0.00 B)

```
Training Stacked LSTM...
Epoch 1/10
776/776 ━━━━━━━━━━━━━━━━━━━━ 547s 701ms/step - loss: 0.1586 - mae: 0.3086 - val_loss: 0.1465 - val_mae: 0.2970
Epoch 2/10
776/776 ━━━━━━━━━━━━━━━━━━━━ 612s 765ms/step - loss: 0.0801 - mae: 0.2225 - val_loss: 0.1654 - val_mae: 0.3188
Epoch 3/10
776/776 ━━━━━━━━━━━━━━━━━━━━ 573s 703ms/step - loss: 0.0444 - mae: 0.1638 - val_loss: 0.1697 - val_mae: 0.3238
Epoch 4/10
776/776 ━━━━━━━━━━━━━━━━━━━━ 564s 706ms/step - loss: 0.0274 - mae: 0.1278 - val_loss: 0.2018 - val_mae: 0.3523
Epoch 5/10
776/776 ━━━━━━━━━━━━━━━━━━━━ 588s 758ms/step - loss: 0.0198 - mae: 0.1087 - val_loss: 0.1961 - val_mae: 0.3456
Epoch 6/10
776/776 ━━━━━━━━━━━━━━━━━━━━ 628s 767ms/step - loss: 0.0159 - mae: 0.0966 - val_loss: 0.1891 - val_mae: 0.3385
Epoch 7/10
776/776 ━━━━━━━━━━━━━━━━━━━━ 550s 708ms/step - loss: 0.0133 - mae: 0.0884 - val_loss: 0.1884 - val_mae: 0.3367
Epoch 8/10
776/776 ━━━━━━━━━━━━━━━━━━━━ 600s 773ms/step - loss: 0.0115 - mae: 0.0820 - val_loss: 0.1975 - val_mae: 0.3477
Epoch 9/10
776/776 ━━━━━━━━━━━━━━━━━━━━ 572s 709ms/step - loss: 0.0102 - mae: 0.0773 - val_loss: 0.1904 - val_mae: 0.3412
Epoch 10/10
776/776 ━━━━━━━━━━━━━━━━━━━━ 566s 713ms/step - loss: 0.0095 - mae: 0.0739 - val_loss: 0.1787 - val_mae: 0.3300
```




```
Test evaluation:
Test MAE: 0.3406
Test MSE: 0.1853

==================================================
Building CNN+RNN Hybrid Model
==================================================
```

Model: "sequential_3"

Layer (type)	Output Shape	Param #
conv1d (Conv1D)	(None, 116, 64)	4,544
max_pooling1d (MaxPooling1D)	(None, 38, 64)	0

conv1d_1 (Conv1D)	(None, 34, 64)	20,544
gru_3 (GRU)	(None, 34, 64)	24,960
gru_4 (GRU)	(None, 64)	24,960
dense_3 (Dense)	(None, 1)	65

Total params: 75,073 (293.25 KB)
Trainable params: 75,073 (293.25 KB)
Non-trainable params: 0 (0.00 B)

```
Training CNN+RNN Hybrid...
Epoch 1/10
776/776 ━━━━━━━━━━━━━━━━━━━━ 294s 372ms/step - loss: 0.2076 - mae: 0.3513 - val_loss: 0.1581 - val_mae: 0.3089
Epoch 2/10
776/776 ━━━━━━━━━━━━━━━━━━━━ 320s 370ms/step - loss: 0.1043 - mae: 0.2535 - val_loss: 0.1885 - val_mae: 0.3409
Epoch 3/10
776/776 ━━━━━━━━━━━━━━━━━━━━ 322s 370ms/step - loss: 0.0676 - mae: 0.2041 - val_loss: 0.2025 - val_mae: 0.3535
Epoch 4/10
776/776 ━━━━━━━━━━━━━━━━━━━━ 360s 419ms/step - loss: 0.0449 - mae: 0.1661 - val_loss: 0.1843 - val_mae: 0.3362
Epoch 5/10
776/776 ━━━━━━━━━━━━━━━━━━━━ 286s 368ms/step - loss: 0.0321 - mae: 0.1401 - val_loss: 0.2146 - val_mae: 0.3631
Epoch 6/10
507/776 ━━━━━━━━━━━━──────── 1:24 316ms/step - loss: 0.0252 - mae: 0.1243
```

```
# 6. Results Comparison
results = {
    "Baseline GRU": test_results1,
    "Stacked GRU": test_results2,
    "Stacked LSTM": test_results3,
    "CNN+RNN Hybrid": test_results4
}

results_df = pd.DataFrame.from_dict(results, orient='index', columns=['MSE', 'MAE'])
print("\nModel Comparison:")
display(results_df)

plt.figure(figsize=(10, 5))
plt.bar(results_df.index, results_df['MAE'])
plt.title("Model Comparison by Test MAE")
plt.ylabel("MAE")
plt.xticks(rotation=45)
plt.tight_layout()
plt.show()
```

```
Model Comparison:
```

	MSE	MAE
Baseline GRU	0.185081	0.336409